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Environment and human health

Joint EEA-JRC report

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Preface

Human health and well-being are intimately linked to environmental quality. This has been recognised for decades amongst policymakers in Europe, and most recently appears as a cornerstone in the European Commission's proposal for the 7th Environment Action Programme. This report, produced jointly by the European Environment Agency and the European Commission's Joint Research Centre, outlines a number of environmental issues with a direct influence on people's health and well-being and is a follow-up and update to the 2005 EEA/JRC report.

In the 8 years that have passed, the political context of environment and health has evolved. As highlighted in EEA's *The European Environment — state and outlook 2010* the policy focus is increasingly shifting from single environmental pollution issues towards systemic challenges regarding the maintenance of ecosystem resilience and the delivery of ecosystem services to human society. Climate change is a good example with its combined impacts on food and water security, heat waves, flooding risks and potential spread of diseases.

Where problem detection and measures in the environment and health area have typically been based on dose-effect studies of individual polluting substances and stressors, this new report makes the case for a more integrated take on health issues, acknowledging the complex inter-linkages between resource-use patterns, environmental pressures, multiple exposures and disease burden, as well as the key role that social inequalities play.

It also touches upon emerging issues resulting from long-term environmental and socio-economic trends, such as climate change, lifestyle and consumption changes and the rapid uptake and application of new chemicals and technologies. As such, it complements the recent EEA publication *Late lessons from early warnings; science, precaution and innovation*, which makes a strong argument for precautionary science in political decision-making, allowing us to strike a better balance between using economic opportunities and avoiding disproportionate risks to the environment and human health and well-being.

Environment and health is not just 'an aspect' of environmental policy, it is at the heart of it. In fact, it is central to Europe's ambition to move towards a Green Economy. With this report, taking stock of the most pertinent environment and health issues, and combining the expertise of our two institutes in environmental reporting and scientific research, we hope to contribute to this goal.

Jacqueline McGlade, Executive Director European Environment Agency	Maria Betti, Director, Institute of Environment and Sustainability, JRC European Commission

Executive summary

In 2010, the comprehensive *European environment — state and outlook 2010* report showed that environmental policies have delivered substantial progress in improving the state of the environment in Europe. However, it also stressed that major environmental challenges remain.

Water and air pollution have declined but not enough to achieve good ecological quality in all water bodies or to ensure good air quality in all urban areas. Widespread exposure to multiple pollutants and chemicals and concerns about long-term damage to human health together imply the need for more integral and precautionary approaches.

Given the complex links between environmental challenges, identification of environmental risks to human health and well-being should go beyond immediate and individual health impacts of a few well-known stressors. Multiple exposures, long-term impacts, inequalities and resource use patterns should also be addressed.

It is in this context that this EEA-JRC reference report on environment and health has been produced. It tries to capture the most pertinent environmental problems and their policy implications, as identified and addressed in on-going work at the JRC and EEA.

Part I discusses the evolving understanding of environmental and health relationships, from focusing on isolated, specific issues, towards increasing recognition of highly complex, multifactorial interdependencies.

Key points:

- The quality of the environment in Europe has improved considerably over recent decades with benefits to human health. EU citizens live longer than in many other parts of the world, but health challenges of the ageing population may increase due to lifestyle changes and environmental megatrends (climate change, depletion of natural resources and the disruption of ecosystems services).
- Non-communicable diseases represent the greatest burden of mortality and morbidity in the EU. These diseases have multifactorial backgrounds that are not sufficiently understood. Exposure to air pollution, noise, poor quality water, chemicals, radiation, biological agents, and otherwise degraded environments are important components.
- Considerable health inequalities exist. Life expectancy and the number of Healthy Life Years differ substantially between Member States and between genders. Evidence from European countries indicates that low-income populations are more exposed to degraded environments.
- A more integrated analytical framework is needed to fully identify the environmental factors that contribute to the burden of disease and at the same time address the interactions between the social, ecological, and physical aspects of our environment.

Part II presents 11 thematic chapters, addressing several environmental issues which, currently and in the future, are likely to affect human health and well-being in Europe.

Key points:

Chemicals

- Humans are exposed to a wide and increasing range of chemicals. Whilst policy action is taken to assess and mitigate impacts on human health, large knowledge gaps still exist. The effects of long-term and low-dose exposure to mixtures of chemicals, particularly in young children, are poorly understood.
- The environmental and potential human health impacts of chemicals used in large volumes, including pharmaceuticals and some compounds used in personal care products deserve more attention, especially those with suspected endocrine disrupting properties.

- Efforts to promote more sustainable consumption and production of chemicals are needed. A 'green chemistry' approach will require a mix of policy responses, including regulation, economic incentives and information-based instruments.

Outdoor air

- Air pollution remains one of the major environmental problems in Europe, affecting health and well-being of European citizens. Key air pollutants in this respect are particulate matter (PM), ground-level ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and polycyclic hydrocarbons (such as benzo(a) pyrene).
- Evidence is growing for a range of effects of prenatal exposure, and exposure during early childhood, on health in adult life. Exposure to air pollutants during pregnancy can result in reduced foetal growth, pre-term birth, and spontaneous abortions. The associations are of the same order of magnitude as those reported for passive smoking.
- The potential health and economic benefits of mitigation measures are considerable.

Indoor air

- Levels of pollutants in indoor air are often higher than in outdoor air. With European citizens spending more than 85–90 % of their time indoors, indoor air is an important source of personal exposure to contaminants.
- Exposure to indoor chemicals, particulate matter, dust and dampness, moulds and other biological agents, has been linked to increased prevalence of respiratory symptoms, allergies and asthma as well as perturbation of the immunological system.
- There is no dedicated European legislation on indoor air quality except for banning of tobacco smoke in public buildings and commercial establishments and a number of ventilation standards in residential and non-residential buildings. The need for a horizontal policy framework which bridges safety, health, energy efficiency and sustainability aspects across existing legislative instruments and standardisation activities related to the built environment is widely recognised.

Radon

- Radon is a radioactive gas escaping naturally from uranium-containing soils and rocks. Radon exposure is not evenly distributed over Europe — the occurrence is patchy with strong regional variations. The most efficient way to reduce indoor radon exposure is by increasing ventilation.
- Radon is the second largest cause of lung cancer after smoking in Europe. Most of the radon-induced lung cancer cases occur among smokers due to a strong combined effect of smoking and radon.
- Prevention approaches vary across Member States. European legislation is underway that will oblige Member States to establish a radon action plan to reduce long-term risks of radon exposures in dwellings, buildings with public access and workplaces.

Water

- One of the cornerstones of a public health policy is safeguarding access to water of good quality for consumption, for recreation and as a source for food. Due to effective drinking water purification, outbreaks of water-borne diseases are infrequent and often associated with small-scale drinking water supplies in rural areas.
- Progress in the collection and treatment of wastewater in the EU since the 1990s has substantially improved surface water quality, but certain pollutants, including pesticides, pharmaceuticals and cosmetics, are not fully removed. Of particular concern are endocrine-disrupting substances that can have detrimental effects on aquatic biota at very low concentrations.
- Climate change is expected to increase regional water shortages, as well as reducing contaminant dilution capacity and leading to elevated concentrations of hazardous substances.

Noise

- Noise affects people in both physiological and psychological ways, interfering with basic activities such as sleep, rest, study and communication. Airport noise and traffic noise are considered the most disturbing.

- Health effects include increased risk of cardiovascular disease, high blood pressure, myocardial infarction and even stroke. The World Health Organization has estimated that 1 million healthy life years are lost in the European population due to traffic noise.

- Scientific studies show that environmental noise and air pollution act in concert with respect to health effects. Future policy work has to adjust to this reality and develop an integrated approach to obtain maximal protection from both noise and air pollution.

Electromagnetic fields

- Exposure to electromagnetic fields (EMF) is an unavoidable fact of modern life. High levels of electromagnetic radiation — from radars, radio stations, etc. — can cause significant health effects, but the exposures most people face in their daily lives are typically much lower.

- Available studies of the relationship between mobile telephone use and the incidence of head and neck cancers are not conclusive, but point at the merit of precautionary action. The WHO's International Agency for Research on Cancer (IARC) has classified radio-frequency electromagnetic fields as possibly carcinogenic to humans (Group 2B).

- Particular caution is advisable regarding mobile phone use by children as they may be more sensitive to radiofrequency field exposure than adults in view of their continuing neural development.

Ultraviolet radiation

- Excessive exposure to the ultraviolet part of sunlight may lead to different types of skin and eye diseases. The incidence of the most aggressive form, malignant melanoma, is related to intermittent high-exposure events, particularly at a young age.

- There has been a significant increase in the incidence of skin cancer in Europe and in large parts of the world since the 1950s. This is probably due to changed lifestyles and thinning of the stratospheric ozone layer, that acts as UV filter.

- Policy responses include prevention campaigns and the provision of public information on the level of ambient UV radiation, for example in meteorological bulletins.

Nanotechnology

- Nanotechnology makes use of the specific properties of small ('nano'-sized) particles in a wide range of products, from electronics, textiles and cosmetics to medicine. Because of the wide application perspectives, many people may get exposed to nanomaterials via inhalation, oral intake and dermal contact.

- Little is known about the effects of nanomaterials in the human body. Some studies in animals and in-vitro (isolated cells) indicate that they can trigger inflammation, which may lead to fibrosis and cancer. Given the speed of innovation with nanomaterials, further research is needed to better understand their potential toxicity.

- The risk assessment of nanomaterials is still in its infancy, as information on release, occurrence, environmental fate, and persistence of nanomaterials is hardly available. Research should focus on the determination of appropriate parameters to model the fate and transport of nanomaterials in the environment and in the body.

Green spaces and the natural environment

- Access to natural, green environments can offer multiple benefits to physical health, mental and social well-being and improved quality of life. The mechanisms of these interactions are not entirely clear and would benefit from further research.

- Available data suggest that people with better access to a green environment are more likely to be physically active and have a reduced tendency to become overweight and obese.

- The Green infrastructure Strategy, released by the European Commission in 2013, will be instrumental in increasing multiple health benefits of green spaces.

Climate change

- Climate change may affect human health via changing weather patterns and extreme events, such as heat waves, floods, droughts, windstorms, precipitation and storm surges. On average, adverse impacts on human health are projected to outweigh beneficial impacts, but no specific estimates are available for Europe.

- Climate change is likely to affect the spread of diseases in Europe, as many pathogens, vectors, and non-human reservoir species are climate-sensitive. Nearly half of over 50 infectious diseases currently reportable in the EU can be directly or indirectly affected by climate change; five other climate-sensitive diseases are considered emerging infectious diseases.

- Climate change-related health effects depend largely on the vulnerability of the population and its ability to adapt, linked to ecological, social, economic and cultural factors. Some regions, such as the Arctic and the Mediterranean, appear particularly vulnerable. In 2013, the European Commission published the EU Strategy on adaptation to climate change, aiming at promoting adaptation actions by Member States, better informed decision-making, and climate-proofing of EU action by promoting adaptation in key vulnerable sectors.

Part III reflects on the future, highlighting a need for a broader framing of environment, health and well-being issues.

Key points:

- The current, predominantly hazard-focused and compartmentalised approach to environment and health is insufficient to address interconnected and interdependent challenges, such as climate change, depletion of resources, ecosystem degradation, the obesity epidemic, and persistent social inequality. The policy focus therefore needs to be widened to social and other policy domains, such as consumption, resource efficiency, natural capital, ecosystem services and spatial planning. This implies a greater need for a multidisciplinary and multi-stakeholder dialogue to take account of values and attitudes.

- Climate mitigation is an area where complex systemic interactions, feedbacks and trade-offs are particularly obvious. A shift towards renewable (bio-based) energy may have consequences for food security and human well-being, as energy cropping increasingly competes with food production. Where it replaces extensive farming systems, a negative side-effect on biodiversity and landscape amenity values can also be expected, affecting, for example, recreation opportunities.

- With the EU 2020 strategy, and particularly its focus on smart growth and resource efficiency, European environment and health policy moves into a more systemic direction. As human demand for the world's natural resources increases and the environmental consequences become more and more manifested, it is imperative that we increase our understanding of the intricate links between environmental conditions and human health and well-being.

Part I Introduction

1 Setting the scene

1.1 The European environment has improved but challenges to health remain

Over the past decade, the quality of the environment in the EU and its neighbours has improved considerably, but major challenges remain. Trends in main environmental policies relevant to health over the past ten years reveal a mixed picture (Table 1.1). Air pollution from particulate matter still contributes to premature death and disease in many urban areas. Human health is also being harmed by transboundary air pollution, and water quality targets have not fully been met. For several issues, such as noise, chemicals and hazardous substances, and natural and technological hazards, it is difficult or too early to assess progress.

Water and air pollution have declined, but not enough to achieve good ecological quality in all water bodies or ensure good air quality in all urban areas. Noise may affect the health of up to 40 % of people living in the largest cities in the EU. Widespread exposure to multiple pollutants and chemicals raise concerns about long-term damage to human health (EEA, 2010d). There is also increasing concern over the health impacts of prolonged low-dose exposures; long-term effects of endocrine-disrupting chemicals, and the emergence of new diseases in a changing environment.

In the past, specific environmental issues have been dealt with through targeted policies and single-issue instruments. While such dedicated measures have been successful in reducing particular burdens, increasingly recognised complex and interlinked environmental challenges can no longer be tackled in an isolated manner. The links between environmental issues, coupled with global developments, point towards the existence of

Table 1.1 Indicative summary table of progress towards meeting environmental targets or objectives, and highlights of related trends over the past 10 years

Environmental issue	EU-27 target/objective	EU-27 — on track?	EEA-38 — trend?
Environment and health			
Water quality (ecological and chemical status)	To achieve good ecological and chemical status of water bodies	☐	→
Water pollution (from point sources, and bathing water quality)	To comply with bathing water quality, urban wastewater treatment	☑	↘
Transboundary air pollution (NO_x, NMVOC, SO_2, NH_3, primary particles)	To limit emissions of acidifying, eutrophying and ozone precursor pollutants	☐	↘
Air quality in urban areas (particulate matter and ozone)	To attain levels of air quality that do not give rise to negative health impacts	☒	→

Legend		
Positive developments	**Neutral developments**	**Negative developments**
↘ Decreasing trend	→ Stable	(↘) Decreasing trend
↗ Increasing trend		(↗) Increasing trend
☑ EU on track (some countries may not meet target)	☐ Mixed progress (but overall problem remains)	☒ EU not on track (some countries may meet target)

Note: EEA-38 = 32 EEA member countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, the United Kingdom, Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia, Turkey, Iceland, Liechtenstein, Norway, Switzerland + 6 EEA cooperating countries (Western Balkans): Croatia, the former Yugoslav Republic of Macedonia, Albania, Bosnia and Herzegovina, Montenegro, Serbia.

Source: EEA, 2010d.

systemic risks, meaning the potential loss or damage to an entire system, rather than a single element (Table 1.2) (EEA, 2010d; WEF, 2010).

Climate change, the depletion of natural resources, loss of biodiversity and the disruption of ecosystem services illustrate the complexity of environmental challenges in a world faced with 'systemic disruptions to environment' (McMichael et al., 2009) with potentially wide-ranging, long-term, and irreversible impacts, including on human health and well-being.

The ecosystem perspective on emerging infectious diseases in human population receives growing attention; while primarily focused on wild animal reservoirs, consideration is also given to industrial food animal production (Graham et al., 2008; Leibler et al., 2009). Climate and land use change, urbanization, international travel and trade, and deficits in public health systems can influence risks of pandemics with potentially significant burden on health and global economies. A systems approach is needed to address those challenges, taking account of linkages between human and animal health, environmental drivers of health, and the socio-ecological context of disease emergence (Bogich et al., 2012; Zinsstag et al., 2011; Coker et al., 2011).

Therefore, whereas targeted efforts will continue to provide relevant evidence on particular environmental issues relevant to human health and well-being, more integrated analytical frameworks are needed for 'interdisciplinary and population-focused research that would support a systems approach to fully identifying the environmental factors that contribute to disease burden […], able to address the interactions between the social, ecological, and physical aspects of our environment' (Gohlke and Portier, 2007).

1.2 European citizens live longer, but the ageing population faces several health challenges

People in the EU live longer than in many other parts of the world, but the quality of the years of life lived could further be improved, particularly in terms of equality across the population. In fact, both life expectancy and the number of Healthy Life Years differ substantially between Member States and between genders (Table 1.3). Social factors are also important determinants. For example, in Norway (in 2001) life expectancy at age 30 was around five years higher for men with university education than for those with lower secondary education (Jakab and Marmot, 2012). Even larger differences in life expectancy with education level exist in many EU Member States (Eurostat, 2010).

A range of challenges needs to be addressed to protect and strengthen the health and well-being of current and future generations in Europe. The EU population is ageing rapidly. By 2060, median age is projected to reach almost 48 years, compared to 40.9 years in 2010, and the number of people aged 80 or over is expected to almost triple (Eurostat, 2011a). More than half of EU citizens aged 65 to 74 report a long-standing illness or health problem; diseases of circulatory, respiratory and digestive systems, as well as cancers, are the main causes of death in EU citizens aged 65 or over (Eurostat, 2011a). The current urbanisation trend may aggravate some health issues in the ageing

Table 1.2 Reflecting on environmental challenges

Characterisation of the type of challenge	Key features	In the spotlight in	Policy approach example	Environment and health example
Specific	Linear cause-effect; large (point) sources; often local	1970s/1980s (and continuing today)	Targeted policies and single-issue instruments	Reduce emissions of specific pollutants into air, water, soil; improve wastewater treatment.
Diffuse	Cumulative causes; multiple sources; often regional	1980s/1990s (and continuing today)	Policy integration and raising public awareness	Reduce emissions of pollutants from common sources (such as transport-related noise and air pollution) into air, water, soil; improve regulation of chemical substances.
Systemic	Systemic causes; interlinked sources; often global	1990s/2000s (and continuing today)	Policy coherence and other systemic approaches	Reduce people's combined exposure to harmful pollutants and other stressors; better link human and ecosystem health.

Source: EEA, 2010d.

Table 1.3 Life expectancy at birth and Healthy Life Years at birth in the EU, 2011

	Life expectancy at birth (years)		Healthy Life Years at birth	
	Men	Women	Men	Women
EU-27	76.7 ([a])	82.6 ([a])	61.8	62.2
Maximum	79.9 (Sweden)	85.0 (France)	71.1 (Sweden)	70.7 (Malta)
Minimum	68.1 (Lithuania)	77.8 (Bulgaria)	52.1 (Slovakia)	52.3 (Slovakia)

Note: ([a]) 2009 data.

Source: Eurostat, online database (accessed 8 March 2013).

population, as concentration in urban areas may increase average exposure to harmful pollution levels; implications of societal changes, such as the growing number of smaller households, also need to be considered.

Non-communicable diseases and disabilities represent the greatest burden of mortality and morbidity in the EU (EUGLOREH, 2009). Mental health problems are on the rise, and infectious diseases, likely to be affected by changing climate, are emerging as a public health issue in Europe. In children and adolescents, of particular concern are obesity, cancer, and neurodevelopmental disorders (Nadeau, 2009; Polańska et al., 2012; Bosetti et al., 2010).

While most chronic, non-communicable diseases have a multifactorial aetiology, understanding of causal pathways and the role of specific factors, including environmental, remains limited. A role of occupational exposures to chemical, biological, physical and psychological factors cannot be ignored (though it is beyond the scope of this report). Exposures to air pollution, noise, poor quality water, chemicals, radiation, biological agents, and otherwise degraded environments have been linked to a range of health effects, including those of major public health concern in Europe. However, the strength of the available evidence for multi-causal associations differs, and complex, uncertain issues are often considered insufficient to trigger actions/responses.

As estimated by WHO, the fraction of non-communicable diseases attributable to selected environmental factors doesn't differ between Europe, other developed regions of the world, and developing ones. However, per capita numbers of healthy life years lost from cardiovascular diseases and cancer are higher in developed countries than in less developed sub-regions (WHO, 2006c). Non-communicable diseases, mainly heart disease, stroke, cancer, diabetes, and chronic respiratory diseases pose an increasing threat worldwide (Beaglehole et al., 2011). Global disease burden is shifting away from communicable to non-communicable diseases and from premature death to years lived with disability: non-communicable diseases account for almost two-third (65.5 %) deaths (Lozano et al., 2013), and for 54 % of disability adjusted life years (DALY) (Murray et al., 2013) with substantial regional heterogeneity. Besides human suffering, they also are *driving up health costs while reducing productivity and economic growth* (WEF, 2010).

1.3 Health, environment, and social aspects are interconnected

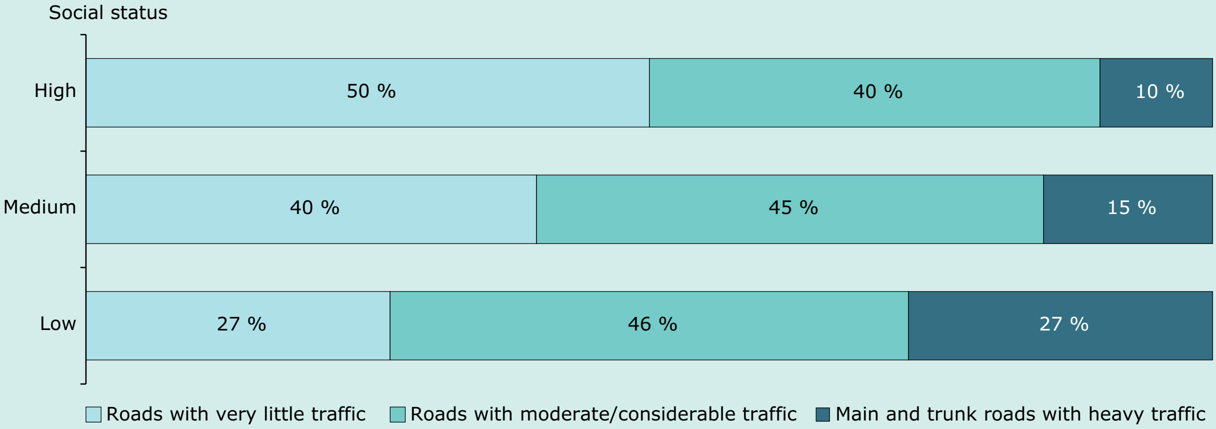
It is increasingly understood that 'overall' indicators of improved environmental quality are not sufficient to assess exposure and potential health impacts across the population. Health inequalities are pervasive in the EU Member States; similarly, environmental and socio-economic conditions, which determine the risk of people getting ill, their ability to prevent sickness and get access to treatment, are unequally distributed within societies.

The fragmentary evidence from European countries indicates that low-income populations often live in areas with high pollution and poor-quality housing, near industrial and waste dumping sites, noisy roads, with limited access to a good-quality green space. Disadvantaged groups are often disproportionally affected by the cumulative impacts of overall degraded environments (Box 1.1) and lack financial, educational, and cultural capacities to avoid such exposure (De Hollander and Staatsen, 2003; Forastiere et al., 2007; EC, 2008a; Marmot, Allen, et al., 2010; UBA, 2011). Poor environmental conditions tend to be spatially correlated with social stressors, though little is known about the combined and potentially synergistic health effects of stress and pollution (Clougherty et al., 2007; Clougherty and Kubzansky, 2009).

Box 1.1 Social factors play a role in exposure to poor environmental conditions

People of low social status can be more heavily exposed to traffic and traffic-related air pollutants than people of a higher social status. According to the German Environmental Survey, children aged 3 to 14 years from families of low social status more frequently live next to heavy-traffic main roads than children from families of medium and high social status (Figure 1). Similarly, 11 % of children with low social status were annoyed by road traffic noise, compared with 3 % of children with higher social status. Urban air quality and noise often share a common source and may cluster spatially. Moreover, as shown in the Federal Health Survey, the lower the education, income and job levels, the more likely that people's residences are on main roads with heavy traffic: living on heavily-trafficked streets was reported by over 30 % of those from the lowest income group, but less than 15 % of those in the highest income group.

Figure 1.1 Exposure to traffic of children aged 3–14 years according to social status



Source: Federal Environment Agency (UBA), 2009.

Environmental-, housing- and injury-related inequalities exist throughout the WHO European Region; evidence is growing that the unequal distribution in the population of exposure to poor environmental conditions, and potentially to the related health impacts, is strongly related to a range of socio-demographic determinants (WHO, 2012b). While environment-related inequalities contribute to health inequalities, more work is needed to clarify the relationships and implications for policy.

Socioeconomic and demographic inequalities in exposure to environmental hazards often represent inequities, which are avoidable and unjust. Lack of *'distributive justice'*, meaning uneven distribution of environmental risks within populations, and a lack of *'procedural justice'*, indicating that different population groups may have different opportunities to influence decisions concerning their close environment, as well as the unequal distribution of 'environmental goods' are often a root cause of these inequities (WHO, 2012b).

Measures to reduce health inequalities involve (among others) a range of interventions aimed at changing human behaviour and the quality of the environment people live in. Potential benefits both for health and for the sustainability agenda can be expected from measures such as: active travel (walking or cycling), availability and accessibility of green space, healthy eating, and reduced carbon-based pollution (Marmot, Allen, et al., 2010).

1.4 Methods to address complex and multi-causal interactions need to be improved

A growing understanding of the subtle and complex contribution of the environment to health and well-being calls for innovative, integrated approaches to better understand the complexities and ensure good quality environments for all, including vulnerable groups.

Environment and health assessments are faced with large, partly irreducible, uncertainties, knowledge gaps, and imperfect understanding. The definitions of the 'environment' and 'environmental factors' differ; major discrepancies in the precision of the estimates of human health effects and assessment of exposure to environmental factors affect the quality of environment and health assessments. A number of choices and assumptions have to be made throughout the assessment process, from the selection of health effects considered, through the choice of data (prevalence or incidence of disease), relevant exposure-response relationships, the data and approaches used to assess exposure, etc. The uncertainties related to every step of the assessment may substantially affect the final results, and potentially, influence the decisions based on such an assessment. Therefore, it is critical to be explicit about the assumptions made to report uncertainties (Knol et al., 2009; Saracci and Vineis, 2007; Vineis et al., 2009; Briggs et al., 2008). Establishing causal relationships between environmental factors and specific health effects may be extremely difficult, due to multiple exposures, different vulnerabilities, the often non-specific nature of the health end-points, and different time lags between exposures and health effects. Some health effects of exposures experienced in early childhood or even prenatally can manifest themselves years later, in adulthood; some can even be trans-generational (Nadeau, 2009).

Different methodological approaches have been developed to estimate the impacts of environmental factors on human health and well-being, including Environmental Burden of Disease (EBD) or environmental health impact assessments (Fischer et al., 2010).

Environmental burden of disease (EBD) methods aim to quantify the proportion of the total burden of disease in a population that can be attributed to environmental factors. WHO has estimated that, globally, 24 % of the disease burden, expressed as disability adjusted life years (DALYs) and 23 % of all deaths (premature mortality) is attributable to environmental factors, with children being generally more affected, and with large regional differences due to different environmental exposures and access to health care across the regions (WHO, 2006c). DALY is a widely accepted and used metrics of a 'health gap' in a population, combining loss of healthy life years due to premature mortality and due to years lived with a diseases/disability. However, some aspects of DALY (and similar health indices) are subject of a heavy debate. Concerns were expressed about the approach to measuring disability weights, not distinguishing clearly between health and well-being. In the 2010 global burden of disease study, a new set of disability weights was calculated, focusing on quantifying health loss rather than welfare loss (Salomon et al., 2012). Age-weighing is considered highly controversial, as it assigns different values to time lived at different ages, with less value given to the lives of children and elderly; discounting makes the future years of healthy life lived valued less than present years; thus, it is not favorable for children and future generations (RIVM, 2005; Knol et al., 2009; WHO, 2006c).

The EBD approach is likely to underestimate the overall burden of ill health, as it focuses on single risk factors and health outcomes, rather than taking full account of complex causal pathways. EBD estimates are not yet available for many environmental risk factors, and many of the emerging environment and health challenges cannot be addressed by this methodology (WHO, 2006c; Prüss-Ustün et al., 2011). While population attributable proportions of a disease are attractive metrics due to their simplicity, they are subject to severe limitations. They provide only relative estimates of a magnitude of public health issue, are of restricted use for etiological research, and the actual preventability need to be carefully considered when prioritizing/ranking environment related health issues (Saracci et al., 2007).

Scientific understanding of the links between the environment and public health has advanced significantly; not least as a result of EU-funded research (such as INTARESE ([1]), HEIMTSA ([2]), HENVINET ([3])), as well as initiatives which promote networking among national programmes (such as ERA-ENVHEALTH ([4])). An integrated environmental health impact assessment (EHIA) framework has been proposed, which involves analysing the impacts of environmental factors, both hazardous and beneficial, within the context of changing external forces, including technological, socio-demographic and economic changes, and policies (Briggs, 2008). However, further work is needed to develop these integrated analytical and assessment approaches further and to apply them in the policy process.

A new approach to assess links between a lifetime exposure to environmental factors and human diseases, based on the concept of the exposome,

([1]) INTARESE — Integrated Assessment of Health Risks of Environmental Stressors in Europe (2002–2006).
([2]) HEIMTSA — Health and Environment Integrated Methodology and Toolbox for Scenario Assessment (2007–2011).
([3]) HENVINET — Health and Environment NETwork (2006–2010).
([4]) ERA-ENVHEALTH — Coordination of Environment and Health research in Europe (2008–2012).

referred to as 'the totality environmental exposures from conception onwards' (Wild, 2005, 2012; Rappaport and Smith, 2010), has recently become a subject of EU-supported research (IARC, 2012d).

Given the complex exposure patterns, uncertainties and time lags in health impacts, there is a need for new ways of appraising health risk evidence, drawing from a range of sources and methods. A growing body of evidence underlines the need for appropriate precautionary measures to reconcile different stakes and societal values (EEA, 2013a).

1.5 The EU 2020 strategy provides an overarching policy framework

The main European policies aim to provide an environment in which the level of pollution does not give rise to harmful effects on human health and the environment, and vulnerable population groups are protected. These include: the 6th Environment Action Programme (EAP), where 'Environment and health and the quality of life' is one of the four priority areas (EC, 2002), the EU Environment and Health Strategy (EC, 2003) and Action Plan 2004–2010 (EC, 2004a), and the pan-European WHO Environment and Health process (WHO, 2004).

The proposal for a 7th Environment Action Programme (EC, 2012f), which will guide EU work in the environment area for the coming years, is building on three main thematic areas of which 'human health and well-being' is one. Compared to the previous, 6th Environment Action Programme, human health and quality of life aspects are strengthened and given more prominence, and framed in a broader picture including the other thematic priorities 'Natural Capital' and 'A Resource efficient low-carbon economy'. In this way the proposal responds to the review of the 6th EAP (EP, 2012a, 2012b) by the European Parliament which stresses that implementation of the environmental acquis is still insufficient. Full implementation and enforcement at all levels will be needed, and further strengthening of key environmental priorities — climate change, biodiversity, resources, environment and health — are crucial. Concerning environment and health, the European Parliament reflects that poor environmental conditions have a substantial impact on health, involving high costs.

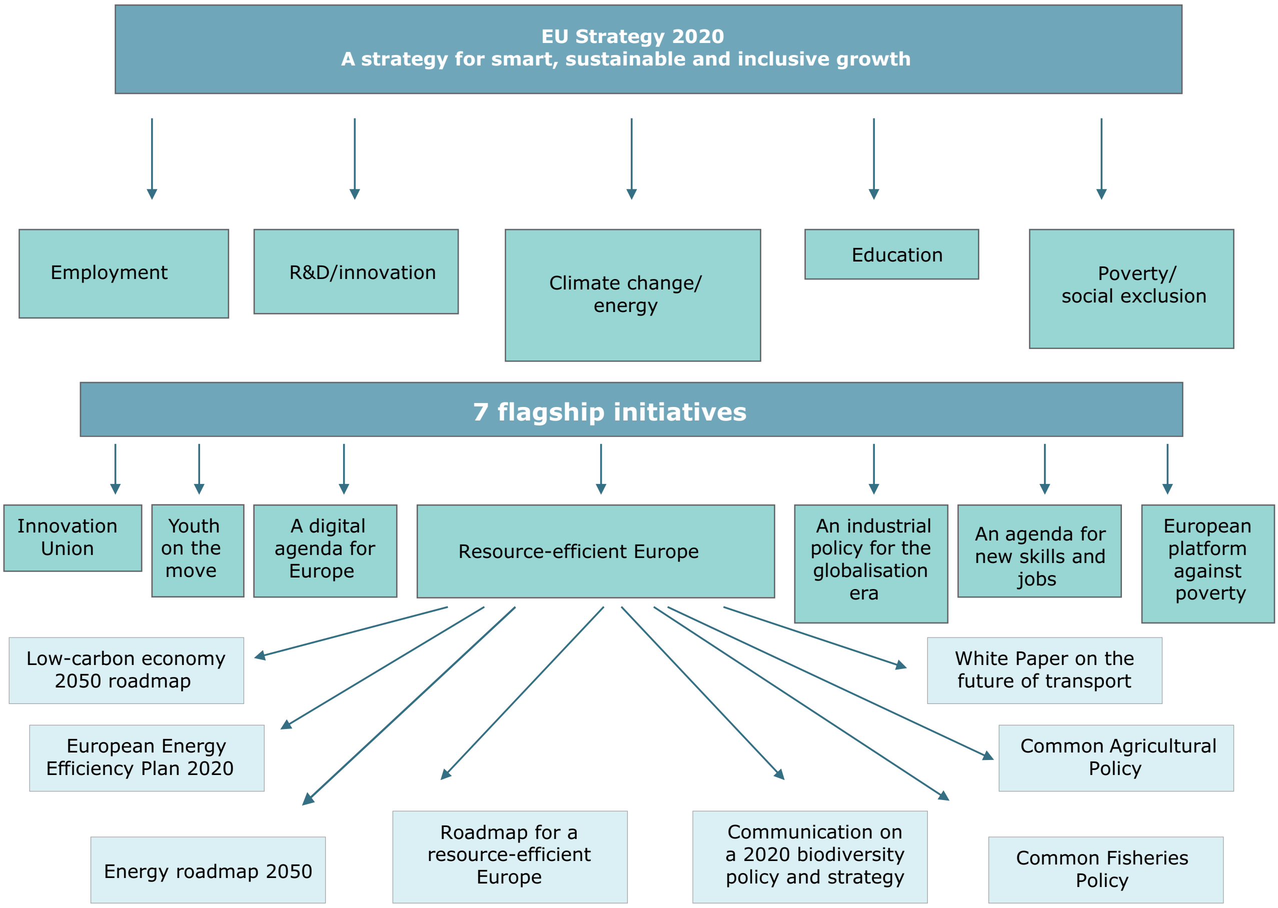
Fostering good health in an ageing Europe is one of the main goals of the EU health policy (EC, 2007); addressing health inequalities linked to environmental, social, and economic factors is part of an approach to achieve healthy ageing (Eurostat, 2011a). Reducing health disparities also has an economic dimension; in 2007, the estimated annual costs of the persistent health inequities in the EU were equivalent to 15 % of social security expenditure and 20 % of health care expenditure (Mackenbach et al., 2007).

The importance of the EU ability 'to meet the challenge of promoting a healthy and active ageing population to allow for social cohesion and higher productivity' is also stressed in the Europe 2020 strategy (EC, 2010b). This articulates a vision of a smart, sustainable and inclusive economy, delivering high levels of employment, productivity and social cohesion. Within this context, human health and environmental concerns may provide incentives for innovation, for example in land use, improvement of building construction, efficient mobility and energy saving.

With high expectations for innovation, including emerging technologies such as nanotechnology, genomics and synthetic biology, a broad perspective is needed to explore the implications of future developments. In the framework of the Responsible Research and Innovation (RRI) concept, several aspects of research and innovation are currently being discussed, including social and environmental benefits, consistent involvement of society, assessments of social, ethical and environmental impacts, risks and opportunities, both now and in the future, transparency of the research and innovation process, as well as development of oversight mechanisms, capable of anticipating and managing problems and opportunities, and responding quickly to changing knowledge and circumstances (EC, 2011h; Sutcliffe, 2011).

The Flagship Initiative 'Resource Efficient Europe' contains elements relevant to environment and health (Figure 1.2). The Road Map to a Resource Efficient Europe outlines that 'by 2050 the EU's economy has grown in a way that respects resource constraints and planetary boundaries, thus contributing to a global economic transformation' (EC, 2011g). It also states that the standard of living will be maintained but with much lower environmental impacts. The classical health threats such as chemicals, air and water are addressed, but health concerns are also cutting into areas such as waste, biodiversity, energy, agriculture and sustainable consumption and production. However, there are also areas where associated health aspects are not mentioned in the roadmap, such as research and innovation, environmentally harmful subsidies, land use, improvement in building construction and ensuring efficient mobility (Rappolder, 2012).

Figure 1.2 The EU 2020 strategy — a strategy for smart, sustainable and inclusive growth



Source: Rappolder, 2012.

Part II Thematic chapters

2 Chemicals

People are exposed to chemicals from a range of sources, through different environmental pathways and exposure routes. Water, air, food, consumer products, and indoor dust can play a role in human exposure — through ingestion, inhalation or dermal contact. Every European citizen has man-made chemicals in their bodies, as indicated by a number human biomonitoring studies. The 'Bad Blood' study carried out by WWF on European environment ministers in 2004, which showed that every minister, regardless of a country, had measureable levels of chemicals in their blood, was a powerful eye-opener for many European citizens (WWF, 2004).

While not all chemicals are hazardous, exposure to some can cause serious human health and/or environmental effects. Toxic effects of chemical contamination on wildlife, with a bearing on human health, have been recognised much earlier. In 1962, a landmark book by Rachel Carson *Silent Spring* highlighted environmental impacts of the use of the pesticide DDT; research and monitoring efforts inspired by this book helped to identify other pollutants with similar properties, like PCBs and dioxins, and heavy metals such as mercury. Over the years, recognition of the potential environmental and health impacts of chemicals has been evolving, moving beyond the 'traditional' sources of exposure and well-recognised hazards. A range of emerging contaminants, including chemicals present in personal care products and pharmaceuticals (PPCP) have been identified, with emerging evidence indicating potential environmental and human health impacts. Pesticides are an important component of modern agriculture and, with increasing demands on production of food and bioenergy, an increased use of pesticides can be foreseen.

Currently, chemicals of particular environmental concern include persistent, bio-accumulative and toxic (PBT) chemicals. These include endocrine-disrupting chemicals used in plastics, textiles, cosmetics, dyestuffs, pesticides, electronic goods and food packaging. There are speculations that exposure to these chemicals is linked to declining sperm counts, genital malformation, impaired neural development and sexual function, obesity and cancer as discussed in recent reviews of the scientific literature (EEA, 2012h; WHO, 2012a), but firm evidence is lacking. While concerns about chemicals are growing, data for the occurrence of chemicals and their fate in the environment, as well as for exposures and associated risks to wildlife and humans, in many cases remain insufficient. Exposure pathways and health risks for humans and wildlife are relatively well understood for many legacy pollutants such as DDT and PCBs through established European regulatory monitoring of PBT chemicals. For many classes of chemicals, however, environmental data are scarce. A broader knowledge base is needed, in particular with respect to emerging contaminants, to better identify those that pose a significant risk to environmental and human health.

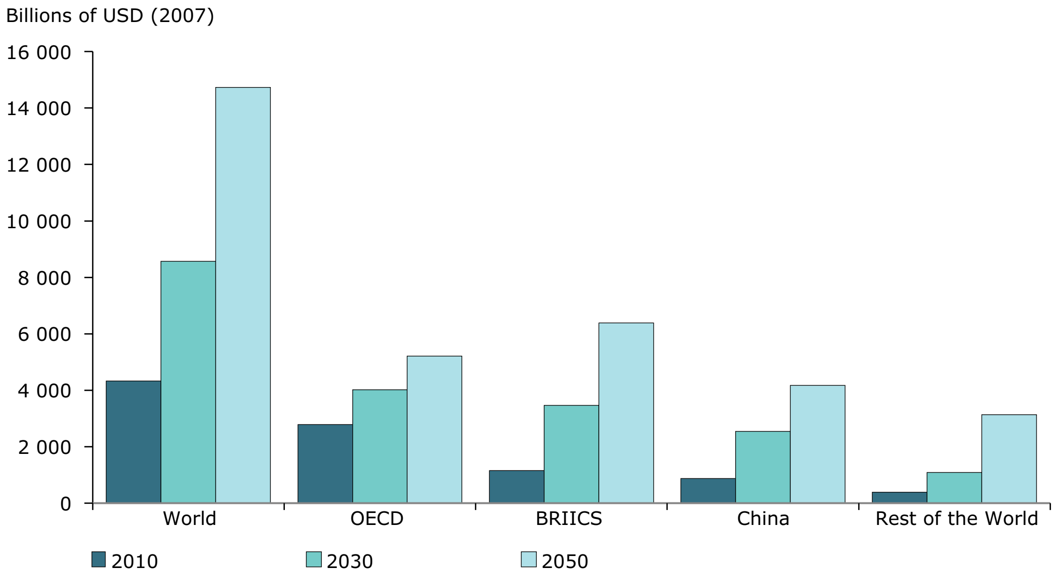
2.1 Global chemical production is on the rise

Globally, annual sales of products from the chemicals sector doubled between 2000 and 2009; the BRIICS (Brazil/Russia/India/Indonesia/China/South Africa) countries increased their share of the global market from 13 % to 28 %, while the OECD's decreased from 77 % to 63 %. The world chemicals industry is projected to grow, in terms of sales, by almost 3 % per year to 2050, with different regional rates of growth (Figure 2.1). This raises questions about risks to human health and the environment, especially in non-OECD countries, taking account of the predicted continued shift in chemical production from OECD to BRIICS countries, and calls for enhanced international co-operation and capacity building for the sound management of chemicals (OECD, 2012).

Between 2002 and 2009 the overall production of toxic chemicals in the EU decreased, on average, by 1.8 % per year, although this was due entirely to the drop in 2008 and 2009 (Figure 2.2). Despite a sharp decline in the production of the two most toxic groups, CMR ([5]) chemicals (by 13.5 %) and chronic-toxic chemicals

([5]) CMR — carcinogenic, mutagenic and reprotoxic.

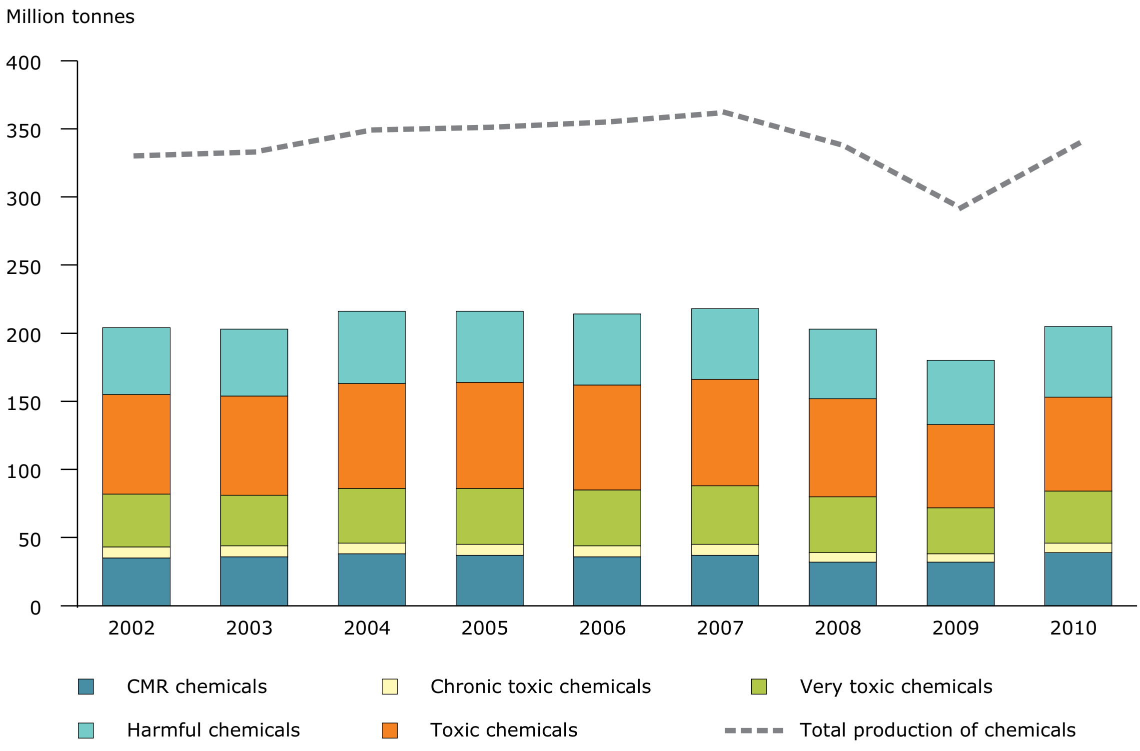
Figure 2.1 Projected chemicals production by region (in sales): baseline 2010–2050



Note: China is included in the BRIICS data, but has also been singled out to show its share in the BRIICS projected chemical production.

Source: OECD Environmental Outlook Baseline; output from ENV-Linkages.

Figure 2.2 Production of toxic chemicals, by toxicity class in the EU-27 (million tonnes)



Source: Eurostat, 2011b.

(by 25 %) between 2007 and 2009, their shares in production did not change. Similarly, the share of total toxic chemicals in the total production of chemicals remained approximately the same at 62 % (Eurostat, 2011b).

Implementation of the regulation for the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH), which entered into force in June 2007 (EU, 2006c), might have contributed to a reduction in the production of chemicals. The decline in 2008 and 2009 is also likely to be at least partly a result of the economic crisis, which led to a fall in industrial production.

2.2 Understanding of health impacts of exposure to chemicals remains limited

Understanding of human health impacts of long-term exposure to low levels of chemicals is still limited. Possible combined effects of exposure to a mixture of chemicals found at low levels in the environment or in consumer goods, especially of young children, are receiving particular attention. The scientific understanding of mixture toxicology has recently advanced significantly, not least as a result of EU-funded research (e.g. NoMiracle ([6]), PHIME ([7])). The OECD also recognises the growing trend at both the national and international level towards considering assessment of combined exposure to multiple chemicals (OECD, 2011b).

Carcinogenic and mutagenic chemicals have long been of prime concern from a public health perspective. With the conclusion of the Human Genome Project it has become clear that not only the gene sequence but also other genetic mechanisms play a role in disease development process. Epigenetic mechanisms, meaning changes not in the gene sequence, but in how the gene sequence is read and translated into proteins, are currently receiving a lot of attention (Skinner, 2012). Chemicals can affect that process through modification of the DNA molecule; such an epigenetically modified DNA can be inherited over generations. Epigenetic mechanisms can help explain how environmental exposures can influence the development of offspring (Nadeau, 2009).

Endocrine disruption (ED) has received increasing attention in relation to the potential impacts on the endocrine system following exposure to low levels of hormone-mimicking chemicals (Vandenberg et al., 2012), and because of an ever-growing number of chemicals used in consumer products that could have ED properties (Box 2.2).

In March 2013, a scientific opinion on the human health and environmental risks associated with the possible presence of endocrine disruptors in the food chain was published by the European Food Safety Authority (EFSA). At the request of the European Commission, the opinion of EFSA's Scientific Committee aimed to answer the following questions, taking stock of the available scientific information: a) what scientific criteria are used for identifying endocrine disruptors, b) what criteria can be applied to distinguish potential adverse effects of an endocrine disruptor from the normal regulation of body function in humans and ecosystems, and c) do existing toxicity testing methods appropriately cover the effects of endocrine-active substances (EFSA, 2013).

Vulnerability to disturbance changes during life. Early human life stages, especially the embryonic, foetal and infant stages, are known to be particularly sensitive to chemicals. Exposure to chemicals in highly vulnerable periods has been linked not only with developmental disturbances and other health disturbances in childhood, but to health disturbances throughout life. Some adult diseases, such as testicular cancer in men and breast cancer in women, are speculated to be linked to early-life or even prenatal exposures; a growing number of studies reveals links supporting an 'early exposure — late effect' concept (Grandjean et al., 2008; WHO, 2012a).

2.3 Heavy metal emissions have decreased, but remain a problem for environment and health

Heavy metals have long been known for their toxicity and are subject to regulation aimed at reducing their emissions to the environment (Figure 2.3). While this has contributed to declining exposure levels in wildlife and humans, metals remain an environmental health issue (PHIME, 2011). Potentially health-relevant exposures in the general population are widespread; metal toxicity, including subclinical effects and their contribution to common (chronic) diseases is increasingly understood, and possible impacts of exposure to new metals, such as tungsten, thorium, rare-earth

([6]) NoMiracle — Novel Methods for Integrated Risk Assessment of Cumulative Stressors in Europe (2006–2009).
([7]) PHIME — Public Health Impact of long-term, low-level Mixed Element Exposure in susceptible population strata (2006–2011).

Box 2.1 Endocrine disruption

Several definitions of endocrine-disrupting chemicals (EDC) have been proposed; controversies remain, also in the context of risk assessment procedures and actions to be taken against EDC. WHO/IPCS and WHO/UNEP defines EDC as substances that 'alter the function(s) of the endocrine system and consequently cause adverse health effects in an intact organism, or its progeny, or (sub)populations' (WHO/IPCS, 2002; WHO/UNEP, 2013) while the Endocrine Society defines EDC as 'a chemical or mixture of chemicals in the environment that can interfere with any aspect of hormone action' (Zoeller et al., 2012). To support a consistent approach to hazard and risk assessment of EDCs, the OECD has developed a conceptual framework for evaluating health effects on humans and other species (OECD, 2002).

United Nations Environment Programme (UNEP) and World Health Organization (WHO) published in 2013 a review of the *State of the Science of Endocrine Disrupting Chemicals — 2012*, updating the International Programme on Chemical Safety (IPCS), (a joint programme of the WHO, UNEP and the International Labour Organization) *Global Assessment of the State-of-the-Science of Endocrine Disruptors* published just over 10 years ago (WHO/IPCS, 2002; WHO/UNEP, 2013).

The WHO/UNEP 2013 report reviews the global status of scientific knowledge on exposure to, and effects of endocrine disrupting chemicals (EDCs), and identifies key concerns. It acknowledges that endocrine systems are very similar across vertebrate species and that endocrine effects manifest themselves independently of species. Effects shown in wildlife or experimental animals may also occur in humans if they are exposed to EDCs at a vulnerable time and at concentrations leading to alterations of endocrine regulation. The review expresses particular concern for effects on early development of both humans and wildlife, as these effects are often irreversible and may not become evident until later in life. They conclude that three strands of evidence fuel concerns about endocrine disruptors:

- the high incidence and the increasing trends of many endocrine-related disorders in humans;
- observations of endocrine-related effects in wildlife populations;
- the identification of chemicals with endocrine disrupting properties linked to disease outcomes in laboratory studies.

In addition the WHO/UNEP 2013 report remarks that:

- close to 800 chemicals are known or suspected to be capable of interfering with hormone receptors, hormone synthesis or hormone conversion. However, only a small fraction of these chemicals have been investigated in tests capable of identifying overt endocrine effects in intact organisms;
- the vast majority of chemicals in current commercial use have not been tested at all;
- this lack of data introduces significant uncertainties about the true extent of risks from chemicals that potentially could disrupt the endocrine system.

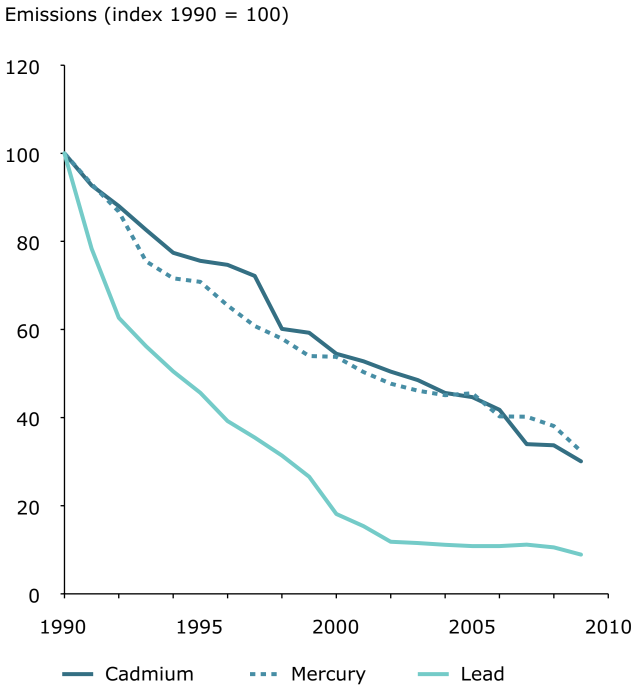
WHO/UNEP 2013 concludes that despite substantial advances in our understanding of EDCs, uncertainties and knowledge gaps still exist that are too important to ignore. These knowledge gaps hamper progress towards better protection of the public and wildlife. An integrated, coordinated international effort is needed to define the role of EDCs in current declines in human and wildlife health and in wildlife populations.'

metals, platinum, rhodium and palladium are emerging.

Lead exposure is a public health concern due to its serious adverse effects, in particular neuro-developmental impairment in young children, often expressed as loss of IQ points. In recent decades, there have been major decreases in exposure to lead, following the phasing-out of leaded petrol and reductions in other sources of exposure. Further measures are however needed to prevent even low-level exposure, as 'no threshold for these (IQ loss) effects has been identified, and the evidence suggests that the response at concentrations of lead in blood below 100 μg/L is steeper than at higher exposure levels' (EFSA, 2010a).

Less progress has been seen in the case of cadmium, a highly toxic metal affecting kidneys and bones,

Figure 2.3 Emission trends of cadmium (Cd), mercury (Hg) and lead (Pb) in the EEA member countries

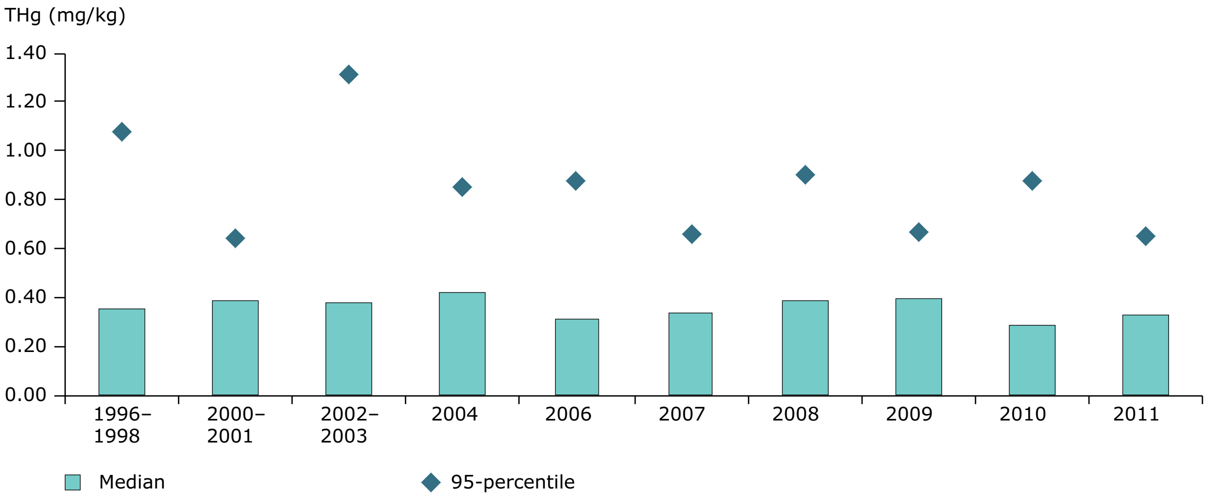


Source: EEA, 2011a.

and linked to lung cancer. For the non-smoking general population, food is the major source of exposure. While ambient air concentrations and deposition in Europe have decreased, cadmium body burdens in non-smokers have not decreased over the past decade (WHO, 2007b). In 2009, the EFSA Scientific Panel on Contaminants in the Food Chain (CONTAM) concluded that the mean dietary exposures in European countries are close to or slightly exceed the established Tolerably Weekly Intake (TWI) of 2.5 µg/kg body weight (EFSA, 2009). Some groups, such as vegetarians, children, smokers and people living in highly contaminated areas, may exceed the TWI; therefore every effort should be made to reduce cadmium exposure at the population level (EFSA, 2011).

Human exposure to mercury and its compounds remains a serious public health concern. All forms of mercury are toxic; however, of particular concern is methylmercury — a potent neurotoxin, especially for unborn children (i.e. foetuses) and infants (Mergler et al., 2007). Available data indicate that methylmercury exposure is considerable in subpopulations that consume large amounts of fish, for example in the Mediterranean region — Spain, France, and in Scandinavia (Björnberg et al., 2003; WHO, 2007b; Castaño et al., 2012) (Figure 2.4). While fish and sea mammals represent the main dietary source of mercury exposure, health benefits of fish consumption cannot be underestimated (see for example: (EC, 2004b; Wennberg et al., 2010, 2012; Moreno, 2012). Mercury pollution is a complex multi-scale issue, due to the worldwide origins of mercury emissions from a multitude of sources and extensive long-range transport, with potential impacts in remote areas, such as the Arctic. International mercury policy has been developed

Figure 2.4 Mercury in hair (total mercury, THg, mg/kg) in first-time mothers, Uppsala County (1996–2010)



Source: Dr Marika Berglund, Karolinska Institute, Stockholm, Sweden.

since the 1970s; in February 2009, (UNEP, 2009) the Governing Council of UNEP adopted Decision 25/5 on the development of a global legally binding instrument on mercury. On 19 January 2013, governments agreed to the text of the global legally binding instrument on mercury and gave birth to the 'Minamata Convention on Mercury' (UNEP, 2013).

In addition to well-established environmental sources, consumer products may play a role in exposure to metals. In 2010, based on a survey of lead and other metals in jewellery, the Danish Ministry of the Environment invited the Commission to consider whether the possible health risks to consumers justify regulatory action (SCHER, 2010). Waste electrical and electronic equipment (WEEE), containing, among others, heavy and rare-earth metals, has become one of the fastest-growing waste types globally. Of environmental and health concern is improper disposal and recycling of WEEE, especially in developing countries, resulting in increased human exposure, contamination of food, soil, and surface water (Wäger et al., 2012; Zheng et al., 2008).

2.4 Persistent chemicals and endocrine disruptors are of increasing concern

A range of persistent and bio-accumulative compounds and endocrine-disrupting chemicals used in plastics, textiles, cosmetics, dyestuffs, pesticides, electronic goods and food packaging, which are considered safe according to regulatory criteria, still raise concern about possible adverse health impacts. They are used in large quantities and almost every citizen is exposed to them every day. Chemicals in consumer goods may also be of concern when products become waste, as many chemicals migrate easily to the environment and can be found in wildlife, ambient air, indoor dust, wastewater and sludge. A relatively new concern in this context is WEEE, which contains brominated flame retardants and other hazardous chemicals as well as heavy metals.

Phtalates, bisphenol A, perfluorinated chemicals, and brominated flame retardants are most often discussed because of their suspected health effects (for example: Jurewicz and Hanke, 2011; Masuo and Ishido, 2011; Polańska et al., 2012; WHO, 2012a; Jurewicz et al., 2009) and ubiquitous presence in the environment and in humans, as indicated by bio-monitoring studies (Becker et al., 2009; Koch et al., 2012; Kasper-Sonnenberg et al., 2012; Koch and Angerer, 2012). Another concern is pharmaceutical contaminants from production processes, in household waste and in wastewater from sewage treatment plants (EEA, 2010a).

Phthalates, used as plasticisers to increase the flexibility, transparency, durability, and longevity of plastics, raise concerns over their possible endocrine-disrupting effects and adverse reproductive effects. Phthalates are found in a variety of personal care and industrial products including: food packages, children's toys, lubricants, baby-care products, chemical stabilisers in cosmetics, vinyl flooring, adhesives and glues, electronics, modelling clay, paints, printing inks and coatings, pharmaceuticals, medical devices, and textiles. Phthalates can be released to the environment at all stages of the life cycle; not chemically bound to PVC, they can leach, migrate or evaporate into indoor air and the atmosphere, foodstuff, other materials, etc., resulting in human exposure.

The EU Risk Assessment Report for diethylhexyl phthalate (DEHP) (JRC, 2008) estimated a release of about one quarter of the amount of substance produced per year. The report also concluded that there is concern for effects on testis, kidney, fertility, and about developmental toxicity, for workers, children exposed to DEHP-containing toys and child-care articles, children and adults undergoing some medical treatments using medical equipment containing DEHP, and children eating food grown near industrial sites handling DEHP. There is also concern for aquatic and terrestrial ecosystems, linked with the use of DEHP in the production of lacquers, paints, printing inks, sealants, and adhesives, and at industrial sites processing polymers containing DEHP.

Bisphenol A (BPA) is a widely discussed, highly controversial chemical with endocrine-disrupting properties. An extensive overview of the issues around BPA is presented in the report *Late lessons from early warnings* Vol. II (EEA, 2013a). BPA is a high-volume chemical used in very large quantities. The total amount manufactured in the EU is approximately 1 million tonnes/year and the total EU consumption is estimated to exceed 700 000 tonnes/year. BPA is used mainly for the production of epoxy resins and polycarbonate plastics present in many consumer products; its leaching has been measured in food containers, baby bottles, and dental sealants under normal conditions of use. Since it is included in food packing material and also in plastic containers used for food preparation and storage, humans are constantly exposed. BPA is however, rapidly metabolised in the body and excreted.

BPA has structural similarities to the female sex hormone estrogen and has been shown in animal experiments and cell-based test systems to have weak estrogenic effects. The potency of BPA is approximately 1/1 000 of the natural estrogen. The fact that it is commonly present in our daily environment and that direct measurements show human exposure has nursed the hypothesis that it may act as an estrogenic endocrine disruptor in humans and be responsible for a number of endocrine-related diseases, which are on the rise in many European countries. Examples are the well-established reduction in sperm counts in fertile men, the increase in breast cancer in women and testicular cancer in men and the occurrence of developmental malformations in newborn boys. BPA exposure has also been linked to learning disabilities in children and to increased risk of cardiovascular disease in adults (Lang et al., 2008; Masuo et al., 2011; WHO, 2012a).

The controversy over the toxicity of BPA has been reflected in the opinions/reports of different bodies/organisations. *Despite the fact that more than 5 000 safety-related studies have been published on Bisphenol A (BPA) there seem to be no resolution of the apparently dead-locked controversy as to whether exposure of the general population to BPA causes adverse effects due to its estrogenicity*; this statement by Hengstler et al. (2011), referring to an analysis made by the Advisory Committee of the German Society for Toxicology, seems to well describe the current debate/dispute. In September 2010, the European Food Safety Authority (EFSA) stated in its 'Updated advice on Bisphenol A' that there was no scientific evidence which necessitated a revision of the current Tolerable Daily Intake (TDI) value of 0.05 mg/kg body weight/day (EFSA, 2010b). The Advisory Committee of the German Society for Toxicology Committee reviewed the background and the most recent topics of the BPA controversy, and concluded, on the basis of available knowledge, that there was no scientific ground for the criticisms of the recommended TDI value of 0.05 mg/kg body weight/day established by EFSA (Hengstler et al., 2011). A parallel assessment has been made in a report 'Health effects of bisphenol A' published by ANSES (France) in September 2011 (ANSES, 2011). This gave an extensive review of BPA health effects, based on a literature review (until 25/01/2011), and should be considered as a first and intermediary report before publication of the full BPA risk assessment report (ANSES, 2013).

Brominated flame retardants like polybrominated diphenyl ethers (PBDE) were originally developed as substitutes for PCBs in applications of flame and fire resistance. There is still large uncertainty about exposure routes and levels, effects and mechanisms of action. PBDE are persistent and bioaccumulative, with the exception of BDE-209. PentaBDE and OctaBDE have been banned because of their toxicity, bioaccumulation and persistence since 2003 under the EU legislation (EU, 2003). Tetra-, penta-, hexa, hepta- and octa-BDE were added to the Stockholm Convention in 2009.

Perfluorinated compounds (PFCs) are widely used in industry as polymers, surfactants, lubricants, and pesticides; and in consumer products such as textile coatings, non-stick coatings, stain repellents, food packaging, and fire-fighting foams, because of their unique physico-chemical properties (such as thermal and acid resistance, both hydro- and lipophobic). Long assumed to be inert and thus safe, PFCs can be released during certain industrial applications and during the lifetime of commercial products that contain them. Among these, the eight carbon-chained PFOS and perfluorooctanoic acid (PFOA) are persistent in the environment and are found even in remote areas such as the Arctic, and have been detected in wildlife and humans (AMAP, 2009). A study on children in Greenland linked PFOA body burdens with a weakened immune response in vaccination programmes, leading to a reduced protection against diseases (Grandjean et al., 2012). The current information on toxicity and adverse health effects in humans is largely incomplete and too inconclusive to warrant immediate global action against PFOS. One of the disagreements within the scientific community and among the stakeholders is about the extent to which PFOS can cause serious or irreversible damage. However, the biological and chemical properties that PFOS share with POPs resulted in its being listed by the United Nations Stockholm Convention.

2.5 'Green chemistry' may provide sustainable alternatives

Despite the comprehensive suite of legislation, the ubiquitous use of chemicals in society and their continuous release represent a major challenge in terms of the protection of ecosystems and human health. Efforts to promote more sustainable consumption and production of chemicals are needed. These are likely to require a mix of policy responses, including regulation, economic incentives and information-based instruments.

Implementing a more sustainable approach to the consumption and production of chemicals would not only benefit Europe's environment but also reduce the detrimental effects arising in other parts of the world as a result of the growing proportion of goods imported to Europe. To help achieve a more sustainable production of chemicals, wider implementation of 'green chemistry' is required. This approach involves not only considerations of toxicity and eco-toxicity of a chemical, but also address the starting materials, water and energy use, transport, release of CO_2 and other emissions, as well as waste generation throughout the life cycle. Such a 'sustainable chemistry' approach requires new, resource-efficient production processes and the development of chemicals that use fewer raw materials and are of high quality, but reduce or eliminate the use and generation of hazardous substances (OECD, 2011a; UBA, 2012).

The adoption of sustainable, green chemistry techniques has been shown to generate financial benefits and hence provide competitive advantage. For example, the OECD report shows that the rate of patents in certain green chemistry technologies, such as biochemical fuel cells and green plastics, has grown at least seven times faster than in the chemicals industry overall (OECD, 2012). Currently, however, there is no comprehensive EU legislation on sustainable chemistry in place.

2.6 Approaches to risk assessment need to be revised to better reflect the health risks of chemicals

There is increasing recognition that the current paradigm in chemical risk assessment, considering substances on a chemical-by-chemical basis, under the assumption of linearity of exposure-response relationship, underestimates the risks to human health and to the environment (Kortenkamp et al., 2009; EC, 2012a). A change towards a cumulative risk assessment, taking account of non-monotonic exposure-response relationships and effects at low levels of exposure is necessary to avoid underestimation of the risks that might occur from exposure to chemicals present in the environment and consumer products (Kortenkamp et al., 2009, 2012; Meek et al., 2011; OECD, 2011b). Acknowledgment of the principles of endocrinology alongside those of toxicology in risk assessment is needed to address chemicals with endocrine-disrupting properties (EC, 2012e; Hass et al., 2012; Zoeller et al., 2012).

Challenges remain in collecting sufficient data to complete risk assessments on the thousands of chemicals on the market, and in assessing the effects of chemicals on human health. Work towards developing new or updated test methods and harmonising integrated approaches to testing and assessment needs to continue, coupled with well-designed large-scale epidemiological studies of the patterns of illness in the population that might be associated with chemical exposures.

Much more research is needed to fully understand the impacts on health and the environment of endocrine-disrupting chemicals. However, according to many experts, despite remaining uncertainties, there is enough scientific evidence to start regulating these chemicals (EC, 2012e).

As a precautionary measure, the European Union in March 2011 banned the use of BPA in the production of baby bottles, and since 1 June 2011 it has not allowed the marketing of baby bottles with BPA within EU. There are also recommended restrictions on the use of BPA in food contact material (EC, 2011a, 2011b; EU, 2011a). Sweden banned BPA in food packing material of children's food from 1 January 2013. Based on the assumption that BPA can be absorbed through the skin, the Swedish Chemicals Inspectorate has proposed a ban on BPA in thermal printer paper for receipts and tickets (KEMI, 2012).

The current EU-wide bans on phthalates apply only to specific products such as toys and cosmetics. From 2015, manufacturers will have to apply for authorisation when using phthalates (DEHP, DBP and BBP); another phthalate (DIBP) is recommended to be added to the REACH authorisation list. Denmark has proposed to the EU a ban of a combination of four phthalates (DEHP, DBP, BBP and DIBP), arguing that there is sufficient scientific evidence for restricting the use of these endocrine disruptors (MIM, 2012a). Although the European Chemicals Agency's risk assessment committee considered the proposed restriction unnecessary, Denmark published an executive order on the ban of certain phthalates, to enter into force in December 2013 (MIM, 2012b), applying to all consumer products for indoor use, such as shower curtains and vinyl flooring.

Many initiatives are being undertaken by different stakeholders (at the national level, by NGOs, etc.) to reduce exposure to chemicals, including endocrine-disrupting substances, also through awareness raising and support for more conscious consumers' choices (WECF, 2012; Danish EPA, 2011) (Box 2.2).

Box 2.2 Reducing children's exposure to chemical cocktails — an example of an awareness-raising campaign

Based on a comprehensive analysis of a typical day of a two year-old child, the Danish EPA has published guidelines on how to reduce children's exposure to chemical cocktails.

The majority of the endocrine disruptors that children are exposed to derive from the indoor environment and food. The guidance focuses on: *parabens*, used as a preservative in some cosmetics; *phthalates*, used as softeners in plastics; and *PCBs*, previously used in buildings, etc.

The advice to reduce exposures of young children, also valid for adults and children of all ages, includes:

- make sure there is a good indoor environment — ventilate and clean rooms;
- serve varied food and use appropriate kitchen utensils;
- buy Swan labelled (eco-labelled) and perfume-free personal care products and toys;
- avoid the most dangerous phthalates; wash new products before use;
- throw away old soft plastic toys.

Source: Danish EPA, 2010.

2.7 Environmental and human monitoring can be improved to provide early signals of health impacts

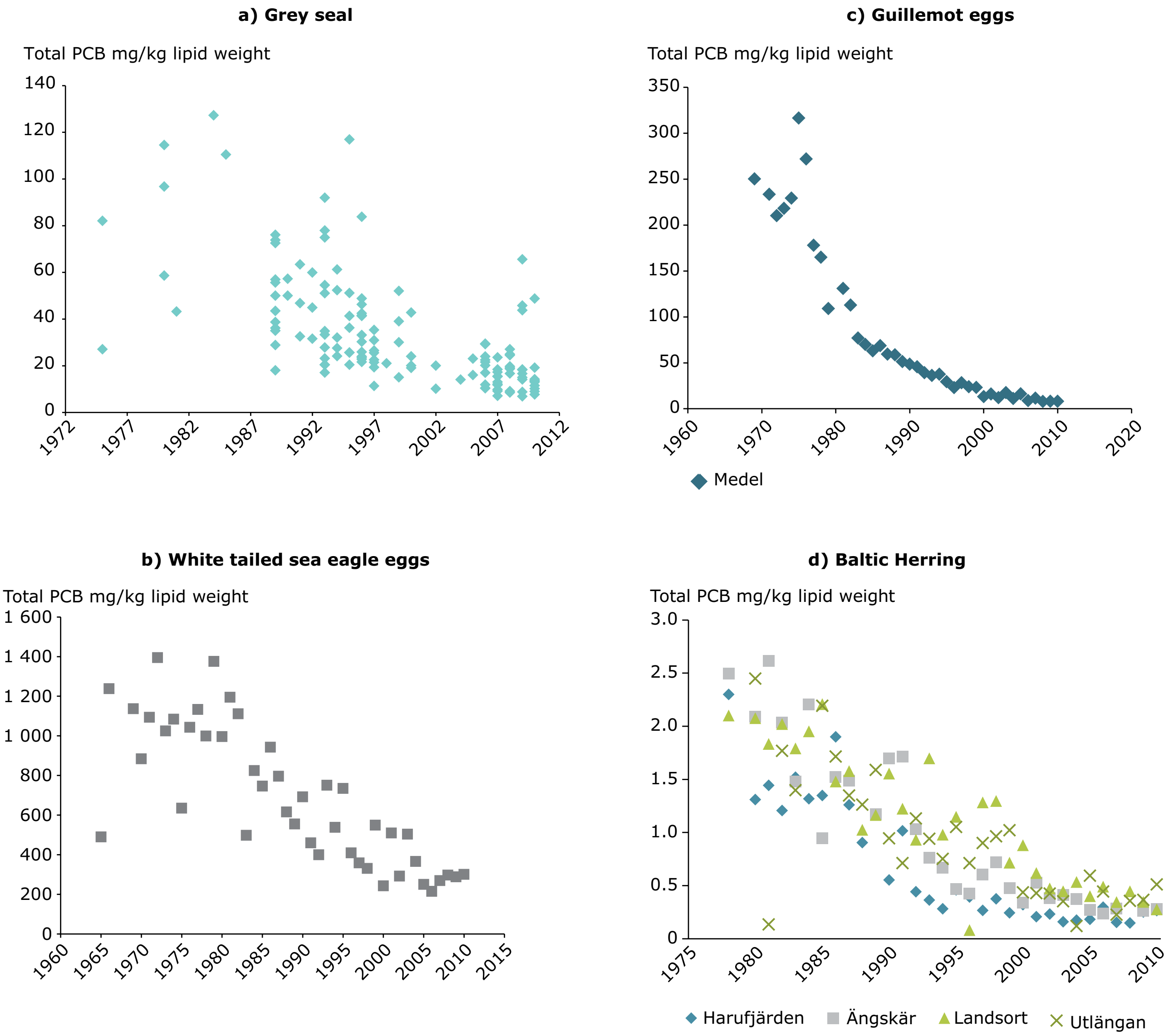
Human and environmental monitoring should be considered complementary tools that give a good insight into the occurrence of chemical contaminants in environmental components and into human exposure. An information system on concentrations of chemicals in various environmental compartments and in humans is much needed to facilitate the accessibility of existing data and encourage sharing of new data generated through different processes.

Long-term environmental monitoring programmes have been instrumental in detecting the occurrence of anthropogenic chemicals in the environment and unveiling trends and developments in relation to policy action. Pollutants like DDT and PCB were originally detected by environmental monitoring programmes, and later, when they were banned in the 1970s and 1980s, monitoring programmes showed clearly how levels in the environment decreased over time (Figure 2.5). Environmental programmes are based on analysis of certain plants or animals which are known to take up and accumulate chemicals. Examples are mosses and lichens for heavy metals, and fatty fish (salmon, herring) and sea-bird eggs for organic chemicals. The environmental programmes also provide alerts when new chemicals appear, for example substitutes of chemicals that have been banned. The mandatory environmental monitoring of certain chemicals under European legislation and under international conventions will continue to be an important tool for following chemicals of specific concern. Many European countries have included a type of surveillance monitoring of chemicals in their general environmental monitoring programmes and this monitoring is important as an 'early warning' mechanism for new and emerging chemicals.

Human biomonitoring (HBM) allows the measurement of environmental contaminants in the human body, usually through analyses of blood, urine, hair, breast milk or other tissues. It provides an integrated measure of the level of exposure to chemicals through different pathways and exposure routes. It is an important research and policy tool for assessing exposures of the human population to contaminants, and in some cases estimating potential health effects linked to the exposure. Analysed over time, human biomonitoring data allow evaluation of trends in exposure and can be used to assess the efficiency of implemented policies.

While many European countries have developed human biomonitoring programmes (for example: Kolossa-Gehring et al., 2012; Gurzau et al., 2012; Schoeters et al., 2012; Frery et al., 2012), differences in methodologies and analytical practices make comparisons of the results very difficult. The

Figure 2.5 PCB levels in grey seals (a), white-tailed sea eagle eggs (b), Guillemot eggs (c) and Baltic Herring (d) in the Baltic region between 1970 and 2010



Source: Anna Rooss, the Department of Contaminant Research at the Swedish Museum of Natural History; Stockholm, Sweden.

European Environment and Health Action Plan 2004–2010 (EC, 2004a) highlighted a need for a consolidated European effort on HBM. Two, recently concluded, major EU-supported projects address the need for a harmonised approach to achieve comparable HBM data across Europe to support environment, health and chemicals policies. The FP-7 research project COPHES ([8]) has developed harmonised European protocols for HBM; with partners in 28 European countries, the project aimed to strengthen the comparability of measurements of certain contaminants in different countries. DEMOCOPHES ([9]) aimed to test the feasibility of a coherent approach to HBM in Europe. In this pilot study, samples and data were collected from 120 mother-child pairs in each participating country, focusing on biomarkers for mercury, cadmium, phthalates as well as

([8]) COPHES — Consortium to Perform Human Biomonitoring on a European Scale (2009–2012).
([9]) DEMOCOPHES — testing the feasibility of a coherent approach to Human Biomonitoring in Europe (2009–2012)

environmental tobacco smoke in human hair and urine (COPHES/DEMOCOPHES, 2009).

Human biomonitoring is the most direct method for assessing human exposure to chemicals since it integrates exposures from different sources and also different combinations. In addition it gives a picture of what humans are exposed to in their daily lives. Therefore, together with environmental monitoring, human biomonitoring provides essential information for the risk management of chemicals in society.

2.8 European policies regarding chemicals focus primarily on 'end of pipe' solutions

In 2007 the EU implemented the Registration, Evaluation, Authorisation and restriction of Chemical regulation (REACH) for coherent management and control of chemicals within the EU (EU, 2006c). The European Chemicals Agency (ECHA) in Helsinki, Finland, was created in 2008 to overview the implementation of REACH. To improve the protection of human health and the environment from the risks of chemicals, manufacturers and importers are required to gather and register information on the properties of chemical substances and propose risk management measures for safe production, use and disposal. REACH also calls for the progressive substitution of the most dangerous chemicals once suitable alternatives have been identified. However, the regulation does not address simultaneous exposures to multiple chemicals.

Taking account of the growing evidence and societal concerns, the European Commission is foreseeing legislative work in the coming years with respect to endocrine disruptors and combined effects of chemicals (mixtures) (EC, 2012a).

Sectorial chemicals legislation is in the process of renewal. The Framework Directive on the Sustainable Use of Pesticides (EU, 2009a) and the Regulation on Authorization of Plant Protection Products (EU, 2009b) entered into force in November 2009 and in June 2011, respectively. In June 2009, the Commission proposed a new regulation concerning the placing on the market and use of biocidal products (EC, 2011e).

The EU Thematic Strategy on the sustainable use of pesticides (EC, 2006) sets objectives to minimise the hazards and risks to health and the environment stemming from the use of pesticides, and to improve controls on their use and distribution. The Pesticides Directive contains a number of rules, including the establishment of National Action Plans to set objectives to reduce hazards, risks and dependence on chemical control for plant protection. Source-control measures, including a 'greener' management identified in the directive should result in a reduced use of pesticides. The potential to reduce the amounts of harmful active substances by their substitution with safer alternatives is also recognised. National legislation has a role to play in limiting pesticide levels; for example, Denmark's green growth action plan has set a limit to the frequency with which pesticides are applied to agricultural land.

A number of international and legally-binding agreements address toxic chemicals in the environment, including: the Stockholm Convention of the United Nations Environment Programme (UNEP) on monitoring and reporting persistent organic pollutants (POPs); the Basel Convention on transboundary movements of hazardous waste; the Rotterdam Convention on export of hazardous chemicals; and the Montreal Protocol on CFCs and other ozone-depleting substances. UNEP is also currently leading work on developing a Global Strategy for Mercury with the aim of reducing mercury emissions and human and environmental exposure (UNEP, 2009).

A relevant international policy framework to foster the sound management of chemicals is the Strategic Approach to International Chemicals Management (SAICM), adopted by the International Conference on Chemicals Management in 2006 in Dubai. SAICAM supports the achievement of the goal that by 2020, chemicals are produced and used in ways that minimise significant adverse impacts on the environment and human health. The Third International Conference on Chemicals Management in September 2012 reviewed progress on SAICM implementation (SAICM, 2012).

3 Outdoor air

In Europe, emissions of many air pollutants have decreased, resulting, for some pollutants, in improved air quality. Nevertheless, due to the complex links between emissions and air quality, emission reductions do not always produce a corresponding drop in atmospheric concentrations, especially for particulate matter (PM) and ozone (O_3). Air pollution remains one of the major environmental problems in Europe, with direct consequences for the health and well-being of European citizens (EEA, 2012a). PM is one of the most relevant pollutants linked with health problems and premature mortality. Ground-level ozone (O_3), SO_2, NO_2, benzo(a)pyrene can also affect the health of European citizens. Exposure and vulnerability to the health effects of poor air quality is not equally distributed across the population, with children, the elderly, and the socially disadvantaged more likely to experience adverse impacts.

Humans and the environment in Europe are exposed to a complex mixture of many air pollutants emitted from various sources and subject to atmospheric processes which can create new pollutants, with potentially severe health impacts. While exposure to air pollution is largely a multi-pollutant process, a single-pollutant approach is adopted, both in WHO air quality guidelines, and in EU air quality legislation. Though challenging, a better understanding of possible additive, synergetic or antagonistic effects between air pollutants, and of potential interactions with other factors such as noise exposure and social stress, is much needed (Clougherty et al., 2007, 2009; EEA, 2010e; URBAN-NEXUS, 2012). In this perspective, a source approach has been adopted by several studies assessing the health impacts of air pollution, mainly in relation to the risks of proximity to traffic (APHEKOM, 2011).

3.1 Air pollutant concentrations are still too high and affect the health of European citizens

Air quality in Europe has been improving for some pollutants (Figure 3.1), but a large proportion of European citizens are still exposed to harmful air pollution (Table 3.1) (Map 3.1).

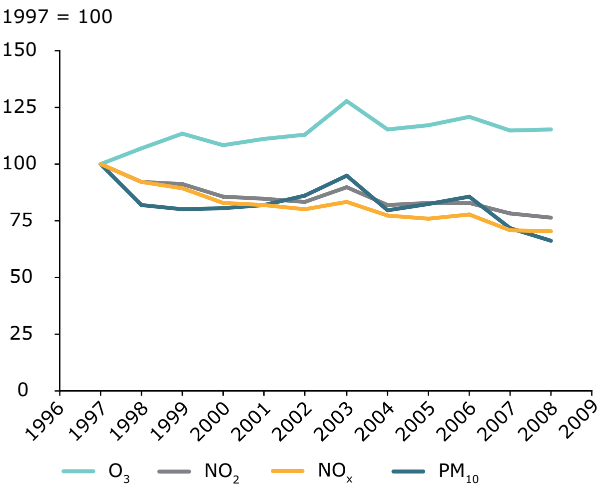
In 2010, an estimated 21 % of the urban population was exposed to PM_{10} concentration levels exceeding the daily EU limit value designed to safeguard health. Up to 30 % of the urban population was exposed to $PM_{2.5}$ concentration levels above the indicative annual EU limit value (to be met by 2020). Referring to more stringent WHO health-based air quality guidelines, respectively up to 81 % and 95 % of urban dwellers were exposed to PM concentrations above the values set for the protection of human health in the period 2008–2010.

Exposure to ground-level ozone (O_3) has not decreased since 2001 (excluding the estimated exposures in 2003 and 2006, which were due to specific meteorological factors in those two years). Between 15 % and 61 % of the EU urban population was exposed to O_3 concentrations above the EU target value for protecting human health in the period 2001–2010. High O_3 concentrations are most pronounced in southern Europe. In 2010, 17 % of the EU urban population lived in areas where the EU O_3 target value for protecting human health was exceeded; when referring to the WHO guideline value, 97 % of EU urban inhabitants were exposed to O_3 concentrations above the reference level (EEA, 2012a).

In 2010 at least 7 % of Europeans living in cities were exposed to NO_2 levels above the annual EU limit value. After a 20 year period of a decreasing trend, NO_2 levels in some urban areas are tending to increase. While the introduction of catalytic converters has efficiently reduced NO_2 emissions from gasoline-fuelled cars, the current change in the trend is linked to a change of the European car fleet, to small diesel-fuelled cars, which emit up to 60 % of their nitrogen oxides as NO_2, as their exhaust after-treatment systems increase the direct NO_2 emissions (Guerreiro et al., 2010).

SO_2 has been a success story, as 2010 was the first year that the EU urban population was not exposed to SO_2 concentrations above the daily EU limit

Figure 3.1 Annual mean concentrations of air pollutants in urban areas



Source: EEA, 2010g.

value. Concentrations of other health-relevant air pollutants, such as carbon monoxide, benzene and heavy metals (arsenic, cadmium, nickel, lead) are generally low, localised and sporadic, with few exceedances of the limit and target values set by EU legislation. A considerable proportion of the urban population in the EU (20–29 % between 2008 and 2010) were exposed to concentrations of an airborne carcinogen, benzo(a)pyrene (BaP) exceeding the EU target value, which must be met by 2013 (EEA, 2012a).

3.2 The knowledge of air pollution-related health impacts is growing…

The health impacts of air pollution have been extensively studied; most of the recent work focuses on respiratory and cardiovascular effects attributed to short- and long-term exposures, at high and at very low levels of exposure, and on the development of pregnancy-related outcomes (Brunekreef and Holgate, 2002; WHO, 2005, 2006b, 2006a, 2007b, 2008a). From a public health point of view, it is important to

Table 3.1 Percentage of urban population in the EU exposed to air pollutant concentrations above the EU and WHO reference levels (2008–2010)

Pollutant	EU reference value	Exposure estimate (%)	WHO reference level	Exposure estimate (%)
$PM_{2.5}$	Year (20)	**16–30**	Year (10)	**90–95**
PM_{10}	Day (50)	**18–21**	Year (20)	**80–81**
O_3	8-hour (120)	**15–17**	8-hour (100)	**> 97**
NO_2	Year (40)	**6–12**	Year (40)	**6–12**
BaP	Year (1 ng/m³)	**20–29**	Year (0.12 ng/m³)	**93–94**
SO_2	Day (125)	**< 1**	Day (20)	**58–61**
CO	8-hour (10 mg/m³)	**0–2**	8-hour (10 mg/m³)	**0–2**
Pb	Year (0.5)	**< 1**	Year (0.5)	**< 1**
C_6H_6	Year (5)	**< 1**	Year (1.7)	**7–8**

Colour coding of exposure estimates fraction of urban population exposed to concentrations above the reference levels:

< 10 %	10–50 %	50–90 %	> 90 %

Note: The pollutants are ordered in terms of their relative risk for health damage — highest on top.

For each pollutant, exposure estimate refers to a three year period (2008–2010) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

The reference levels in brackets are in µg/m³ except for CO which is in mg/m³, and BaP in ng/m³.

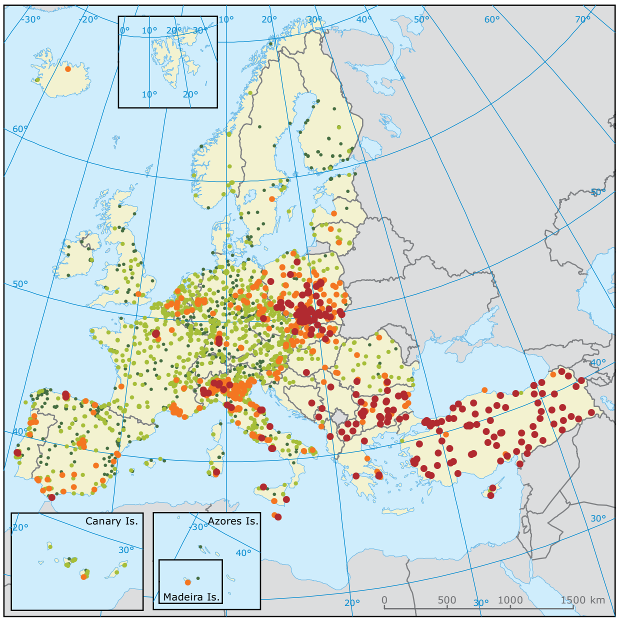
For some pollutants EU legislation allows a limited number of exceedances; this aspect is considered in the compilation of exposure estimates in relation to EU air quality limit and target values.

The comparison is made for the most stringent EU limit or target values set for the protection of human health. For PM_{10} the most stringent standard is for 24-hour mean concentration. For $PM_{2.5}$ the most stringent EU standard is the 2020 indicative annual limit value (20 µg/m³). As the WHO has not set AQG for BaP and C_6H_6, the WHO reference level in the table was estimated assuming an additional lifetime risk of 1×10^{-5}.

Source: EEA, 2012a.

Map 3.1 Concentrations of selected air pollutants in Europe in 2010

Annual mean concentrations of PM_{10}



Annual mean particulate matter (PM_{10}) 2010, based on daily average with percentage of valid measurements ≥ 75 % in µg/m³

- ≤ 20
- 20–31
- 31–40
- > 40
- Countries/regions not included in the data exchange process

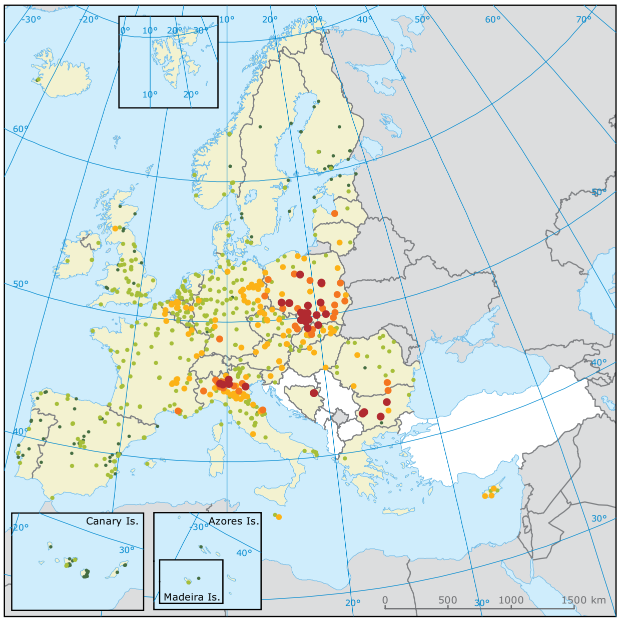
Note: The red dots indicate stations reporting exceedances of the 2005 annual limit value (40 µg/m³), as set out in the Air Quality Directive.

The orange dots indicate stations reporting exceedances of a statistically derived level (31 µg/m³) corresponding to the 24-hour limit value, as set out in the Air Quality Directive.

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for PM_{10} of less than 20 µg/m³ but not in exceedance of limit values as set out in the Air Quality Directive.

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for PM_{10} and implicitly below the limit values as set out in the Air Quality Directive.

Annual mean concentrations of $PM_{2.5}$



Annual mean fine particulate matter ($PM_{2.5}$) 2010, based on annual average with percentage of valid measurements ≥ 75 % in µg/m³

- ≤ 10
- 10–20
- 20–25
- 25–30
- > 30
- No data
- Countries/regions not included in the data exchange process

Note: The red dots indicate stations reporting exceedances of the 2010 annual target value (25 µg/m³) plus at least 5 µg/m³.

The dark orange dots indicate stations reporting exceedances of the 2010 annual target value (25 µg/m³), as set out in the Air Quality Directive.

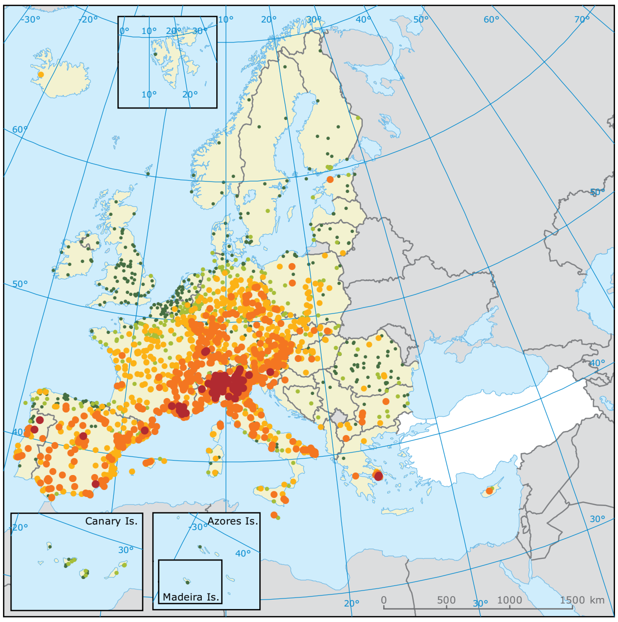
The orange dots indicate stations reporting exceedances of the 2020 indicative annual limit value (20 µg/m³), as set out in the Air Quality Directive.

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for $PM_{2.5}$ of less than 10 µg/m³ but not in exceedance of target or limit values for $PM_{2.5}$ as set out in the Air Quality Directive.

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for $PM_{2.5}$ and implicitly below the target and limit values for $PM_{2.5}$ as set out in the Air Quality Directive

Map 3.1 Concentrations of selected air pollutants in Europe in 2010 (cont.)

26th highest daily max. 8-hour average O_3 concentration at each monitoring station



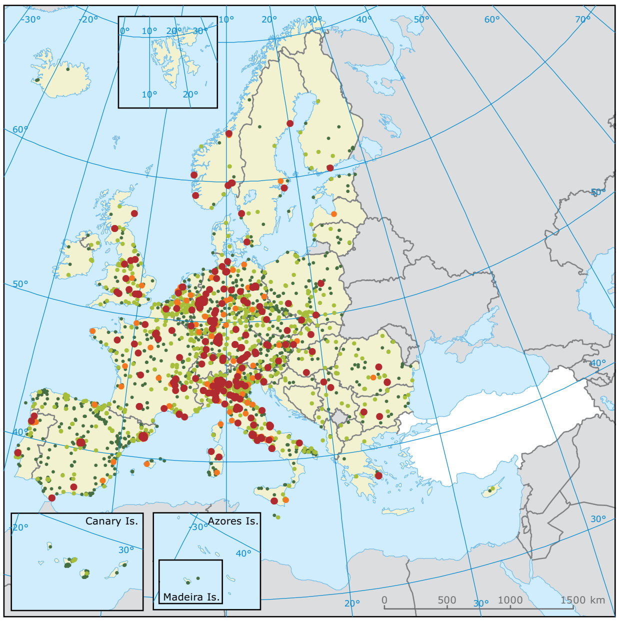
Twenty-sixth highest ozone 2010, based on daily running 8h max with percentage of valid measurements ≥ 75 % in µg/m³

• ≤ 100 • 100–110 • 110–120 • 120–140 • > 140

No data | Countries/regions not included in the data exchange process

Note: The map shows the proximity of measured O_3 concentrations to the target value set in the European Union's Air Quality Directive. At sites marked with dark orange and red dots, the daily maximum 8-hour mean O_3 concentration exceeds the 120 µg/m³ threshold on more than 25 days per year (the policy target is set at max. 25 days of exceedance per year, averaged over 3 years).

Annual mean concentrations of NO_2



Annual mean nitrogen dioxide 2010, based on daily averages with percentage of valid measurements ≥ 75 % in µg/m³

• ≤ 20 • 20–40 • 40–45 • > 45

No data | Countries/regions not included in the data exchange process

Note: Orange and red dots correspond to exceedances of the annual limit value (40 µg/m³).

Red dots correspond to exceedances of the annual limit value + 5 µg/m³.

Source: EEA, 2012a.

acknowledge that in addition to premature death and contribution to chronic diseases, the impacts of air pollution include less severe health effects. The spectrum of health responses to air pollution in a population can be characterised as a pyramid, with the number of people affected by less severe health outcomes (minor symptoms, use of medication, days of restricted activity, visits to doctors, emergency visits, and hospital admissions) being much higher than those affected by the most extreme effects (mortality) (ATS, 2000; WHO, 2000). Nevertheless, the severe outcomes (including increased risk of mortality and reduced life expectancy) are most often considered in epidemiological studies and risk analysis, owing usually to the better availability of routinely collected data. However, recent studies have reported the role of motor vehicle pollution in the development of new cases of asthma in children (Gasana et al., 2012), and new evidence points to the adverse effects of air pollution on the nervous system (Genc et al., 2012). Based on a review of the evidence, the WHO has produced health-based air quality guidelines (WHO, 2006a).

Epidemiological studies attribute the most severe health effects of air pollution to particulate matter (PM) and scientific evidence suggests that there is no threshold below which no adverse health effects of exposure to PM would be anticipated (WHO, 2006a, 2006b). There is strong scientific evidence that exposure to PM is substantially increasing mortality and hospital admissions due to respiratory and cardiovascular diseases (Colais et al., 2012). A recent review of more than 100 independent studies established a strong relationship between myocardial infarction and short-term exposure to PM (Mustafić, 2012). There are also indications that air pollution (PM) is associated with increased incidence of ischemic stroke (Mateen and Brook, 2011). The evidence base for the association between PM and short-term, as well as long-term, health effects has become much larger and broader. Based on the recent long-term studies showing associations between PM and mortality at levels well below the current annual WHO air quality guideline level for $PM_{2.5}$ (10 $\mu g/m^3$), it would be important to update the current WHO Guidelines (WHO, 2013a).

PM is a collective term for a complex heterogeneous mixture of particulate matter with different sizes and chemical compositions, mixes of various compounds originating from different sources, such as soot particles resulting from incomplete combustion, organic compounds, inorganic salts (sulphate, nitrate), re-suspended or wind-blown dust, seasalt, fly ash, etc. Specific sources may play a role locally; for example, in Scandinavia where many cars are equipped with studded winter tyres, particles from road wear make up a significant fraction of the PM in the urban environment, contributing to PM-related mortality (Meister et al., 2011). Several cities in Scandinavia have introduced restrictions on traffic with studded tyres in areas with the highest traffic density.

Different size classes of PM are considered in health impacts assessment: PM_{10} (particles having an aerodynamic diameter smaller than 10 µm); $PM_{2.5}$ (particles having an aerodynamic diameter smaller than 2.5 µm) and ultra-fine particles (those smaller than 0.1 µm). PM mortality effects are associated mainly with the $PM_{2.5}$ fraction, which in Europe represents 40–80 % of the PM_{10} mass concentration in ambient air. The health effects of $PM_{2.5}$ are caused by inhalation and penetration of fine particles into the lungs; both chemical and physical interactions with lung tissue can induce irritation or damage. The smaller the particles, the deeper they penetrate into the lungs. In the EU, average life expectancy is estimated to be reduced by 8.6 months due to exposure to $PM_{2.5}$ (EEA, 2012a). Although evidence is growing that $PM_{2.5}$ is of greater health concern, ambient air quality measurements and emissions data are often only available for PM_{10}. Ultrafine PM is deemed to be the most damaging as they penetrate deeper into the airways and have a relatively large surface-to-volume ratio, yet no estimates of health impacts of exposure to these particulates are available. However, the most recent US EPA assessment, in 2011, indicates that the currently available evidence does not provide a sufficient basis for supplementing the mass-based $PM_{2.5}$ indicator with a separate particle number based indicator for ultrafine particles. They also conclude that the currently available evidence is too limited to provide support for considering a separate indicator for a specific $PM_{2.5}$ component or group of components associated with any source categories of fine particles or for eliminating any individual component or group of components associated with any source categories from the mix of fine particles included in the mass-based $PM_{2.5}$ indicator (EPA, 2011).

Ground-level ozone is a powerful and aggressive oxidising agent, which can lead to respiratory health problems and premature mortality. High concentrations of ground-level O_3 are associated with increased hospital admissions and emergency room visits for asthma and other respiratory problems, as well as an increased risk of respiratory infections. Long-term, repeated exposure to high levels of O_3 may lead to reductions in lung function, inflammation of the lung lining and more frequent and severe respiratory discomfort. Ozone pollution is particularly dangerous for children, the elderly, and people with chronic lung and heart diseases, but can also affect healthy people who exercise outdoors (Cakmak et al., 2011). Another air pollutant which primarily affects the respiratory system is NO_2. Health effects have been indicated both for short-term exposure (e.g. changes in lung function in sensitive population groups) and long-term exposure (e.g. increased susceptibility to respiratory infection). Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2. Reduced lung function is also linked to NO_2 at concentrations currently found in European cities (Krzyzanowski, 2008). As NO_2 is highly correlated with other pollutants (in particular PM) it is often difficult to differentiate the effects of NO_2 from those of other pollutants in epidemiological studies. In March 2011, the Health Protection Agency and Department of Health in the United Kingdom organised a workshop to consider this and other issues. This brought national and European experts together with officials from relevant Government departments with policy or advisory responsibilities in this area. The main aim of the workshop was to develop ideas for future research that would help disentangle the possible adverse health effects of NO_2 from those of other pollutants, notably particles. Invited speakers set out the issues and outlined the available scientific evidence. Proposals for different types of scientific investigation were discussed and research recommendations agreed (HPA, 2012).

The increased risk of suffering from the most common health effects caused by exposure to air pollution is relatively small (a few per cent). Nevertheless, the absolute number of people affected is significant owing to the widespread nature of the exposure and our inability to selectively protect more vulnerable groups from its effects.

3.3 …but important gaps still exist

The mechanisms by which air pollutants affect human health are not yet fully understood. A role of inflammatory and oxidative stress-related processes has been extensively studied; for other health effects, such as adverse pregnancy outcomes, understanding of biological pathways remains limited (WHO, 2005, 2006a).

Exposure in an urban setting is complex and several exposures augment each other's effects. In relation to climate change, increased temperatures have been shown to augment the negative health impact of particulate matter, resulting in increased mortality (Meng et al., 2012). Another factor is environmental noise which in combination to exposure to PM leads to increased risk of cardiovascular disease (Selander et al., 2009).

Evidence is growing for a range of effects of prenatal exposure to air pollutants, during very early stages of development, in the new-born child and later on health in adult life. Exposure to air pollutants during pregnancy has been associated with reduced foetal growth, pre-term birth and spontaneous abortions (WHO, 2005). Pregnancy-induced hypertension (pre-eclampsia) can be augmented by exposure to air pollution (Pereira et al., 2012). Significantly reduced birth weight was linked to prenatal exposure to airborne polycyclic aromatic hydrocarbons (PAHs) in an international study from Poland (Krakow) and the US (New York) (Choi et al., 2006). Reduced birth weight and length of new-borns was associated with exposure to traffic-related air pollutants, particularly during early pregnancy (Aguilera et al., 2010). In Scandinavia, exposure to air pollutants such as O_3 and NO_2 was shown to shorten the gestation period and was linked to pre-term birth; the effect of O_3 was most prominent for exposure in the first trimester. A good vitamin D status of the mother seemed to have a protective effect (Olsson et al., 2012). The associations between air pollution (black smoke) and birth weight are of the same order of magnitude as those reported for passive smoking (Pearce et al., 2012). There are indications that the new-born's immune system might be affected, resulting in weakened immune responses. Maternal exposure to air pollution during pregnancy increases the risk of the child developing allergies and asthma later in life (Jedrychowski et al., 2010; Baïz et al., 2011). Prenatal exposure to airborne PAHs is also suggested to adversely affect cognitive development in young children (Edwards et al., 2010). Impacts of air pollution on the developing foetus are particularly worrying, as they do not only affect the child's development, but can also trigger diseases (like asthma or diabetes) later in life (Chiusolo et al., 2011). Even weak associations may have strong public health implications, since air pollution affects the whole population, especially in major cities, and people are continuously exposed. The mechanisms by which adverse effects of air pollution may act on the nervous system have recently been documented (Genc et al., 2012) and a few epidemiological studies report positive associations between exposures to air pollution and impaired cognitive function (Van Kempen et al., 2012) but more studies are needed to better understand these effects.

3.4 Some population groups are more vulnerable to the health effects of air pollution

An increasing proportion of European citizen are living in cities where transport, industrial activities and combustion processes have a major impact on air quality. Certain population groups may be disproportionally affected by air pollution due to their age, health status, as well as social, cultural, and economic conditions. Susceptibility is determined not only by personal characteristics, but also by environmental factors including exposure characteristics (e.g. time-activity pattern), housing and environmental conditions at the neighbourhood level.

For example, death occurs more frequently in those who are already ill, and those with pre-existing medical conditions are more likely to be admitted to hospital or visit an emergency department. In people with existing heart, respiratory or other chronic diseases, air pollution could exacerbate their symptoms and diminish their life quality (Karakatsani et al., 2012). It is well established that air pollution exacerbates asthma symptoms in asthmatic patients (Jacquemin et al., 2012) but, as stated previously, recent studies have also reported the role of motor vehicle pollution in the development of new cases of asthma in children (Gasana et al., 2012). Air pollution in combination with diabetes seems to increase the risk of ischemic stroke (Oudin et al., 2011).

Children are particularly vulnerable to the health effects of air pollution because they spend more time outdoors, have higher respiratory rates, and breathe larger volumes of air relative to their body weight. Young children and infants may be especially sensitive to the effects of air pollution because their immune, respiratory, and central nervous systems are not fully developed (WHO, 2005). Respiratory responses to air pollution in infants have been studied much less extensively than those in older children. There seem to be a connection between ambient air pollution and an increased risk of apnea (prolonged pauses in breathing) and bradycardia (decreases in heart rate) in babies at high risk for these conditions (Peel et al., 2011). These findings are consistent with previous studies linking air pollution with respiratory symptoms, related hospital admissions, and increased mortality in infants. Although the underlying causes of apnea and bradycardia are unclear, some evidence suggests that immaturity in the nervous control of breathing patterns and the regulation of the respiratory system may be involved. Hospital admissions of children and infants (aged 0–1 year) with asthma symptoms show increasing trends when concentrations of traffic-related air pollutants such as NO_2 increase (Iskandar et al., 2011), and living near busy roads substantially increases the total burden of disease attributable to air pollution, also for children (Aphekom, 2011).

Social inequity is another important factor. Socially-deprived population groups tend to be more exposed to air pollutants, living in areas with high traffic intensity and pollution (see also 'Setting the scene'). For example, in Spain younger women coming from Latin American countries, and those belonging to the lower social strata, were exposed to higher NO_2 levels, both as measured outside their homes, as well as when time-activity patterns were taken into account (Llop et al., 2011). They were also more likely to be exposed to NO_2 levels exceeding the annual limit for exposure (40 $\mu g/m^3$) set by European legislation (EU, 2008b). There is a need to link, to a greater extent, exposure and health data to social and demographic data using geographic information systems. This also means treating inequities in the delivery of environmental risk as a fundamental problem that requires explanation and action (Brochu et al., 2011).

3.5 Reducing air pollution brings public health benefits

Several studies have looked into health effects related to different interventions to reduce air pollution through changes in emissions from different sources, including industry (e.g. German reunification; a steel mill in the US), traffic (congestion charging zone in London and Stockholm) and domestic (e.g. the Irish coal ban) (Clancy et al., 2002); the Olympic Games (Atlanta 1996 and Beijing 2008) also provide interesting case studies. A recent review of intervention studies concluded that, irrespective of their nature, interventions have been successful at reducing air pollution levels. The published evidence also consistently suggests that most of these interventions have been associated with health benefits, mainly through reduced cardiovascular and/or respiratory mortality and/or morbidity (Henschel et al., 2012).

A major European project (APHEKOM ([10])), involving 25 cities from 12 European countries, estimated, on the basis of traditional health impact assessment

([10]) APHEKOM — Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe (2009–2011).

methods, that a decrease of long-term exposure to $PM_{2.5}$ to 10 µg/m^3 (the WHO annual air quality guideline) could prevent more than 19 000 premature deaths annually in the investigated APHEKOM cities in Europe, of which more than 15 000 are due to cardiovascular diseases. This decrease would also add up to 22 months of life expectancy, depending on the city and its average level of $PM_{2.5}$. The calculated monetary health benefits from the reduction in $PM_{2.5}$ levels totalled some EUR 31.5 billion annually, including savings on health expenditure and absenteeism, and on intangible costs, such as well-being, life expectancy and quality of life.

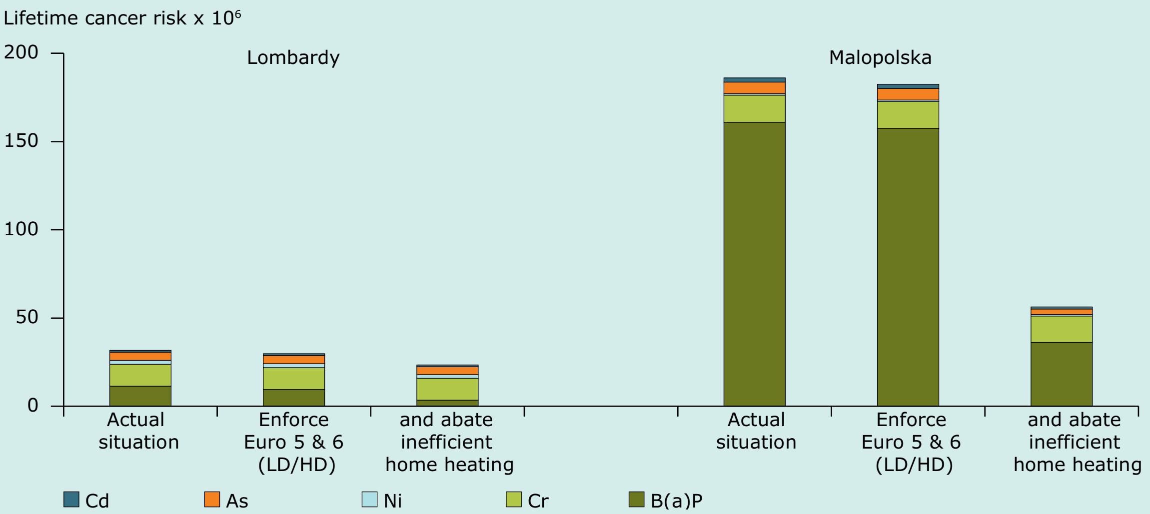
The findings indicating substantial health and economic gains of further reduction of PM pollution are of particular relevance, given that many EU Member States have exceeded PM limit values since 2005, especially in large urban areas. While the societal costs of intervention should not be underestimated, substantial expected gains in terms of better population health, better productivity and lower health care costs are predominant.

The Joint Research Centre (JRC) has developed an integrated approach to assessing health benefits from air pollution reduction in support of EU efforts to reduce air pollution in Europe. This approach is based on: an apportionment of significant pollution sources through chemical analysis of PM from receptors and sources, combined with multivariate receptor modelling, and health impact assessments using epidemiological data for PM and cancer risks of carcinogenic compounds in PM (Larsen et al., 2008; Larsen, 2009). This integrated approach was applied to two highly polluted regions in Europe, namely Lombardy, Italy and Malopolska, Poland (Box 3.1) to assess potential benefits of abatement strategies in terms of reduced mortality and improved life expectancy.

Box 3.1 Assessing health benefits from the reduction of air pollution — the Lombardy (Italy) and Malopolska (Poland) study

Lombardy (Italy) and Malopolska (Poland) are two highly polluted regions in Europe, where residential heating by solid fuel combustion (wood in Italy, and coal in Poland) in small appliances is still common. JRC conducted a study aiming to identify hazards and assess population exposure in order to characterise the health risk and the incremental lifetime cancer risk from chemical substances associated with ambient particulate matter; and to quantify potential benefits of abatement strategies in terms of reduced mortality and improved life expectancy. An effort was made to estimate health benefits of realistic abatement strategies for residential heating by solid fuel combustion in small inefficient appliances, using a recommended epidemiological methodology. The estimated health benefits of different abatement measures are presented in Figures 3.2–3.4.

Figure 3.2 Potential reduction in life-time cancer risk in Lombardy and Malopolska by abatement of inefficient residential heating with solid fuel combustion and by abatement of road transport exhaust emissions



Note: Euro 5 (EC, 2008); Euro 6 (EC, 2009). LD — light duty diesel; HD — heavy duty diesel.

Box 3.1 Assessing health benefits from the reduction of air pollution — the Lombardy (Italy) and Malopolska (Poland) study (cont.)

Figure 3.3 Potential reduction of premature death in Lombardy (left) and Malopolska (right) by abatement of inefficient residential heating with solid-fuel combustion and by abatement of road transport exhaust emissions

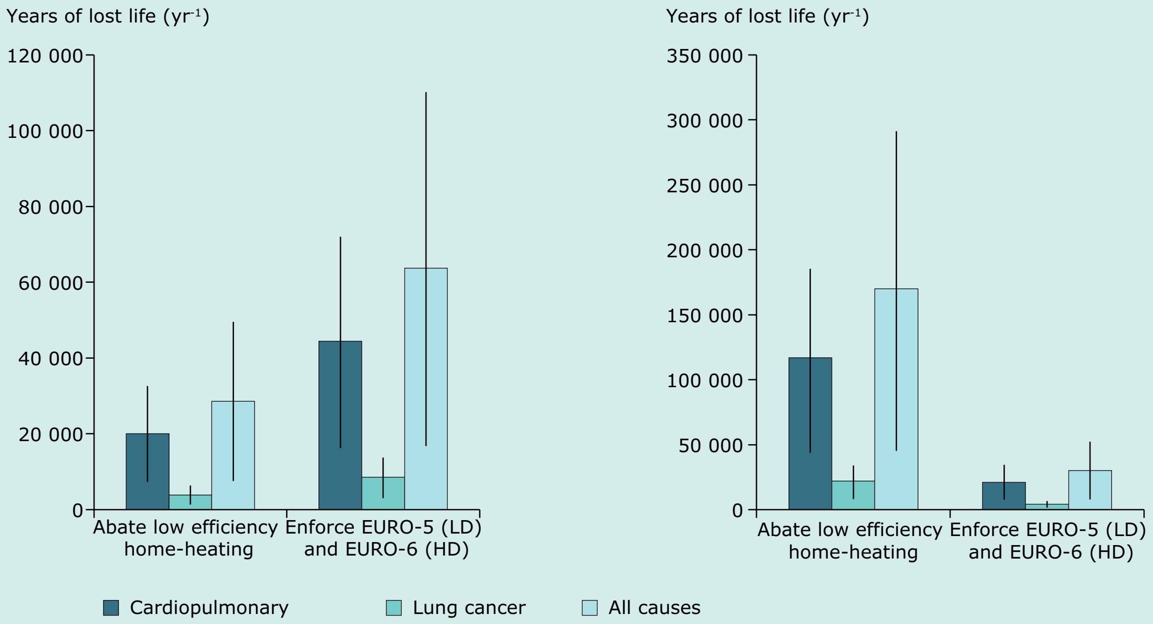
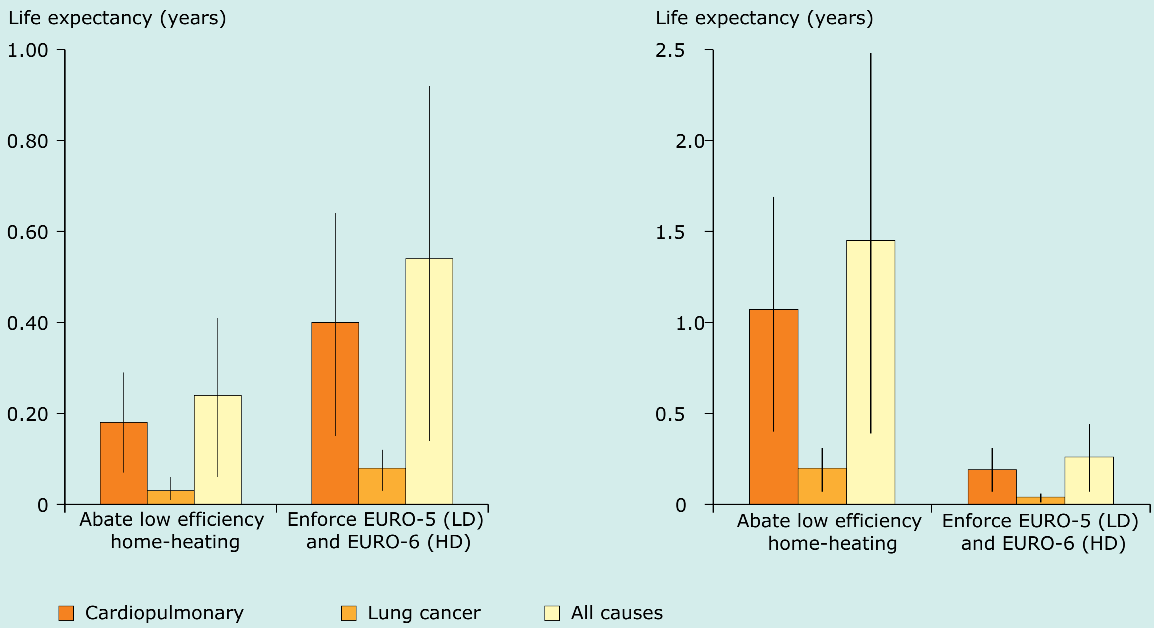


Figure 3.4 Potential increase of life expectancy in Lombardy (left) and Malopolska (right) by abatement of inefficient residential heating with solid-fuel combustion and by abatement of road transport exhaust emissions



3.6 Air quality policies are well-developed but based mainly on single pollutant approaches

In recent decades, the EU has introduced and implemented a range of legal instruments to improve air quality. The EU Thematic strategy on air pollution (EC, 2005), formulated in the framework of the 6th EAP (EC, 2002), sets specific long-term objectives for improvements in 2020 relative to the situation in 2000 to be achieved through emission reductions of several pollutants. Health-related objectives include a 47 % reduction in loss of life expectancy as a result of exposure to PM; and a 10 % reduction in acute mortalities from exposure to O_3; specific objectives are also set for ecosystem protection (EEA, 2012a).

The 'Roadmap to a Resource Efficient Europe' (EC, 2011g) includes an explicit air quality-related milestone: 'By 2020, the EU's interim air quality standards will have been met, including in urban hot spots, and those standards will have been updated and additional measures defined to further close the gap to the ultimate goal of achieving levels of air quality that do not cause significant impacts on health and the environment'.

The European directives that currently regulate the ambient air concentrations of the main pollutants, designed to avoid, prevent or reduce harmful effects of air pollutants on human health and the environment, comprise:

- Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which regulates ambient air concentrations of SO_2, NO_2 and NO_X, PM_{10} and $PM_{2.5}$, O_3, Pb, C_6H_6, and CO (EU, 2008b);

- Directive 2004/107/EC relating to As, Cd, Hg, Ni and PAH (including BaP) in ambient air (EU, 2004a).

The directives set limit and target values for regulated pollutants. The EU limit values are legally binding concentration thresholds that must not be exceeded. Set for individual pollutants and made up of a concentration value, limit values are accompanied by an averaging period, the number of periods exceeding the limit value allowed per year, if any, as well as a date by which the obligation should be met. Some pollutants have more than one limit value covering different endpoints or averaging times. The EU target values are not legally binding; they are to be attained where possible by taking all necessary measures not entailing disproportionate costs. According to Directive 2008/50/EC (EU, 2008b), the Commission shall review in 2013 the provisions related to certain pollutants. The WHO in Europe is coordinating an international project (Review of evidence on health aspects of air pollution — REVIHAAP) to provide the European Commission and its stakeholders with evidence-based advice on the health aspects of air pollution. This advice will be grounded on a review of the latest scientific evidence on the health effects of all pollutants regulated in air quality directives (EU, 2004a, 2008b). Project results will support the comprehensive revision of the EU air quality policies due in 2013. To effectively advice the revision of EU air quality policies, REVIHAAP is addressing a list of 26 key questions regarding health aspects of particulate matter, ground-level ozone, nitrogen dioxide, and sulphur dioxide, as well as of emissions to the air of arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (PAH); evaluating emerging issues on health risks of air pollution related to specific source categories (e.g. transport, biomass combustion, metals industry, refineries, power production); assessing evidence of the role of specific components or characteristics of particulate matter in producing health effects; considering a possible need to revise WHO Air Quality Guidelines (WHO, 2006a), which are often more stringent than current EU target and limit values for specific pollutants; and communicating the results of this review to the European Commission for its review of the Thematic Strategy on Air Pollution and its associated legal instruments.

Several other EU directives regulate anthropogenic emissions of pollutants to air, including precurser air pollutants which form ozone O_3 and PM as well as emissions of the main air pollutants from specific sources and sectors. In addition, a number of international conventions, in particular the UN Convention on Long-range Transboundary Air Pollution (LRTAP) with its eight protocols, address emissions of the main air pollutants from different sources and sectors (UNECE, 2012). Within the LRTAP, the Joint Task Force on the Health Aspects of Air Pollution established in 1998 works to quantify how long-range transboundary air pollution affects human health (WHO, 2003a, 2006b, 2007b, 2008a), and helps define priorities to guide future monitoring and abatement strategies. It also advises on monitoring and modelling activities to improve the quality of assessments.

In June 2012, the WHO International Agency for Research on Cancer (IARC) classified diesel engine exhausts as category 1 carcinogens to humans (category 1: Sufficient evidence in humans and sufficient evidence in animals and strong mechanistic data in humans) (IARC, 2012a).

4 Indoor air

Indoor air pollution is often higher than outdoor air pollution. This has been observed in indoor spaces including public buildings, schools, kindergartens and homes in developed countries, especially when significant sources of indoor and outdoor air pollution exist. The quality of the indoor environment is affected by the quality of ambient air; building materials and ventilation; consumer products, including furnishings and electrical appliances, cleaning and household products; occupants' behaviour, such as smoking; and building maintenance. For example, energy-saving measures make buildings and houses airtight by reducing ventilation, thus raising concerns over indoor air quality, as chemical and biological pollutant concentrations can reach high levels.

The health effects of exposure to indoor air pollutants are a function of several factors: time spent in a certain micro-environment, the actual air pollutant concentration, temperature and humidity levels, chemical processes, etc. Since most people spend 85–90 % of their time indoors — at home, at the workplace, in public buildings or in cars — indoor sources actually provide the bulk of personal exposure to certain chemicals, such as aldehydes, and can be the only source of exposure of some pollutants. In day-care centres, retirement homes and other special environments, indoor air pollution may affect population groups that are particularly vulnerable due to their health status or age. Exposure to chemicals (household chemicals, formaldehyde, terpene) particulate matter (PM), as well as dampness, moulds and other biological agents indoors, has been linked to asthma and allergic symptoms, lung cancer, and other respiratory and cardiovascular diseases (EnVIE, 2009; WHO, 2009a, 2010c).

Outdoor air pollutants can also infiltrate indoors; however, the relative amount of an outdoor pollutant found indoors depends mainly on its physicochemical properties. Highly reactive gases such as O_3 may be removed from the air in or prior to entering an indoor environment and the resulting indoor concentrations may be much lower than those found outdoors.

Because of the complexity of indoor pollution sources, health effects pathways, and the multitude of parties responsible for generating and controlling indoor air pollution, measures to improve indoor air quality (IAQ) need to be part of a comprehensive management strategy, taking account of climate and outdoor air quality, building materials and technologies, knowledge of behaviour patterns of the occupants, including use of consumer products, as well as energy and sustainability policies.

4.1 Indoor air is a significant source of exposure to chemicals

In recent decades it has become increasingly evident that the indoor environment is a significant source of personal exposure to several air contaminants, e.g. formaldehyde and other volatile organic compounds (VOCs). Many pollutants have a higher concentration indoors than outdoors, for example indoor versus outdoor ratios (I/O) in homes reported in the literature for total VOCs range from 1.4 to 11.7, for benzene from 0.9 to 2.2 and for formaldehyde from 5.0 to 15.9.

While there are no harmonised guidelines for the estimation of total VOCs, values between 300 and 500 $\mu g/m^3$ are reported in the literature as an indication of good indoor air quality. That is, however, without any toxicological justification. Domestic exposure to VOCs at lower levels may increase the risk of childhood asthma (6 months–3 years); it has been reported that children exposed to concentrations of VOCs higher than 60 $\mu g/m^3$ as the median level of exposure had a fourfold increased risk of having asthma (Rumchev et al., 2004, 2007).

In addition to VOCs, interest in particulate matter (PM) indoors has increased strongly in recent years, as relatively low concentrations of $PM_{2.5}$ in urban ambient air have been found to significantly elevate cardiovascular and respiratory mortality (WHO, 2006a). Similar findings have been reported on the health impacts of indoor environmental tobacco smoke (ETS). Questions have been raised about the role of indoor air particulate matter from sources other than infiltrated ambient air and ETS. There is still a limited understanding of PM from indoor sources and of PM generated by indoor air chemistry although increasing evidence that indoor generated particles may be more bioactive than ambient particles. The reason could be the presence of endotoxins and other pro-inflammatory components in indoor particles or to semi-volatile organic compounds (SVOC) adsorbed on particles (EC/JRC, 2012).

As in the outdoor environment, reactive VOCs (mostly compounds with one or more double bonds) may undergo chemical reactions indoors in the presence of other reactive species such as O_3 and hydroxyl radicals ($OH^{\cdot}$), forming degradation products, partly as a secondary organic aerosols (SOA) (Weschler and Shields, 1999). Terpenes constitute a class of VOCs highly reactive with O_3 and $OH^{\cdot}$ radicals, present in indoor environments. They are frequently found in homes, public buildings and schools, at relatively high concentrations of up to 500 $\mu g/m^3$ compared to other compounds measured indoors. In the past ten years, much attention has been paid to indoor air chemistry: to chemical reactions occurring indoors between terpenes and generally between unsaturated compounds and O_3, and to the formation of oxidation products including SOA with unknown toxicological properties. As an example, in an experimental study, at concentrations of organic mass between 5–40 $\mu g/m^3$, oxidation of mono-terpenes by $OH^{\cdot}$, O_3 and NO_3 produced aerosol yields in the range 2–23 % (Weschler and Shields, 2003) with intermediate exchange rates.

Health-based indoor air quality guidelines for several pollutants, including: benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, polycyclic aromatic hydrocarbons (especially benzo(a)pyrene), radon, trichloroethylene and tetrachloroethylene, have been issued by WHO (WHO, 2010c).

4.2 Biological pollution is a major factor in indoor air quality

The microbial indoor air pollutants of relevance to health are widely heterogeneous, ranging from pollen and spores of plants coming mainly from outdoors, to hundreds of species of bacteria, fungi (in particular filamentous fungi — mould), algae and some protozoa emitted outdoors or indoors. The most important health effects include increased prevalence of respiratory symptoms, allergies and asthma as well as perturbation of the immunological system. In private homes, household dust is an important source of exposure and principally associated with socio-economic factors, quality of housing, presence of pet animals and geography (Thorne et al., 2008).

Sufficient moisture and insufficient ventilation are key conditions for microbial growth indoors. It is estimated that dampness affects 10–50 % of indoor environments in Europe (as well as in North America, Australia, India and Japan) (WHO, 2009a). Dampness not only facilitates the growth of many biological agents, but initiates chemical or biological degradation of materials, which also pollutes indoor air.

The WHO guidelines for the protection of public health from health risks due to dampness-associated microbial growth and contamination of indoor spaces (WHO, 2009a) state that, as the relationships between dampness, microbial exposure and health effects cannot be quantified precisely, no quantitative health-based guideline values or thresholds can be recommended. Instead, it is recommended that dampness and mould-related problems should be prevented. When they occur, they should be remedied because they increase the risk of hazardous exposure to microbes and chemicals.

WHO also points out that 'building standards and regulations with regard to comfort and health do not sufficiently emphasise requirements for preventing and controlling excess moisture and dampness'; this needs to be carefully taken into account in the context of energy-efficiency measures in buildings.

4.3 Assessment of direct health impacts of indoor air pollution remains challenging

Despite the importance of measurements of individual compound and mixtures as integrated action plan indicators, there is still little evidence of their direct impact on human health at the concentration levels found indoors. Existing information in Europe is partial and not conclusive, since the design of experimental and epidemiological investigations so far have not followed an integrated approach to studying the human health effects of chronic low-dose exposure to pollutants and pollutant mixtures. Thus, progress in quantifying exposure to indoor air toxicants and in assessing the associated health risk is limited. The current paradigm for assessing the health risks of indoor air contaminants needs to be changed so that it pulls together chemical, toxicological and epidemiological information regarding health effects of typical indoor air mixtures instead of focusing solely on the toxicity of individual chemicals. Linking such observations with exposure scenarios on the basis of consumer choice and environmental conditions would allow the translation of scientific evidence into policy-relevant knowledge.

Similarly, while there is strong evidence regarding the hazards posed by several biological agents that pollute indoor air, individual species of microbes and other biological agents that are responsible for health effects cannot be identified. Exceptions include some common allergenic agents, such as house-dust mites and pets (WHO, 2009a).

4.4 EU-funded research delivers new tools for improving indoor air quality

The FP-6 supported European project EnVIE ([11]) developed a new modelling tool to evaluate the quantitative relationship between IAQ-related diseases, sources of relevant indoor exposures, and the impact of policy control measures to cope with these sources to minimise the unwanted health consequences in terms of achievable public health benefits, invasiveness, as well as political, legal, technological, economic and social feasibility. The project also recognised that we are still a long way from being able to characterise all the effects on health of certain pollutant substances at their current indoor concentrations.

More specifically, the EnVIE tool was developed to quantify the most important health risks attributable to IAQ (i.e. allergic and asthma symptoms, lung cancer, chronic obstructive pulmonary disease, airborne respiratory infections, cardiovascular morbidity and mortality, sick building syndrome), and to associate these health risks to a short list of exposure agents (tobacco smoke, [other] combustion particles, carbon monoxide, radon, dampness, mould and bioaerosols, and VOCs), and to the main sources of exposure (outdoor air, building/equipment/ventilation, consumer products and occupant behaviour). Using this model and expert elicited source control coefficients for a variety of alternative policy actions, the maximum potential health benefits of these policies were assessed.

Based on the analysis of sources, exposures, and policies related to indoor air in the EU and the estimated potential public health gains, policy recommendations, together with the associated costs, have been formulated in the context of the IAIAQ project (Promoting Actions for Healthy Indoor Air) funded by the European Commission's Directorate-General for Health and Consumers (DG SANCO) (Jantunen et al., 2011). The largest health benefits are linked to smoking restrictions. Building and ventilation policies that control indoor exposure to PM, allergens, ozone, radon and noise from outdoors offer large long-term benefits. Better building management and training can lead to substantial medium-term benefits; while prevention of moisture accumulation and mould growth in buildings, and prevention of exposure to exhausts of indoor combustion sources can bring substantial medium- to long-term benefits. Substantial short- to medium-term benefits result from harmonised testing and labelling of indoor materials and consumer products.

EnVIE highlighted two main strategies for controlling IAQ: eliminating sources or mitigating their strength (source control), and using ventilation as the ultimate strategy to control exposure indoors (exposure control). The growing restrictions regarding the use of energy in buildings and its implication of a ventilation strategy oriented to minimising ventilation rates, unavoidably shifts the focus in favour of the source control strategy. The importance of indoor air quality for human health has been increasingly recognised in Europe. Within the framework of the EU Action Plan on Environment and Health (2004–2010), several initiatives have been undertaken with the aim of improving air quality in indoor environments and to address related health risks, including:

- prioritising of IAQ-relevant pollutants with respect to health effects (THADE ([12]); INDEX ([13]); SCHER ([14]) report);
- establishing guideline values for key IAQ pollutants (INDEX; INDEX-UPRIC ([15]); HEALTHVENT ([16]));

([11]) EnVIE — European Co-ordination Action on Indoor Air Quality and Health Effects (2003–2008).
([12]) THADE — Towards Healthy Indoor Air in Dwellings in Europe (2002–2004).
([13]) INDEX — Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU (2003–2005).
([14]) Scientific Committee on Health and Environmental Risks — Opinion on risk assessment on indoor air quality (2007).
([15]) INDEX-UPRIC - Review of the INDEX health based exposure guidelines for indoor high priority chemicals (2009–2010).
([16]) HEALTH-VENT — Health based ventilation guidelines (2010–2012).

- monitoring exposure patterns versus health effects (INDOOR-MONIT [17]; AIRMEX [18]; HITEA [19]; EPHECT [20]);
- identifying and improving sources of indoor air pollution (BUMA [21];);
- reducing exposure patterns to key IAQ pollutants (CLEAR-UP [22]; RADPAR [23]; OFFICAIR [24]);
- understanding the factors affecting the indoor air quality in specific indoor environments and the associated health of specific population groups (SINPHONIE [25]).

A number of major EU initiatives undertaken in recent years aim at improving source and exposure control in European dwellings in a harmonised and sustainable way. On-going is the process of establishing a harmonisation framework for monitoring, testing and evaluating the health impacts of emissions from consumer products used indoors (Kotzias et al., 2005, 2009; Kephalopoulos et al., 2012), and the development of health-based ventilation guidelines (HEALTHVENT project).

The harmonisation framework is primarily needed to enable the comparability of IAQ exposure-related data and to reliably estimate the associated health burden, within and across the EU Member States. It takes into account recent developments in standardisation (CEN and ISO) related to the measurement, testing and evaluation of chemical emissions, and the work undertaken by existing voluntary or mandatory labelling schemes in the EU. This includes a procedure for establishing a list of compounds with associated threshold values to assess chemical emissions from building products indoors in a harmonised way. Once fully implemented, it should allow industries to provide low-emission products throughout the European market at reasonable costs and also enable building designers and consumers to make informed choices between the variety of building and other indoor-related products available on the market.

The HEALTHVENT project is facing the challenge of developing health-based ventilation guidelines for Europe in such a way that the underlying requirements maximise the benefits in terms of reducing the total burden of disease and energy consumption in buildings.

4.5 Policy frameworks for tackling indoor air quality are largely lacking

There is no dedicated European legislation on indoor air. For public buildings, for example schools, there is legislation with respect of ventilation and CO_2 build-up. There is also an array of national legislations to ban tobacco smoke in public buildings, shops, restaurants and bars. The recent major initiatives concerning IAQ appear in the wake of several Directives, such as the REACH regulation (EU, 2006c); the General Products Safety Directive (EU, 2001), the Construction Products Regulation (CPD, 1989), and subsequent Constructions Products Regulation (EU, 2011b); all of these aim at better control of potentially dangerous substances contained in and/or emitted from construction and other consumer products used indoors. More recently, the Energy Performance Building Directive (EU, 2002b) refers to the need to improve the energy efficiency of the building stock in order to reduce the use of fossil fuels and related CO_2 emissions. Even though IAQ is not actually a core part of EPBD, the future revision of this directive should take into consideration IAQ issues in order to ensure healthy IAQ and energy-efficient buildings, especially in relation to the requirements for nearly zero-energy buildings.

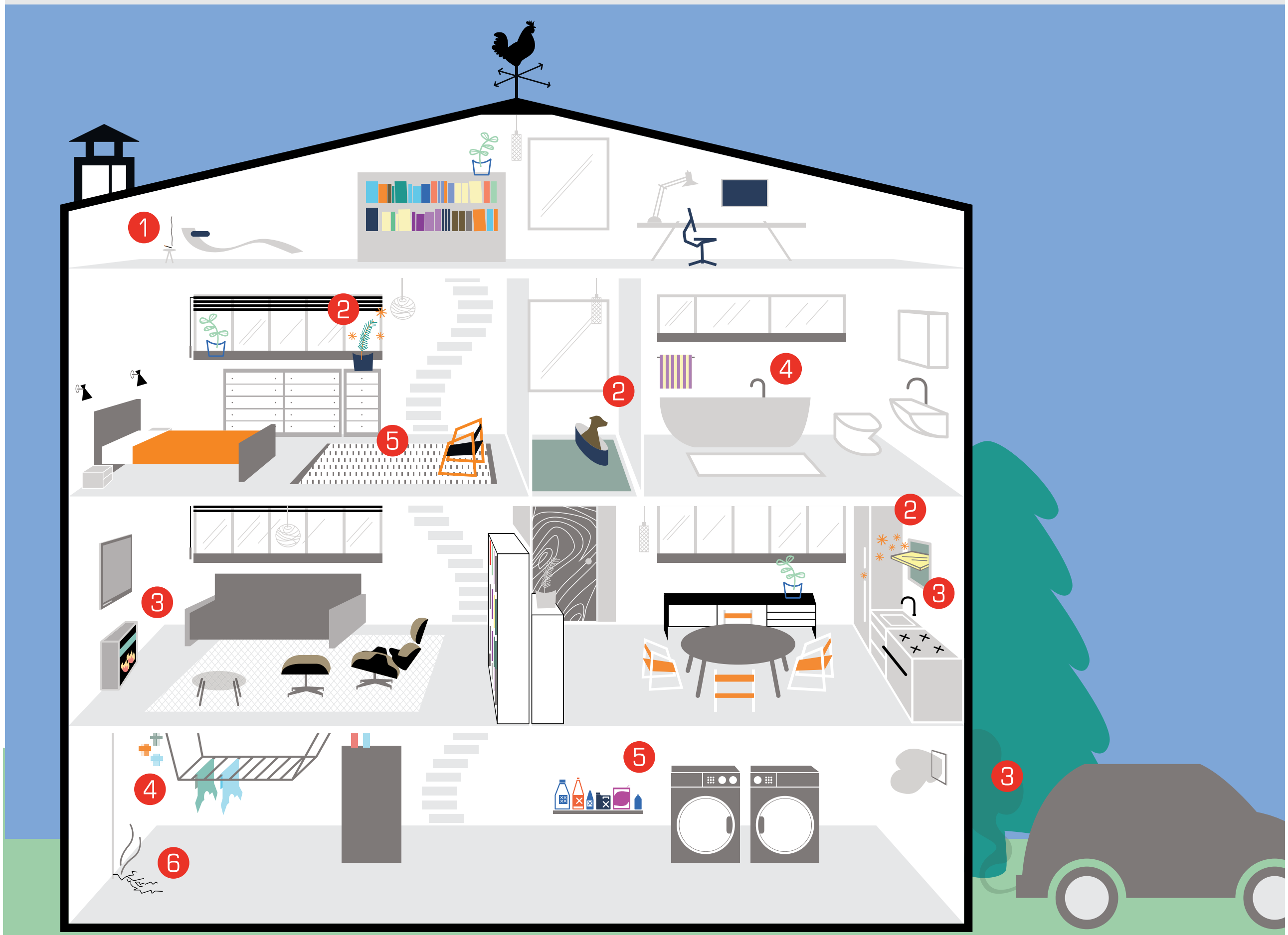
A need has recently emerged for better liaison and progressive alignment of existing overlapping and/or complementary legislative instruments and standardisation work related to the built environment as a horizontal policy framework, with the ultimate objective of improving indoor air quality and its associated health effects.

The possibility of a cross-cutting regulation was first suggested by the EnVIE 'Green Paper' on IAQ,

(17) INDOOR-MONIT — Harmonised criteria and protocols for monitoring key indoor air pollutants (2009–2010).
(18) AIRMEX — The European indoor air monitoring and exposure assessment study (2006–2009).
(19) HITEA — Health effects of indoor pollutants: integrating microbial, toxicological and epidemiological approaches (2008–2013).
(20) EPHECT — Emissions, exposure patterns and health effects of consumer products in the EU (2010–2013).
(21) BUMA — Building materials prioritisation as indoor pollution sources (2006–2009).
(22) CLEAR-UP — Clean and resource efficient buildings for real life (2008–2012).
(23) RADPAR — Radon Prevention and Remediation (2009–2012).
(24) OFFICAIR — On the reduction of health effects from combined exposure to indoor air pollutants in modern offices (2010–2013).
(25) SINPHONIE — Schools Indoor Pollution and Health: Observatory Network in Europe (2010–2012).

Figure 4.1 Indoor air pollution

Indoor air pollution
We spend a large part of our time indoors — in our homes, workplaces, schools or shops.
Certain air pollutants can exist in high concentrations in indoor spaces and can trigger health problems.



1 / Tobacco smoke
Exposure can exacerbate respiratory problems (e.g. asthma), irritate eyes and cause lung cancer, headaches, coughs and sore throats.

2 / Allergens (including pollens)
Can exacerbate respiratory problems and cause coughing, chest tightness, breathing problems, eye irritation and skin rashes.

3 / Carbon monoxide (CO) and nitrogen dioxide (NO_2)
CO can be fatal in high doses and cause headaches, dizziness and nausea. NO_2 can cause eye and throat irritation, shortness of breath and respiratory infection.

4 / Moisture
Hundreds of species of bacteria, fungi and moulds can grow indoors when sufficient moisture is available. Exposure can cause respiratory problems, allergies and asthma, and affect the immune system.

5 / Chemicals
Some harmful and synthetic chemicals used in cleaning products, carpets and furnishings, can damage the liver, kidneys and nervous system, cause cancer, headaches and nausea, and irritate the eyes, nose and throat.

6 / Radon
Inhalation of this radioactive gas can damage the lungs and cause lung cancer.

Source: EEA, 2013b.

and subsequently brought forward by the Belgian presidency in 2010 ([26]). Although the establishment of such a horizontal framework, which would involve all strategic partners and stakeholders in the policy and regulatory domains related to cross-cutting issues such as safety, health, energy efficiency and sustainability, is still pending, the need to have it established and implemented remains strong. Such a framework should encourage and ensure the development of consistent minimum requirements related to these cross-cutting issues, fed into all relevant legislative instruments and based, as far as possible, on harmonised standards. This will allow the EU Member States to conform with the aims of each of the individual legislative instruments and also to apply them in a consistent way while keeping the necessary flexibility to adjust to local conditions.

Indoor air quality and health is one of environment and health issues discussed in the context of the developing 7th Environment Action Programme, expressed in the report of the European Parliament (EP, 2012b), and in the Council Conclusions (Council of the European Union, 2012a).

In the 5th WHO Ministerial Conference Declaration (WHO, 2010a), time-bound targets were agreed to reduce threats to children's health from environmental impacts, including those arising from exposure to outdoor and indoor air (Regional Priority Goal 3).

([26]) http://www.eutrio.be/products-policy-indoor-air-quality.

5 Radon

Current background levels of ionising radiation in Europe are low in general, but there are regional differences because of the presence of radon. Radon is a radioactive gas formed from the radioactive decay of uranium; it seeps out of the ground in areas with uranium-containing soils and rocks. The most important pathway for human exposure is permeation of radon gas into buildings, but radon from water, outdoor air and construction materials can also contribute to the total exposure. Radon exposure is not evenly distributed over Europe — the occurrence is patchy with strong regional variations.

5.1 Radon is the second cause of lung cancer after smoking

Radon decays to radon daughters, some of which emit alpha radiation. Alpha-emitting radon daughters are adsorbed on to dust particles which, when inhaled, are trapped in the lungs and may cause gene damage, mutations and finally cancer. The World Health Organization concludes that studies on indoor radon and lung cancer in Europe, North America and Asia provide strong evidence that radon causes a substantial number of lung cancers in the general population (WHO, 2009c). Radon is actually the second cause of lung cancer after smoking. Current estimates of the proportion of lung cancers attributable to radon range from 3 to 14 %, depending on the average radon concentration in the country concerned and the calculation methods. The analyses assume that the lung cancer risk increases proportionally with increasing radon exposure. This assumption has been questioned. As many people are exposed to low and moderate radon concentrations, the majority of lung cancers related to radon are caused by these low exposure levels rather than by higher concentrations (WHO, 2009c). Most of the radon-induced lung cancer cases occur among smokers due to a strong combined effect of smoking and radon.

WHO proposes a reference level of 100 Bq/m^3 to minimize health hazards due to indoor radon exposure (WHO, 2009c). However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m^3.

5.2 Policies focus on monitoring and action plans in radon-prone areas

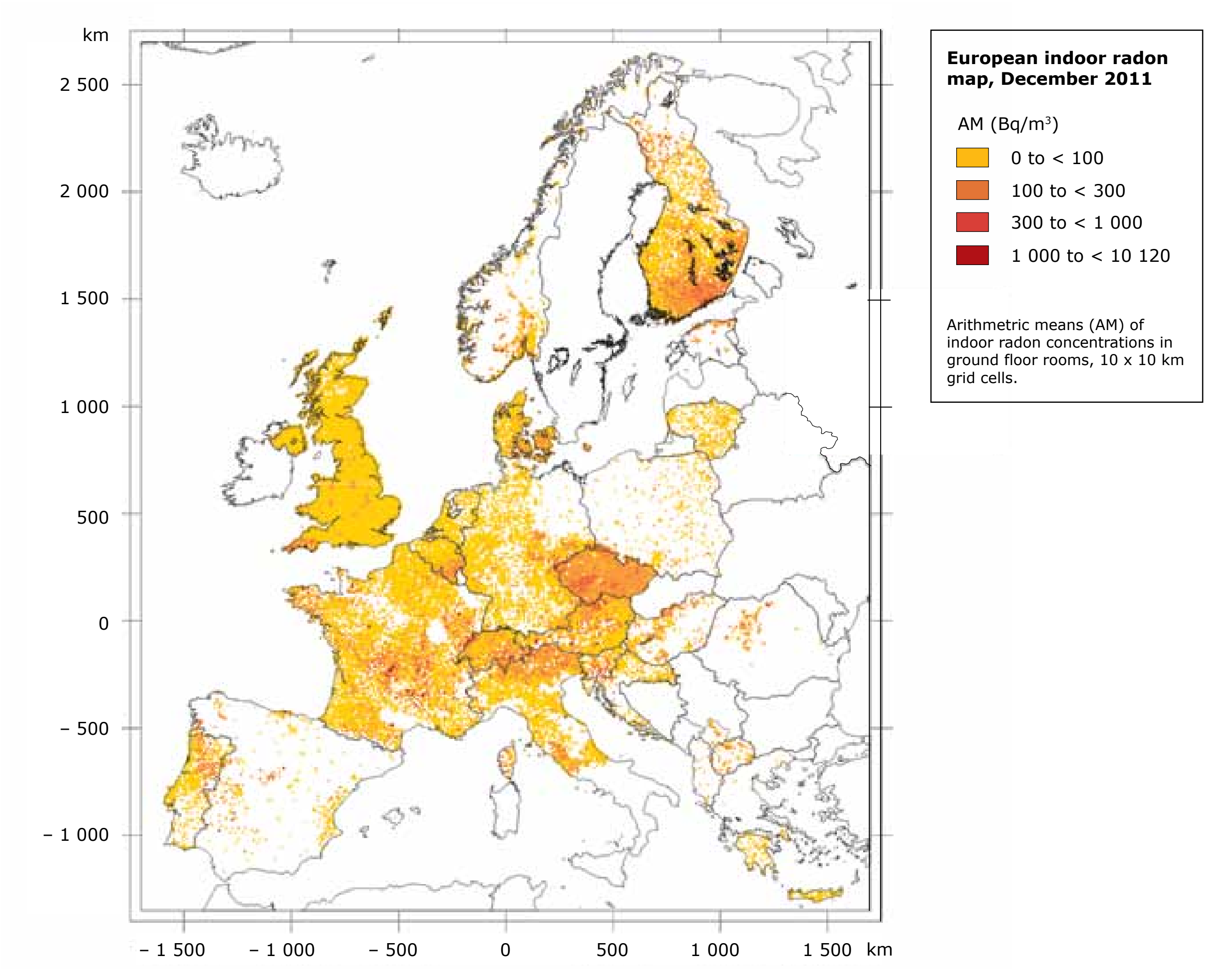
The most efficient way of reducing indoor radon exposure in high-radon areas is by increasing ventilation, and ventilation recommendations are one of the most common preventive measures. Another measure is to seal the basement on order to prevent radon gas from entering the building. Radon exposure from building materials can be reduced by the use of uranium-free materials in construction. A risk outlined by some countries is the implementation of energy-saving policies which recommend reduced ventilation, which may increase indoor radon exposures (WHO, 2009c).

Almost all European countries have monitoring programmes for radon. The frequency and type of monitoring depend on the country and the radon situation. Clearly, radon monitoring and reduction strategies are best developed in countries with an established radon problem. Radon mitigation in these countries includes national information systems, guidance documents for buildings and local and national radon maps. The vast majority of European countries do not have different policies for the various population groups — only a very few countries clearly make distinctions between children and the rest of the population by establishing lower reference levels for radon in schools and kindergartens or offering additional financial support for remediation to reduce children's exposure. Similarly, very few countries explicitly mention additional measurements and monitoring of workers exposed to radon in workplaces.

In its task of harmonising Member States' provisions for the application of the basic safety standards for the health protection of the general public and workers against the dangers arising from ionizing radiation, the European Commission issued a Recommendation (EC, 1990) on the protection of the public against indoor radon exposure (90/143/Euratom). This Recommendation gives guidelines for public information, an indoor radon reference level, an annual average concentration of 400 Bq/m^3 applicable for existing dwellings; and design levels of an annual average concentration of 200 Bq/m^3 for future construction, above which remedial actions and preventive measures should be considered. In addition to reference levels for indoor radon concentration in workplaces (1 000 Bq/m^3) and dwellings and buildings with public access (300 Bq/m^3 for existing, 200 Bq/m^3 for new ones), the new Euratom Basic Safety Standards (in draft) will foresee in an obligation for EU Member States to establish a radon action plan, aimed at managing long-term risks of radon exposures in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water. This action plan and information on any radon-prone areas shall be forwarded by each Member State to the Commission.

Related to this, and in the framework of the publication of a European atlas of natural radiation, JRC is preparing a map on indoor radon concentration (Map 5.1), averaged over 10 x 10 km grid cells. For a better preparedness on radon mitigation at the European level, JRC is currently setting up a procedure to produce a European geogenic radon map.

Map 5.1 European indoor radon map



Note: Version of December 2011.

Source: European Commission, DG Joint Resarch centre (JRC), Institute; for Transuranium Elements, REM action.

6 Water

Water is a natural resource essential to sustain human health and well-being; it is integral to virtually all economic activities, as well as supporting aquatic ecosystems. Many drivers affect water quality and availability, including population growth, environmental degradation, climate change, economic conditions, technological capacity, infrastructure, and governance.

In the EU, the majority of the population enjoys access to treated drinking water from municipal supply systems; the quality of bathing waters has also improved significantly over recent years. While much progress has been observed over the past 20 years, a substantial proportion of Europe's freshwater is still at risk of not achieving good status by 2015, as required by the Water Framework Directive (EEA, 2010c). In addition to water quality issues, water stress is of growing concern. Water shortages have severe consequences for many sectors, and can directly affect Europe's citizens (EEA, 2010f).

6.1 Poor water quality poses risks to human health

While the links between water quality and human health, as well as the benefits of technological interventions, are well established, understanding of the complexities in the water–health nexus has been evolving over recent years. Improvements in urban sanitation and water quality have contributed substantially to reducing the burden of infectious and parasitic diseases. Still, poor water quality remains a potential threat to public health through the consumption of contaminated water and seafood, especially where sanitation is inadequate and access to safe drinking water is lacking, through freshwater and marine recreation, and through occupational exposure to poor quality water.

Several infectious diseases, such as giardiasis campylobacteriosis and cryptosporidiosis, are directly water-borne; for others, such as chikungunya fever, malaria and dengue fever, water is essential as a habitat for disease vectors (Confalonieri and Schuster-Wallace, 2011). The overall burden of water-borne diseases in Europe is poorly characterised and probably underestimated (EFSA, 2010c; WHO, 2010b; ECDC, 2011; EFSA/ECDC, 2013; ECDC, 2013); climate change might affect their occurrence and distribution in Europe.

Public health threats are also posed by pathogenic micro-organisms such as toxin-producing cyanobacteria, which accompany algal blooms. The proliferation of cyanobacteria has been described in the majority of European lakes and other water resources used for aquaculture, drinking-water supply, and recreation; in some European countries, health incidents involving cyanotoxins have been reported (UNESCO/IHP, 2005; Lucentini et al., 2009). Direct contact with water containing cyanotoxins can cause allergic reactions, skin, eye, and ear irritation; when ingested, the toxins may result in gastrointestinal illness and liver damage; they can also affect the nervous system (Funari and Testai, 2008).

The consumption of freshwater and marine food contaminated with mercury and some persistent organics can pose health threats to vulnerable population groups, such as pregnant women (EC, 2004b; EFSA, 2005; Moreno, 2012). Increasing contamination of water, for example with persistent organic pollutants, pharmaceuticals and personal care products, many of which have suspected endocrine-disrupting properties, is an emerging environmental and health concern, raising questions about the potential effects of multiple exposures.

Water-related threats to human health in Europe are likely to be exacerbated by changing climate, through impacts on chemical water quality and biological processes, which may detrimentally affect freshwater ecosystems (EEA, 2010c, 2012b; WHO, 2011a). Increasing water temperature is an important factor for enhanced proliferation of cyanobacterial and other harmful algal bloom organisms, and possibly for their toxicity, and can facilitate the growth of pathogenic microorganisms such as Vibrio sp. (Spatharis et al., 2007; EEA, 2010c; Baker-Austin et al., 2012).

While much of Europe will face increasingly reduced water availability, especially during summer months, episodes of heavy rainfall can also pose health threats, for example through washing zoonotic pathogens from contaminated land into watercourses.

6.2 Drinking water quality issues still occur, particularly in small-scale supplies

Treated drinking water from municipal supply systems is available for the majority of the European population; rather infrequent health threats may occur when contamination of the water source coincides with a failure in the treatment process. Microbiological and chemical quality standards for tap water are set in the Drinking Water Directive (EU, 1998). However, in some rural areas in Europe, drinking water comes from small-scale supplies ([27]), not covered by the directive, or is taken from wells without any purification. For example, in Germany approximately 20 % of the population receives water from small public supplies serving fewer than 5 000 people. In Hungary, approximately 75 % of the registered water supply systems supply fewer than 5 000 inhabitants; and in Lithuania, almost 25 % of the total population is supplied with water from individual wells (WHO, 2011d).

The provision of safe and acceptable drinking water in sufficient quantity may be a challenge to small-scale water supplies, which are often poorly maintained and more vulnerable to breakdown and contamination than larger utilities, potentially posing a risk of water-borne diseases (WHO, 2011d). Campylobacteriosis may serve as example. Transmission of this most commonly-reported gastro-intestinal disease in Europe (53 cases per 100 000 population in 2009) can be facilitated in rural areas through animal faecal contamination of drinking-water and food. The disease is of special concern in children, and most cases are reported between June and August (ECDC, 2011).

In 2008, 10 out of 12 outbreaks of water-borne diseases reported in the EU27 were linked to the contamination of private wells (EFSA, 2010c). In the Czech Republic, between 1995 and 2005, nine out of 27 reported water-borne disease outbreaks were caused by private wells and another 10 by small commercial wells. In England and Wales, while only about 0.5 % of the total population relies on private supplies, 36 % of all detected drinking-water disease outbreaks were associated with such supplies (WHO, 2011a).

The quality and maintenance of public water supply systems matters. Leakage in water supply systems results not only in loss of purified drinking water, but can imply a potential risk of bacterial contamination from surrounding ground.

Climate change and extreme weather events may further affect water supply infrastructure, and pose a risk of chemical and biological contamination of water for human consumption. Such hazards may be more pronounced in poor and rural areas, where utilities infrastructure is lacking or in a poor state, or where small-scale services cannot cope with adverse weather conditions. To ensure the supply of safe drinking water, suppliers will need to adapt to greater variation in both raw water quality and water quantity (EEA, 2011g; WHO, 2011a).

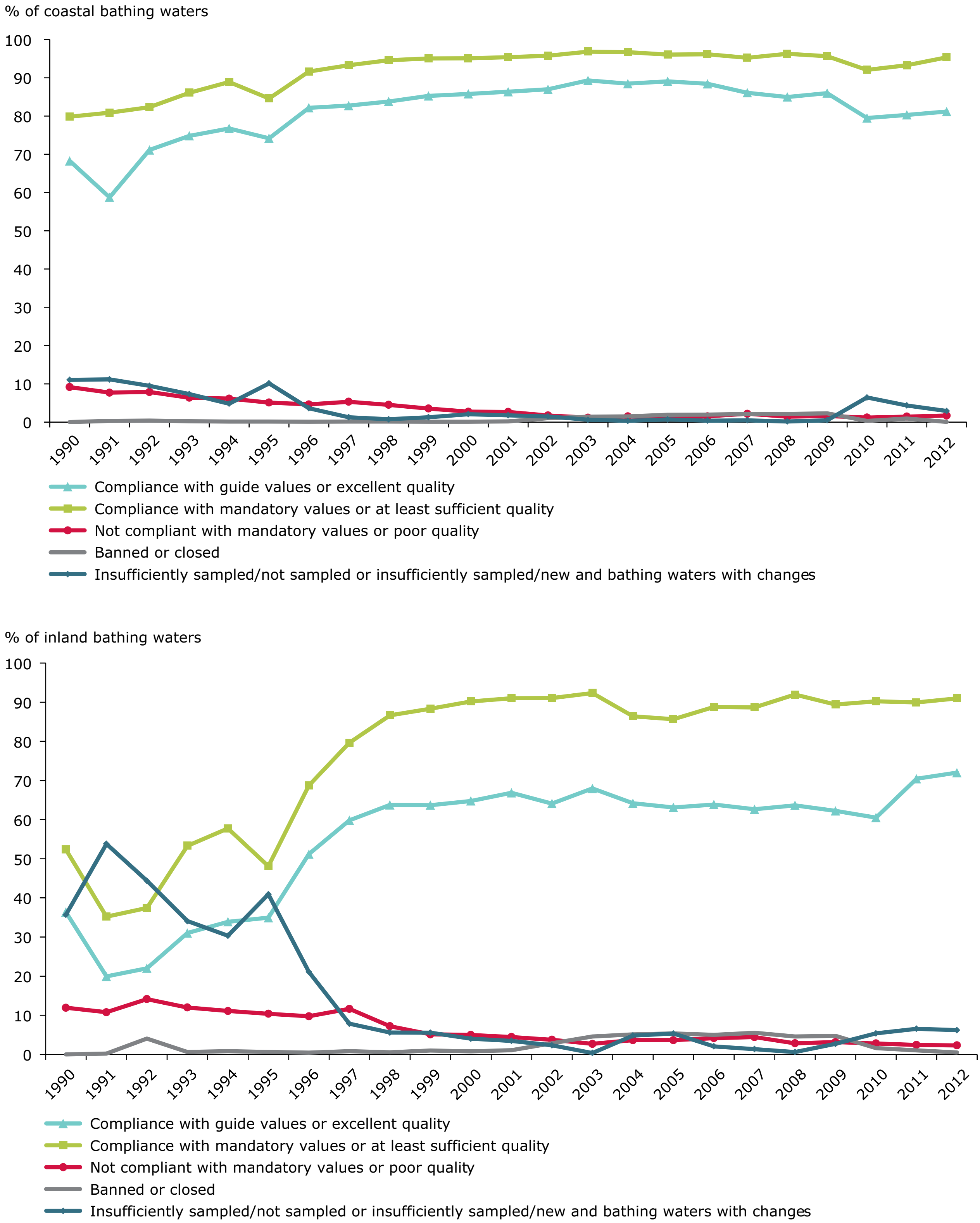
6.3 Bathing water quality has improved...

The quality of European bathing waters ([28]), both inland (rivers and lakes) and coastal, has improved substantially over recent decades (Figure 6.1). Major progress in the collection and treatment of wastewater in the EU since 1990s has resulted in reduced releases of pathogenic micro-organisms, nutrients and some hazardous chemicals to fresh and coastal waters, diminishing public health risks in some regions of Europe (EEA, 2010c, 2012d).

([27]) Supplies serving less than 10 m^3 a day or serving fewer than 50 individuals, unless water is supplied as part of a commercial or public activity; reporting to the EU starts from systems serving more than 5 000 people.

([28]) According to the Bathing Water Directive (EU, 2006a) — any element of surface water where the competent authority expects a large number of people to bathe and has not imposed a permanent bathing prohibition, or issued permanent advice against bathing; does not apply to: swimming and spa pools; confined waters subject to treatment or used for therapeutic purposes; artificially created confined waters separated from surface water and groundwater. Member States shall annually identify all bathing waters and define the length of the bathing season.

Figure 6.1 The quality of inland and coastal bathing water in Europe between 1990 and 2012



Source: EEA, 2013d.

6.4 …but certain pollutants remain of concern

While wastewater treatment has improved, a range of pollutants, including nutrients, pesticides, industrial and household chemicals, metals and pharmaceutical products, can still reach freshwater bodies in Europe, both directly and indirectly, from a range of diffuse and point sources. Agriculture continues to be a major cause of poor water quality, with nutrients, pesticides, pathogenic microorganisms excreted by livestock and organic pollution from manure. Agricultural run-off carrying fertilisers, largely contributes to the eutrophication of fresh and marine waters. For example, the Baltic Sea remains eutrophic and one of the most polluted in the world because of high riverine loads of nitrogen and phosphorus to the sea, mainly originating from agriculture. In urban areas, the combined flows generated during larger storm events can result in overflows and local discharges of a range of chemical and microbiological pollutants (EEA, 2010c, 2012e). The frequency and severity of polluted urban storm flows is likely to increase with the changing climate in regions where more intense rainfall is expected; similarly the flushing to water of agricultural pollutants, including pesticides, medicines, and pathogens, may be exacerbated (EEA, 2010c, 2012b, 2012j).

Wastewater treatment does not remove all pollutants; household and industrial chemicals, including pesticides, pharmaceuticals and personal care products, can therefore be detected in treated effluent discharged to surface waters. Of particular concern are chemical pollutants with potentially endocrine-disrupting properties, including a wide range of compounds: naturally-occurring human and animal hormones, pharmaceutical products, several pesticides, fungicides, insecticides, and industrial chemicals such as polyaromatic hydrocarbons (PAHs). Treatment plants can remove 80 % or more of endocrine-disrupting chemicals; however, even very low concentrations discharged to receiving waters can result in endocrine disruption in aquatic biota (EEA, 2010c, 2011d). Chemicals with endocrine-disrupting properties has been shown to trigger feminising effects in fish, posing questions about potential human health impacts, especially in the context of exposure to multiple chemicals through different routes and pathways (EEA, 2012h).

While wastewater treatment will continue to play a critical role in the protection of Europe's freshwaters, complementary approaches, such as tackling pollutants at source, need to be explored more extensively. Reducing chemical pollution at source is also an important efficiency measure, as advanced wastewater treatment and treating of drinking water is often energy- and chemicals-intensive (EEA, 2012i).

6.5 Water scarcity is an emerging challenge

Awareness of water scarcity and the need for sound quantitative water management in Europe has been gradually growing. Water scarcity and droughts affect parts of Europe, particularly in the south (EEA, 2010f). Water scarcity has severe consequences for most sectors, particularly the provision of drinking water, agriculture, energy, and tourism. Water shortages have already resulted in restrictions in water supply in some parts of Europe; reduced or intermittent supply of piped water can increase the risk of introduction of contaminants and deterioration of drinking water quality.

The balance between water demand and availability is reaching critical levels in parts of Europe. However, there is a large water-saving potential: the European Commission (2010) estimated that overall water consumption in Europe could decrease by 40 % (EEA, 2012i). For example, in agriculture, measures to reduce water use include increased irrigation efficiency, adjustment of timing and irrigation techniques, and use of treated wastewater for irrigation. This practice is well established in Spain, Italy, Cyprus, and Greece, and growing. However, the chemical and microbiological quality of reclaimed water must be properly managed if it is not to pose threats to human health (EEA, 2012i) (Box 6.1).

Climate change, with hotter, drier summers and increasingly severe and frequent droughts, projected to affect parts of Europe (e.g. Mediterranean region), is likely to deplete river flows, increasing the risk of water shortages, as well as reducing contaminant dilution capacity, and leading to elevated concentrations of hazardous substances (EEA, 2011d).

6.6 EU water legislation is well advanced and takes an increasingly systemic approach

A comprehensive range of water-related legislation has been established in the EU, with the Water Framework Directive (WFD) (EU, 2000) representing the single most important piece of legislation on the protection of water resources, both in terms of

Box 6.1 Health safety of recycled water for irrigation

One of the methods of improving the quality of the recovered water through filtering out potentially harmful microorganisms is 'managed aquifer recharge', where recycled water is added to underground aquifers. However, the potential human health risks need to be carefully considered.

In an EU-supported project ([29]) conducted in Italy, Spain, Israel, and Australia, a quantitative microbial risk assessment was performed, focused on three relevant pathogens: rotavirus, Cryptosporidium, and Campylobacter. The risk was calculated for three types of exposure: farm-workers accidently inhaling water particles, local residents accidently inhaling water particles, and end-consumers exposed to the reclaimed water when eating the irrigated crops. The results of the study indicated that the health risks were acceptable except for one site (in Italy). The longer the reclaimed water remained in an aquifer the lower was the risk. Accidental ingestion by growers posed the highest risk, the consumption of crops the lowest. The risk to growers could be reduced by using certain irrigation techniques — drip irrigation instead of the use of sprinklers. Compared to other treatment methods, a 'managed aquifer recharge' was shown to be efficient in reducing human health risk, for the pathogens considered.

Source: WHO, 2003b; Ayuso-Gabella et al., 2011.

quality (chemical and ecological) and quantity. The WFD requires that water bodies achieve 'good status for surface and groundwater' by 2015, meaning that the combined impacts of water use and pollution pressures are managed in such a way that no environmental degradation occurs, and sustainability is restored or maintained.

The 'Blueprint to safeguard Europe's water resources' report, published by the European Commission (EC, 2012c), reviews the WFD, water scarcity and drought and vulnerability and adaptation policies. In the first report under the WFD, the EEA assessed the data on status, pressures and measures for groundwater and surface water bodies (rivers, lakes, coastal and transitional waters), reported by 23 EU Member States (EEA, 2012e). More than half of the surface water bodies are reported to be in less than good ecological status or potential status, and will need mitigation and/or restoration measures to meet the WFD objective. Pollution from diffuse sources causing nutrient enrichment, and hydromorphological pressures resulting in altered habitats, were the most reported pressures affecting surface water bodies. The worst ecological status and pressures in freshwaters are in central and north-western Europe, while for coastal and transitional waters, the worst are the Baltic Sea and Greater North Sea regions.

A high proportion of water bodies with poor ecological status is reported in regions with intensive agriculture, high population density and pollution pressures. Full implementation of the WFD and related water legislation in order to address the challenges of managing aquatic ecosystems, needs to be complemented by enhanced integration of water policy objectives into other policy areas such as the Common Agricultural Policy, the Cohesion and Structural Funds and policies on renewable energy and transport (EEA, 2012e).

Chemical status is assessed in terms of compliance with environmental standards for chemicals that are listed in the WFD (Annex X) and the Environmental Quality Standards Directive (EQSD) (EU, 2008a). The EQSD defines concentration limits for pollutants of EU-wide relevance, known as priority substances (PSs). Some pollutants have been designated as priority hazardous substances (PHSs) due to their toxicity, persistence in the environment or bioaccumulation in plant and animal tissues. The EQSD requires cessation or phase-out of discharges, emissions and losses of PHSs. There are 33 priority substances and priority hazardous substances regulated by the EQSD, and the list is growing. The recent proposal to include three pharmaceutical compounds: two hormonal components of a contraceptive pill (17-alpha-ethinylestradiol (EE2) and 17-beta-estradiol (E2)), and anti-inflammatory drug diclofenac was rejected due to concerns raised on the scientific justification for the chemicals' prioritisation, the socioeconomic impact and the costs entailed, and consistency with EU product legislation (Council of the European Union, 2012b; Owen and Jobling, 2012;

([29]) RECLAIM WATER Water reclamation technologies for safe artificial groundwater recharge (2005–2008), http://www.reclaim-water.org.

UKCSF, 2012). Instead, they will be included in a proposed 'watch list' (Council of the European Union, 2013). For substance of concern at the local, river basin or national level, standards have to be set at the national level.

Full implementation of the WFD, together with the EQS Directive, and the Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is expected to facilitate a source control approach and lead to reduced emission of pollutants to water.

Implementation of the Urban Wastewater Treatment Directive (UWWTD) has resulted in the reduction of microorganisms, nutrients and some hazardous chemicals in fresh and coastal waters. This directive regulates the collection and treatment of wastewater; its full implementation is taking longer than expected. The UWWTD addresses agglomerations of more than 2 000 people; therefore, in areas with small-scale rural sanitation, complementary solutions may be needed to avoid potential threats to public health (EEA, 2010c). The Nitrates Directive addresses water pollution by nitrates from agriculture, a major source of water pollution in Europe; Member States monitor water quality and designate 'nitrate vulnerable zones', where farmers have to apply specific action programme to limit nitrate pollution (EU, 1991).

The implementation of the UWWTD has resulted in significant improvements in the quality of bathing waters (EEA, 2012d, 2013d). The Bathing Water Directive (EU, 2006a) aims to protect public health by setting concentration limits for microbiological pollutants in Europe's inland and coastal bathing waters; it also addresses risks from toxic cyanobacteria. According to this directive, all bathing waters should reach at least a 'sufficient' level of quality (in microbiological terms) by 2015.

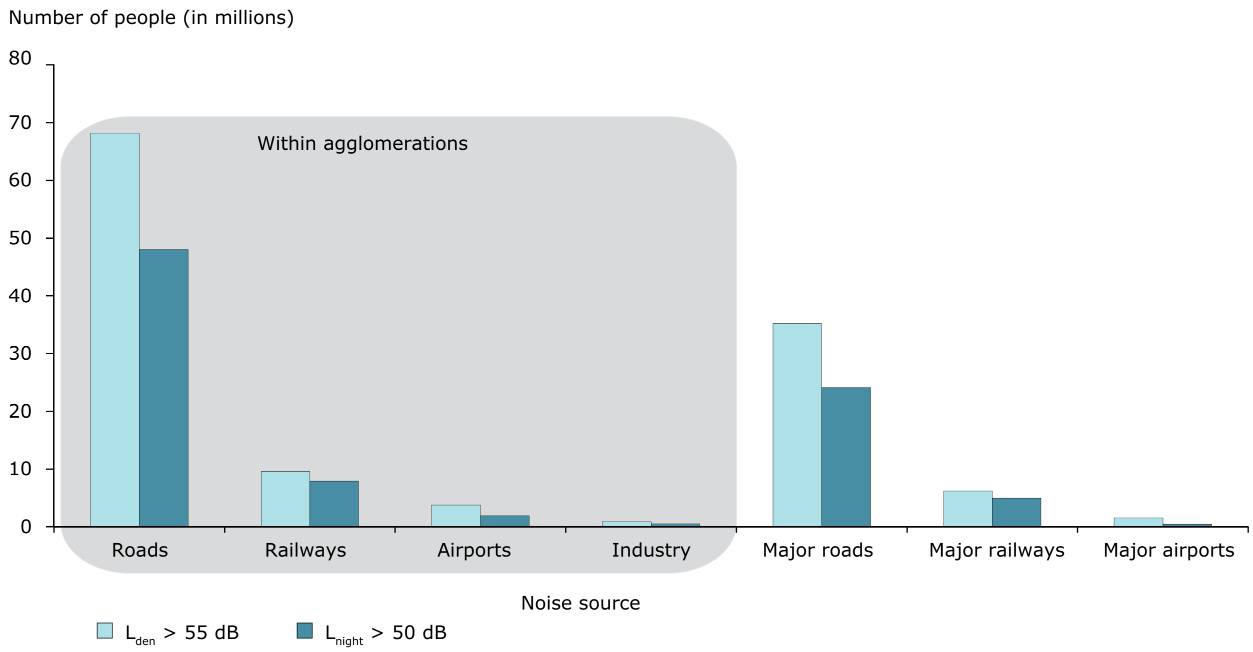
The Drinking Water Directive and its revision (EU, 1998), which came into force in 2003, aim to ensure that water intended for human consumption is safe. It must be free of any microorganism, parasite or substance that could endanger human health. The directive sets minimum requirements for certain parameters. Member States must set standards for these parameters that are no less stringent than in the directive and then monitor the quality of drinking water against those standards. The drinking water directive sets quality standards for water at the tap, based on microbiological and chemical parameters, with the general obligation that drinking water must be 'wholesome and clean'. However, in some rural areas of Europe drinking water is taken from wells and consumed without any purification; small-scale supplies are not covered by the directive.

7 Noise

The general public perceives noise as one of the major environmental problems. According to the latest EEA data, over 103 million people are exposed to road traffic noise levels above 55 dB L_{den} (L_{den} = day-evening-night sound level) and almost 24 million are exposed to noise levels above 65 dB L_{den}. Noise levels above 40 dB can influence well-being, with most people being moderately annoyed at 50 dB and seriously annoyed at 55 dB (Figure 7.1). In terms of sleep disturbance, the WHO recommended guideline for Europe is 40 dB L_{night} and WHO considers environmental noise levels above 65 dB to be detrimental to health (WHO, 2009b). Due to limitations of the Environmental Noise Directive it is not yet possible to make an exposure assessment to this recommended level, but it is known that at least 72 million Europeans are exposed to road traffic noise levels greater than 50 dB L_{night}.

Noise affects people in both physiological and psychological ways, interfering with basic activities such as sleep, rest, study and communication. A number of noise studies in peoples' home environments indicate that airport noise is the most disturbing, followed by traffic noise and railway noise. There is sufficient evidence from large-scale epidemiological studies linking population exposure to environmental noise with adverse health effects. Environmental noise should therefore be considered not only as a cause of nuisance but also a concern for public and environmental health. An Environment Burden of Disease (EBoDE) study in six European countries ranked noise from road traffic as second among the environmental stressors evaluated in terms of their public health impact, immediately after very fine particulate air pollution ($PM_{2.5}$) but ahead of stressors such as radon, passive smoking, dioxins, benzene and formaldehyde (Hänninen et al., 2011). Moreover, noise exposure still shows an increasing trend in Europe while other stressors are declining.

Figure 7.1 Exposure to environmental noise in Europe (EU-27 plus Norway and Switzerland)



Source: EEA, 2012k.

7.1 Noise affects the health, quality of life and well-being of many Europeans

The WHO burden of disease study on noise (WHO/JRC, 2011) was based on several noise-related health impacts:

- *Cardiovascular disease:* a number of studies show that long-term exposure to traffic noise can lead to increased blood pressure. Several epidemiological studies show a correlation between cardiovascular disease and exposure to noise. However, it is not yet clear if the impact of noise on cardiovascular disease risk is independent of the impact of traffic-related air pollution since exposure to one does not exclude exposure to the other. Night-time noise levels are associated with increased risk of myocardial infarction and probably also stroke (Sørensen et al., 2011).

- *Cognitive impairment in children:* there seem to be a quite robust relationship between cognitive development and ability in children and exposure to noise. Some studies point to aircraft noise as particularly important.

- *Sleep disturbance:* probably the most common impact of environmental noise on human health and particularly well-being. Too little sleep has many indirect effects on people's daily lives, function and productivity at work and social capacity and family life. Sleep disturbance has also been connected to cardiovascular disease. Although difficult to quantify, sleep disturbance is probably the most prominent effect of environmental noise on human health.

- *Annoyance:* persons who are annoyed by noise may experience a variety of symptoms, such as anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation and exhaustion. Stress-related psycho-social symptoms such as tiredness, stomach discomfort and stress have been found to be associated with noise exposure as well as noise annoyance.

WHO (WHO/JRC, 2011) concludes that the environmental disease burden of noise, calculated as disability-adjusted life years (DALYs) in the European population, with conservative assumptions, is an estimated 61 000 years for cardiovascular disease, 45 000 years for cognitive impairment of children, 903 000 years for sleep disturbance, 22 000 years for tinnitus and 587 000 years for annoyance. These results indicate that at least one million healthy life years are lost every year from road traffic noise alone in Europe.

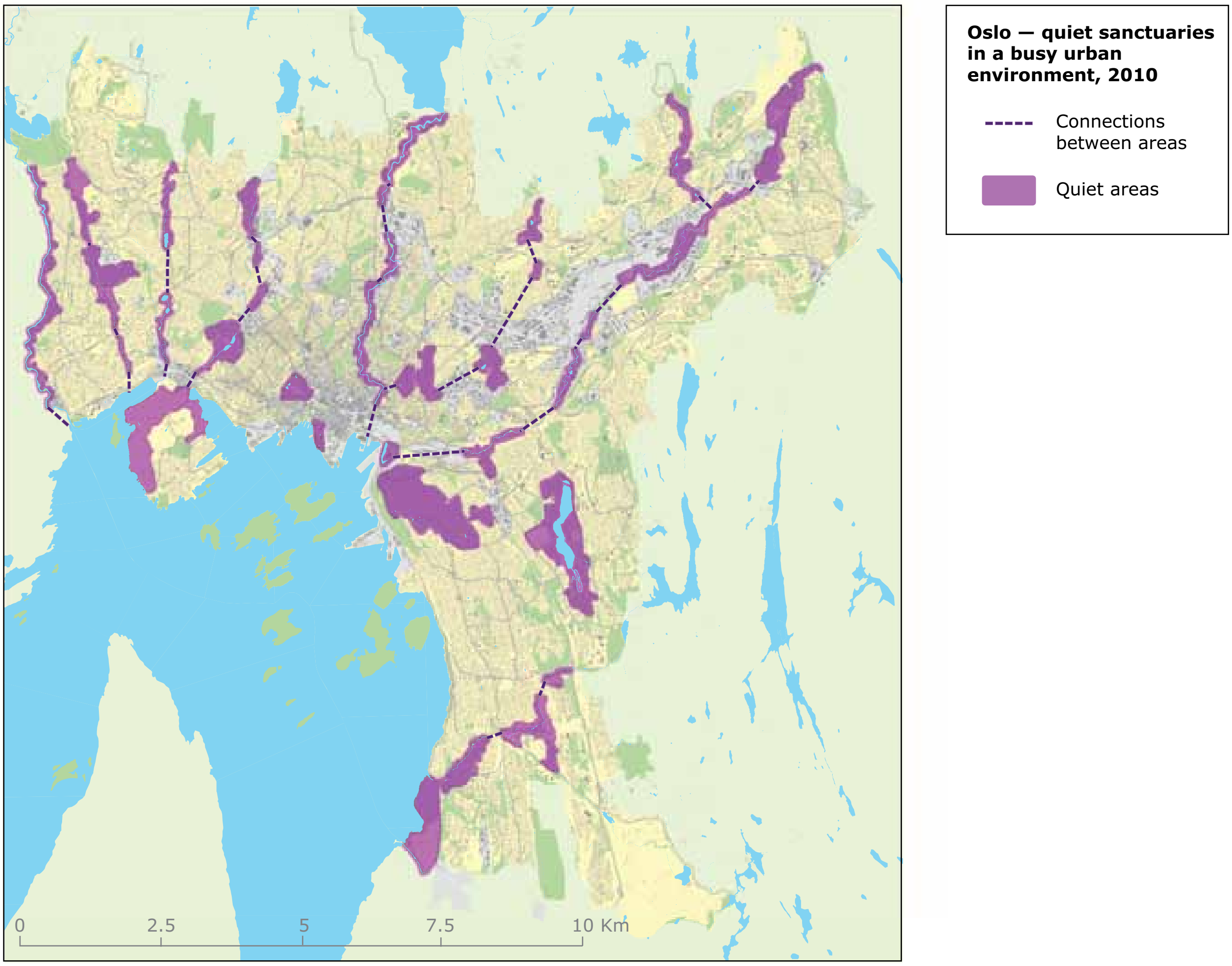
Particularly sensitive to noisy environments are those with hearing problems, because of difficulties with following conversations when background noise is high. Some public health experts advocate that severe forms of noise-related annoyance should be considered a legitimate environmental issue affecting the well-being and quality of life of the population exposed to environmental noise.

7.2 Effective abatement measures are available

With one million healthy life years lost in Europe per year, reduction of traffic noise exposure is an important public health measure. Noise barriers are one method of reducing noise from roads with heavy traffic. In more and more European cities, traffic is directed into tunnels under populated areas which increases traffic flow and reduces noise levels to citizens. Green areas such as parks and courtyards are important in reducing urban noise levels and also for increasing the well-being of citizens (EEA, 2010e). For both those with and without access to a quiet area, the results show that a better availability of nearby green areas is important for reducing long-term noise annoyance and the prevalence of stress-related psychosocial symptoms. There is therefore a need to rethink urban planning and design, architecture, and transport in order to make the urban environment quieter. An example of a step forward is the city Oslo which has created quiet sanctuaries in busy areas (Map 7.1) by reducing or banning road traffic. Aeroplanes can be made quieter in order to reduce airport noise. Both Boeing and Airbus are developing the next generation planes which are 30 % quieter than the planes of today in order to meet stricter noise regulations around airports.

For urban planning, it is important to know where the noisiest environments are. Following the roadmap of the implementation of the Environmental Noise Directive 2002/49/EC, EU Member States recently reported noise exposure data prepared in the context of the first round of strategic noise mapping in Europe. Data reported for major roads, those with ≥ 6 million vehicles per year; major railways with ≥ 60 000 trains per year; major airports with ≥ 50 000 flight movements per year; and agglomerations of ≥ 250 000 people, have been reviewed and analysed by the European Environment Agency. The complete database can

Map 7.1 Oslo — quiet sanctuaries in a busy urban environment, 2010



Source: EEA, 2010e.

be seen on-line through the Noise Observation and Information Service for Europe (NOISE) viewer ([30]).

7.3 Public awareness needs to be increased

EEA, together with the Noise Abatement Society, is raising awareness about the health impacts of noise and stimulating European initiatives that can help reduce excessive noise. The European Soundscape Award is presented annually to any product, campaign, innovation or scheme offering a creative solution to a noise problem (EEA, 2011b). The award for 2011 went to the Dutch province of Gelderland and the municipality of Wijchen for sustainable and integrated traffic noise reduction solution in the village of Alverna. In an effort to tackle noise pollution and improve well-being in the town, the authorities introduced the following measures on the busy main roadway:

- reducing the number of traffic lanes and sinking the road by 0.5 m;
- constructing low-level sound barriers of 1m on each side of the road;
- using special 'quiet' asphalt;
- reducing the speed limit from 80 to 50 km/h.

These measures enabled planners to achieve the same effect as installing the usual unattractive,

([30]) NOISE at http://noise.eionet.europa.eu.

4 m-high noise barriers. The project also included a tree planting scheme to create attractive pedestrian areas. In addition to the noise-reduction benefits, the full package of measures also increased road safety, reduced fuel use, and helped improve air quality and the quality of life in the village.

In 2012, the award was given to a project led by the Technical University of Berlin which redesigned Nauener Platz in Berlin, thus improving the soundscape for residents and users of this urban space.

In order to further involve citizens in identifying noisy environments, EEA released its NoiseWatch service in December 2011. This is a new application of the Eye on Earth online map service (EEA, 2011f), which will allow European citizens to upload ratings of noise levels wherever they are. In addition to the subjective rating, a NoiseWatch mobile application is available for I-Phone and Android, which permits the citizen to make a short measurement of noise in their environment. This decibel level is converted into a rating and can be uploaded directly to the NoiseWatch database and in this way can help inform policy-makers about the scale of concern about noise and the sources that affect citizens most.

7.4 Noise legislation is in place, but requires better data on human exposure

To protect public health from environmental noise, collaboration between the European Commission (DGs ENV, MOVE, ENTR, JRC), WHO, EEA and the EU Member States is increasingly being strengthened with the aim of implementing in a synergistic way the Parma Declaration (WHO, 2010a) and the EU Environmental Noise Directive (EU, 2002a). The NOISE database reflects the information required by the directive and presents officially reported noise that is greater than 55 dB l_{den} and 50 dB l_{night}. In an effort to bridge the gap in data availability and knowledge-based policy development, EEA has put in place an improved reporting mechanism for Round 2 noise maps, which will facilitate the delivery of data relating to the WHO recommended levels by December 2012.

A number of scientific studies show that the combination of environmental noise and air pollution act in concert with respect to health effects. Work is on-going to develop models for a realistic assessment of the health impacts of the combined exposure in urban environments (Gan et al., 2012; URBAN-NEXUS, 2012; Vlachokostas et al., 2012). Future policy work, both in the noise and the air pollution area, will have to adjust to this reality and develop an integrated approach in order to achieve maximal protection from both noise and air pollution.

In 2012, in accordance with Article 6.2 of the Directive 2002/49/EC (END), the European Commission's Joint Research Centre developed Common NOise aSSessment methOdS (CNOSSOS-EU) for road traffic, railway traffic, aircraft and industrial noise, to be used, after adoption by the Member States, for the purpose of strategic noise mapping in Europe (Kephalopoulos et al., 2012). CNOSSOS-EU aims at improving the consistency and comparability of noise assessment results across the Member States, which are performed on the basis of the data becoming available through the consecutive rounds of noise mapping in Europe as required by the END. CNOSSOS-EU will allow facing the challenges ahead:

- making available reliable information on the noise levels, and the associated health implications, to which EU citizens are exposed;
- devising appropriate actions plans to prevent and reduce exposure to harmful levels of noise in a sustainable and resource-efficient way.

WHO and JRC has recently prepared a methodological guidance for estimating the burden of disease from environmental noise (WHO/JRC, 2012a and 2012b). The challenge for noise policy in Europe is to embrace the latest health impact evidence and ensure that levels of exposure do not exceed the recommendations. It will also be imperative that actions go beyond the reduction of noise and also address the protection of those areas in Europe where the impact of noise is still low.

Figure 7.2 CNOSSOS-EU logo

8 Electromagnetic fields

Nowadays, especially in urban environments, exposure to low levels of human-made non-ionising electromagnetic fields (EMF) is an unavoidable fact of life. Electrical power lines are surrounded by electromagnetic fields; electrical appliances generate electromagnetic fields. Many commercial appliances, like theft control systems in shops, and the growing use of WiFi applications, are based on EMF technologies. Mobile phones and the base stations connected to mobile communication are other wide-spread sources of electromagnetic emissions. Along with this, as shown by the European Commission Eurobarometer (Eurobarometer, 2010b) results of March-June 2010, public concerns about possible risks of exposure to electromagnetic fields are significant, with the highest concern for high-voltage power lines and mobile base stations. However, the there is a general trend towards lower concern about EMF sources than in earlier Eurobarometer studies (Eurobarometer, 2007).

8.1 The health effects of electromagnetic fields are controversial

The potential health effects of exposure to electromagnetic fields (EMF) are currently one of the most controversial issues when discussing environmental impacts on human health. A critical analysis and a conclusion in the current discussion can be found in the EEA report *Late lessons from early warnings* Vol. II (EEA, 2013a). What is clear and accepted is that exposure to high levels — radars, radio broadcast stations, etc. — of non-ionising EMF radiation has significant health effects. The EU's Scientific Committee on Environmental and Newly Identified Health Risks, SCENIHR, at the request of the European Commission, has provided a thorough evaluation of the scientific evidence of health effects of low-level EMF exposure below current international limits in recent opinions (SCENIHR, 2007, 2009a) on possible adverse health effects of exposure to EMF across the relevant frequency range (0 to 300 GHz). For all frequency bands of the EMF spectrum, SCENIHR has identified some priority areas where there is insufficient or contradictory information regarding possible adverse health impacts and recommended further research.

For radio frequencies (RF), intermediate frequencies (IF), and static fields, SCENIHR concluded that no health effects have been consistently demonstrated at exposure levels below the International Commission on Non-ionizing Radiation (ICNIRP) limits established in 1998 (ICNIRP, 1998). It is stated that exposure to RF fields is unlikely to lead to an increase in cancer in humans, but due to the lack of epidemiological data for long-term exposure (over more than 10 years) the possibility of some cancer risk cannot be completely excluded, and further studies are required. For intermediate frequencies and static fields, studies are few and the data for a proper risk assessment are very limited. SCENIHR considers that in view of the increasing occupational exposure to IF among workers (for example in security, shops, and certain industries), research in this area must be a priority. In the case of extremely low frequencies (ELF), moreover, carcinogen effects and a possible association between quasi-static magnetic fields and childhood leukaemia cannot be ruled out (associated with average exposure to residential power-frequency magnetic field above 0.3 to 0.4 μT, as stated in IARC evaluation and the update (IARC, 2002; WHO, 2007a). In the absence of a causal mechanism, however, such results could well be explained by the limitations of the epidemiological data.

The SCENIHR conclusions are fully consistent with other recent evaluations and consultations carried out by various independent scientific review bodies and agencies worldwide. A noteworthy exception is the Bio-Initiative Report (2007), which came to different conclusions and re-awoke the debate (Bio-Initiative, 2007). The fundamental disagreement seems to surround the way of deciding when the evidence is sufficient to take action. It may be, as put it in the Bio-Initiative Report's preface, that 'to a great degree, it is the definition of the standard of evidence used to judge the scientific reports that shapes this debate'. The debate is thus of interest as it concerns the standards for evaluating scientific evidence, for dealing with scientific uncertainty, and the possible confusion between risk assessment and risk management and the application of the precautionary principle.

In June 2011, the WHO's International Agency for Research on Cancer (IARC) concluded its Interphone study which was designed to determine whether there are links between the use of mobile phones and head and neck cancers in adults. The international pooled analysis of data gathered from 13 participating countries found no increased risk of glioma or meningioma (two cancer forms) as a result of mobile phone use of more than 10 years. There are some indications of an increased risk of glioma for those who reported the highest 10 % of cumulative hours of cell-phone use, although there was no consistent trend of increasing risk with greater use. Based largely on these data and paying attention to the large uncertainty involved, IARC has classified radio-frequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), a category used when there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals (IARC, 2012c).

8.2 Children could be particularly vulnerable to radiofrequency EMF

SCENIHR highlights the specific case of children and stresses that information on possible effects of RF fields in children is limited. They write — 'A particular consideration is mobile phone use by children. While no specific evidence exists, children or adolescents may be more sensitive to RF field exposure than adults in view of their continuing development. Children of today may also experience a much higher cumulative exposure than previous generations. To date no epidemiologic studies on children are available.' SCENIHR also concluded that evidence against an association between RF fields from broadcast transmitters and childhood cancer has been provided by new improved studies.

The debate will continue as long as more scientific evidence is collected. One of the difficulties in establishing a causal relationship between mobile telephone EMF and cancer is related to the fact that mobile phones have been in public use for less than 15 years while many cancers need 20 years or more to develop.

8.3 Policies focus on exposure limits for devices

Member States in the EU follow Council Recommendation (Council of the European Union, 1999), limiting the public exposure to EMF (in the 0 Hz to 300 GHz frequency range), which applies the guidelines on maximum exposure levels and reference values established by (ICNIRP, 1998). Exposure limits are based on peer review of the scientific evidence on established health effects, and apply to all devices emitting EMF. The basic requirement is that below these limits health must not be affected, even with repeated exposure. Common standards covering all aspects of the emission of electromagnetic fields generated by equipment operating in the different frequencies are ensured within the scope of the Low Voltage Directive (LVD) 73/23/EEC, the Radio & Telecommunications Terminal Equipment (R&TTE) Directive (EU, 1999), the Electromagnetic Compatibility (EMC) Directive (EU, 2004b), and Directive on the harmonisation of the laws of Member States relating to electrical equipment (EU, 2006b). Occupational exposure is regulated by Directive 2004/40/EC of the European Parliament and of the EU Council (EU, 2004c).

9 Ultraviolet radiation

Exposure to ultraviolet (UV) radiation is a natural phenomenon and, at modest intensities, healthy. UV absorption in the skin is the main mechanism of vitamin D production. Lack of sunlight exposure can result in vitamin D deficiency and a disturbed calcium balance which leads to osteoporosis and increasing the risk of rickets and many other symptoms. Human populations in areas with prolonged periods of darkness therefore need additional vitamin D from food (meat, liver) or through artificial supplements. Sunlight exposure also has other beneficial effects on health by contributing to positive psychogenic feelings — seasonal affective disorder is a form of depression during winter from a lack of sunlight.

9.1 Exposure to excess UV radiation increases risk of skin cancer

But there is also a dark side. The incidence of all types of skin cancer is related to exposure to UV radiation. Non-melanoma skin cancer, eye melanoma, and lip cancer have also been related to natural UV light. IARC (WHO International Agency for Cancer Research) classifies UV radiation as a category 1 carcinogen to humans (sufficient evidence in humans and sufficient evidence in animals and strong mechanistic data in humans). UV penetrates the skin and is absorbed by the tissues; UV-B (Box 9.1) only penetrates into the epidermis; UV-A into the epidermis and dermis. A pigment, melanin, protects the skin against UV damage, and UV exposure stimulates melanin production (sun tan). The capacity to produce protective melanin varies in the European population and has a genetic background, with Northern European having lower pigmentation then Mediterranean Europeans; melanoma risk is higher in pale low-melanin producers (Gandini et al., 2005).

Excessive UV exposure of unprotected skin damages not only skin cells but also immune cells in the tissue. The immediate response after irradiation is inflammation — sunburn and blisters — and the suppression of immune reactions in the skin. Long-term exposure can lead to photo-aging and skin cancer. Many eye diseases are also related to UV exposure, also to acute exposure ('snow blindness'). A clear relationship between the occurrence of squamous cell carcinoma and total lifetime exposure to UV has been established. For malignant melanoma, the most aggressive form of skin cancer, the situation seems to be different. The incidence seems to be related to intermittent high-exposure events, particularly at a young age. The case of basal cell carcinoma is somewhere between the two. It should be stressed that many other factors are important for individual risk, such as skin type and the occurrence of nevus or moles (dark skin spots made of a cluster of melanin-containing cells). The skin of children is particularly sensitive. The long delay, from years to tens of years, between exposure and the occurrence of a skin cancer further complicates the studies. Nonetheless there is strong evidence that the observed increase in skin cancer incidence is linked with an increased exposure to UV radiation.

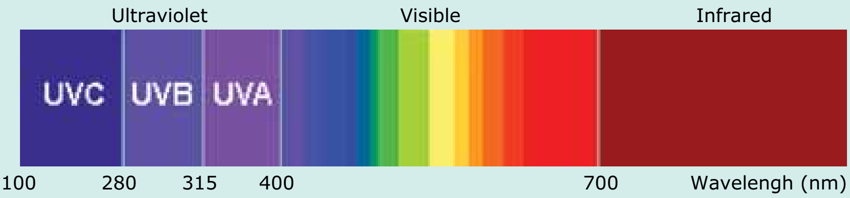
There has been a significant increase in the incidence of skin cancer since the 1950s in Europe and in large parts of the world. In Denmark, Sweden, and Norway, for example, the incidence of cutaneous melanoma per 100 000 people, age-adjusted on the world standard population, rose from fewer than 2 cases each year in the early 1950s to 13–15 cases per year in 2005 (NORDCAN, 2008). This trend is continuous throughout Europe. These increases are related not only to melanoma but also to other forms of cancer such as squamous cell carcinoma (SCC) and basal cell carcinoma (BCC). However, the most recent cancer registry data show that skin cancer incidence is showing a tendency to level off, particularly in some European countries (IARC, 2012b; Erdmann et al., 2013), which could indicate that the trend has been broken.

9.2 Changing lifestyles have affected exposure to UV radiation

The increase in skin cancer is probably related both to changes in lifestyle and to environmental changes. The intensity of UV radiation at ground level has

Box 9.1 The nature of UV radiation

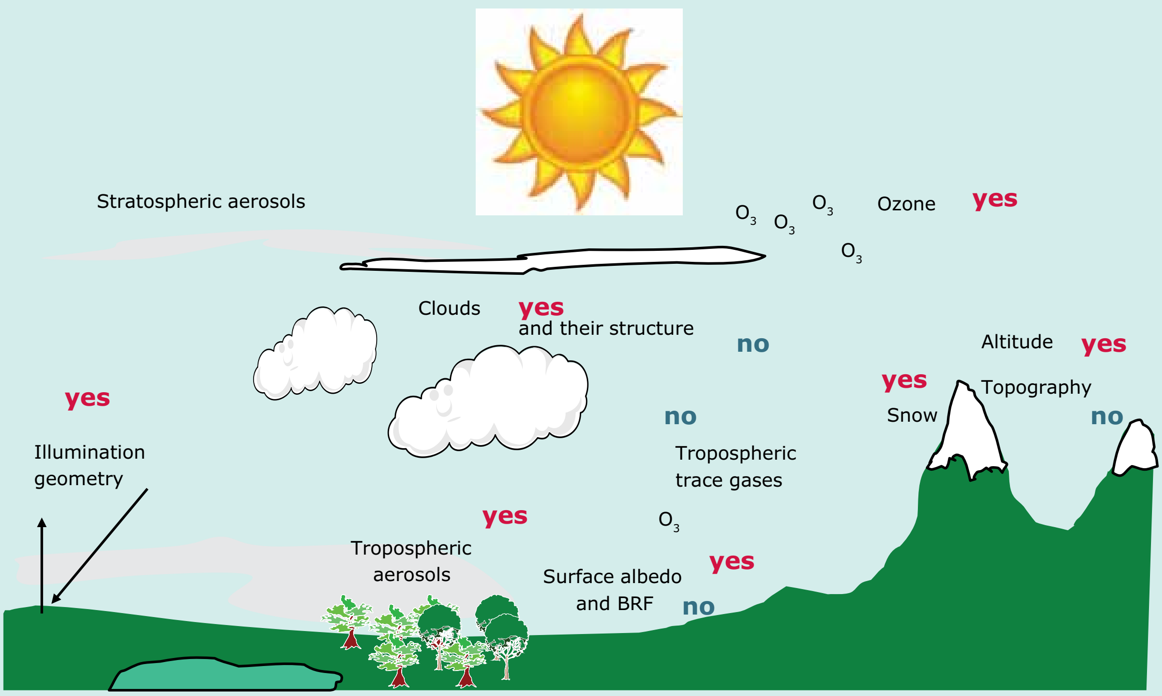
The sun emits energy over a broad spectrum of wavelengths which are expressed in nm. UV radiation covers the range from 100 to 400 nm and is subdivided into:



- UV-C (100–280 nm): the most energetic part, is completely absorbed by stratospheric ozone;
- UV-B (280–315 nm): is strongly absorbed by stratospheric (~ 90 %) and tropospheric (~ 10 %) ozone so that only a small fraction reaches the Earth's surface; more UV-B reaches the surface as the concentration of stratospheric ozone diminishes;
- UV-A (315–400 nm): is only slightly absorbed by stratospheric ozone, and therefore most UV-A radiation reaches the earth's surface.

Only a part of the incident UV radiation reaches the earth's surface. UV-B is of great biological importance because it can damage skin, DNA molecules and some proteins of living organisms, but it is also essential for the synthesis of vitamin D in the human body. Ozone hardly absorb UV-A, and UV-A has much less effect on biological material but, as its intensity is much higher, it also contributes to UV biological effects.

Figure 9.1 Factors influencing UV radiation



Source: Diana Rembges, JRC.

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increased because of a thinning of the stratospheric ozone — 'the ozone hole'. Stratospheric ozone acts as a UV filter (EEA, 1994) and reduces the amount of UV radiation from the sun that reaches the earth. Many Europeans love the sun and being tanned has a positive connotation in European society, particularly in European populations that have a naturally light skin colour. Increased wealth has made the European population more mobile. Many people spend holidays in areas around the equator with high sun intensity and spend many hours in the sun in order to get a tan.

Ultraviolet radiation tanning devices were not widespread or frequently used before the 1990s. The evaluation of health effects related to (caused by) the use of all kinds of tanning devices is therefore still unclear. Due to the long induction time, it will take years before sound data are available to give an answer to the role of tanning devices in inducing skin cancer. By applying a precautionary approach, health authorities in many European Member States advise against the use of sunbeds for tanning since exposure of the general population to UV-radiation should be limited, and especially young persons below 18 years of age and UV-sensitive people (skin type I and II) are strongly recommended not to use sunbeds at all.

9.3 Policy options: increasing awareness is key

The increase in skin cancers is alarming and has led to prevention campaigns informing the public of the dangers of over-exposure to UV and on safe behaviour in terms of protection against solar UV. The importance of protecting children from excess of sun exposure is particularly highlighted. It has also fostered the development of public information on the level of ambient UV radiation. The best-known example is the inclusion of UV-index forecasts in meteorological bulletins. These measures are the object of many national and international initiatives and projects such as WHO INTERSUN (31), ESA GMES PROMOTE UV (32), and EUROSKIN (33). Some European countries are discussing policies to restrict the access and use of solar beds in public places.

(31) WHO INTERSUN http://www.who.int/uv/intersunprogramme/en.
(32) ESA GMES PROMOTE UV http://www.gse-promote.org.
(33) EUROSKIN http://www.euroskin.eu.

10 Nanotechnology

10.1 Nanotechnology is booming

The emerging field of nanotechnology involves the creation and use of new materials and devices with special properties linked to the size and surface properties of small ('nano')particles in the size range 1–100 nm. Nanotechnology is a new discipline that has rapidly gained attention in industry, science and government. The use of nanomaterials has a huge potential and is increasingly applied in a wide range of products, from electronics, textiles and cosmetics to medicine. Nanomaterials are likely to provide benefits in many areas, such as energy supply, food processing, waste treatment, medicine and information technology. Nanotechnology can contribute to purification of air and (drinking) water by employing highly reactive nanoparticles to remove bacterial and chemical contamination. Other possible advantages of nanotechnology are cleaner manufacturing processes and less use of raw materials, more efficient energy production and storage systems, energy saving (e.g. insulation) and improved catalysts for abatement of industrial and vehicle emissions (EC, 2012b).

The global market for nanotechnology is projected to reach USD 26 billion in 2015 with an annual growth rate of 11.1 % since 2009 ([34]). But with this boom in nanotechnology, concerns arise about the potential associated risks. The very properties that promise social, economic and environmental benefits may also pose risks to human health and the environment (JRC-EASAC, 2011). Because of the wide-scale use and diverse emission pathways, many people may be exposed to nanomaterials via inhalation, oral intake and dermal contact. There are relatively limited investigations about whether and how the different types of nanomaterials are taken up via these routes. Some nanomaterials used in medical applications are deliberately injected into the body, where they are found to distribute wider than micro-particles. However, little is known about the actual uptake via other exposure routes, or about the effects of nanomaterials within the human body. Some studies in animals and in-vitro indicate that they can trigger inflammation which may lead to fibrosis and cancer, but more research is needed to better understand the potential toxicity of diverse nanomaterials (SCENIHR, 2009b; Aschberger et al., 2011). A complicating factor is that the materials are often modified (functionalised) to optimise the technical properties, which can change their biodistribution, and thereby also most likely their toxicity (Donaldson et al., 2012).

10.2 Information on exposure pathways is needed

The risk assessment of nanomaterials is still in its infancy, but information about the release, occurrence, environmental fate, and persistence of nanomaterials is fundamental to mapping the potential risks. Developing exposure scenarios requires good knowledge of the production and use of the nanomaterials. Some are mainly embedded or fixed in matrices (e.g. carbon nanotubes), while others are used as 'free' nanomaterials (e.g. silver, titanium dioxide, zinc oxide). Whereas embedded nanomaterials will enter the environment mainly during production, manufacturing and disposal phases, free nanomaterials can also be released into the environment during use of the products containing them (e.g. cosmetic products, cleaning products) (Gottschalk and Nowack, 2011).

Emissions of nanomaterials to air, water and soil need to be measured, as well as their transport and biochemical and physical behaviour in these environmental compartments. As food intake is a plausible route of human exposure, bioaccumulation through the food chain is of concern. Nanomaterials can be adsorbed on the organisms' external (e.g. algae membrane) and internal (e.g. fish gills, worms gut) organs. Furthermore, persistent nanomaterials can be accumulated in tissue along with toxic chemicals (e.g. heavy metals) adsorbed

([34]) http://www.bccresearch.com/report/NAN031D.html.

to the nanomaterials' surface, increasing the overall toxic effect. Data available today are not sufficient to characterise the bioaccumulation potential of the different types of nanomaterials in the food chain. More studies are needed, both on aquatic and on terrestrial organisms, especially on effects from longer exposure times.

Finally, exposure models have to be developed. All data collected about the fate and transport of nanomaterials should be used to define model parameters, which can be based on existing fate and transport models for chemicals and colloids. However, very important parameters used to estimate the fate and transport of chemicals in the environment, such as water solubility, vapour pressure, and partitioning constants (e.g. octanol-water partitioning) are often not available, due to the inherent properties of the nanomaterials or lack of appropriate measuring tools and methods. Research should therefore focus on the determination of appropriate parameters to model the fate and transport of nanomaterials in the environment, as well as on the development of measurement protocols.

10.3 Inclusive governance can help identify and manage risks

Nanomaterials are regulated by REACH because they are covered by the definition of a chemical 'substance' in REACH. The general obligations of REACH therefore apply, as for any other substance; there are no provisions referring explicitly to nanomaterials.

Awareness-raising is high on the policy agenda, as most people are not aware of the specific properties of nanomaterials and the associated risks to human health (EU-OSHA, 2012). The extensive use of engineered nanomaterials is a new phenomenon, with a new terminology and implications beyond existing legislative frameworks. In order to delineate the issue, and to allow meaningful discussion with stakeholders, the European Commission has published, in its Recommendation of 18 October 2011, the following definition: *Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimension is in the size range 1 nm–100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %* (EC, 2011c).

For toxicity testing, the focus should be on types of nanomaterials that are, or will be, manufactured or used in large quantities. Efforts to investigate such priority nanomaterials are ongoing. Within the OECD Working Party on Manufactured Nanomaterial (WPMN), collaboration between industry, regulatory bodies and research institutes has been established to provide physical-chemical, toxicological, and ecotoxicological data for a number of selected nanomaterials. OECD has also established a Working Party on Nanotechnology (WPN) with a more general objective of giving advice on emerging policy issues of science, technology and innovation related to the responsible development of nanotechnology.

Other initiatives will develop standardised platforms to report and store data on the properties and fate of nanomaterials produced by different research projects, improving the ability to compare different studies and providing a reference to identify the minimum information required for safety assessment. The EU framework programmes also support research for the development of sustainable nanotechnologies by focusing on their potential as well as on possible safety issues.

The 2012 Communication on the Second Regulatory Review on Nanomaterials (EC, 2012d) describes the Commission's plans to improve EU law and its application to ensure their safe use. It is accompanied by a Staff Working Paper (EC, 2012b) on nanomaterial types and uses, including safety aspects, which gives a detailed overview of the available information on nanomaterials on the market, including their benefits and risks. Additional information on nanotechnologies in general can be found on the Europa website on nanotechnologies ([35]).

([35]) http://ec.europa.eu/nanotechnology/index_en.html.

11 Green spaces and the natural environment

The significant inequalities in health outcomes seen across Europe cannot be explained by individual, genetic differences only. Dahlgren and Whitehead (1991) have identified a range of factors that influence individual and community health outcomes — these include lifestyle, social, cultural and environmental determinants (Dahlgren and Whitehead, 1991).

Attention to the environmental determinants is growing rapidly. The Millennium Ecosystem Assessment (MA, 2005) introduced the concept of ecosystem services, linking human health and well-being to biodiversity and the functioning of ecosystems. The MA distinguished between provisioning services (e.g. food, fibre), regulating and supporting services (e.g. nutrient, water and carbon cycling) and cultural services (e.g. recreational opportunities). Well-functioning ecosystems thus contribute in multiple ways to human health and well-being. Apart from short-term and immediate relationships, long-term environmental changes, such as global warming, may severely impair safety and well-being through increased risks of heat waves, floods and vector-borne diseases.

Environment and health research and policy domains have traditionally had a much narrower focus, identifying, estimating and preventing adverse health impacts of isolated environmental stressors. However, the integral health benefits of natural ecosystems and access to green spaces are increasingly recognised, due in part to better understanding of ecosystem services (Stone, 2009; Pretty et al., 2011). This is reflected in recent policy initiatives to establish a 'green infrastructure', linking health and well-being concerns to integral ecosystem policy and spatial planning (see Box 11.1).

This chapter addresses the immediate health and well-being benefits of access to green spaces, rather than analysing the more fundamental aspects of ecosystem functioning and its implications for human health and well-being (please refer to Part III for an integrated perspective).

11.1 Access to green spaces offers multiple benefits, especially to urban dwellers

Health appears to be better in people living in greener environments, with agricultural land, forests, grasslands or urban green spaces near where they live (Maas et al., 2006; Greenspace Scotland, 2008a). Access to green space has been shown to increase the longevity of urban senior citizens and encourage social contacts, particularly for low-income people (Takano et al., 2002; HCN, 2004). However, the extent to which these associations are causal and the processes through which the effects might be mediated remain poorly understood (Greenspace Scotland, 2008a; Munoz, 2009).

The growing recognition of the multiple factors behind major public health issues, such as obesity, cancer, mental illness, and other chronic diseases, as well as the ageing of the European population, have generated an increasing interest in the role of residential environments and access to green spaces. Still, the potential of using green space to promote health is not sufficiently exploited, and is occasionally considered as an 'extra', luxury detail in life.

In the EU, the proportion of green space in urban areas differs between Member States (Figure 11.2). Critical for the use of green spaces is their accessibility, quality, safety, and size. Considerable cultural and socio-demographic variations exist both within and between Member States in the perception of green space and attitudes towards its use. Potential risks from green space cannot be completely ignored, including the possibility of contracting vector-borne or other zoonotic diseases or deterioration of local environmental conditions, where green space is poorly managed (Greenspace Scotland, 2008b).

Green space has been shown to contribute to reducing health inequalities. In England, a study of mortality data of more than 300 000 people showed that populations exposed to the greenest environments have the lowest levels of health

Box 11.1 What is green infrastructure and green space?

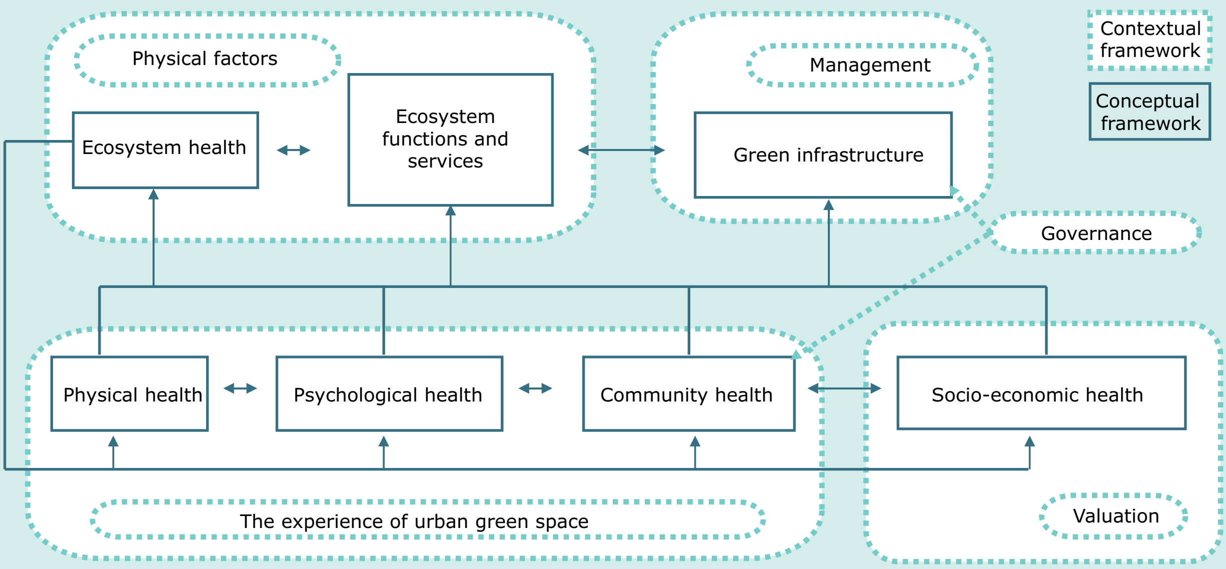
The term **green space** can be applied to any vegetated land or surface water body within or adjoining an urban area, including: natural and semi-natural habitats; countryside immediately adjoining a town which people can access; green corridors — paths, rivers and canals; amenity grassland, parks and gardens; outdoor sports facilities, playing fields, and other functional green space e.g. cemeteries and allotments, or even a derelict and vacant land (Greenspace Scotland, 2008b). The term **green infrastructure** (GI) , however, refers to a **network** of high quality green spaces **planned and managed as a multifunctional resource** capable of delivering a wide range of benefits and services, such as the provision of clean water, productive soil, attractive recreational areas, and climate change mitigation and adaptation (Naumann, McKenna, et al., 2011; EC, 2010a; Naumann, Anzaldua, et al., 2011; Science for Environment Policy, 2012).

While the concept of green infrastructure is still being developed (EC, 2011d), several definitions have been proposed EEA, 2011g (Science for Environment Policy, 2012). One focuses on the structural characteristics and considers GI to comprise 'all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales' regardless of their ownership (Tzoulas et al., 2007). In others, the functional characteristics and policy objectives are made explicit. These describe green infrastructure as a spatial intervention with one or several environmental aims, including ensuring the maintenance and restoration of ecosystem functioning, enhancing ecosystem services, and increasing the connectivity of habitats and the resilience of species populations.

The Green Infrastructure concept can mobilise an array of practices and innovative solutions to enhance overall environmental quality and the provision of ecosystem services (EC, 2011d; EC, 2013a) and is thus instrumental in enhancing human health and well-being.

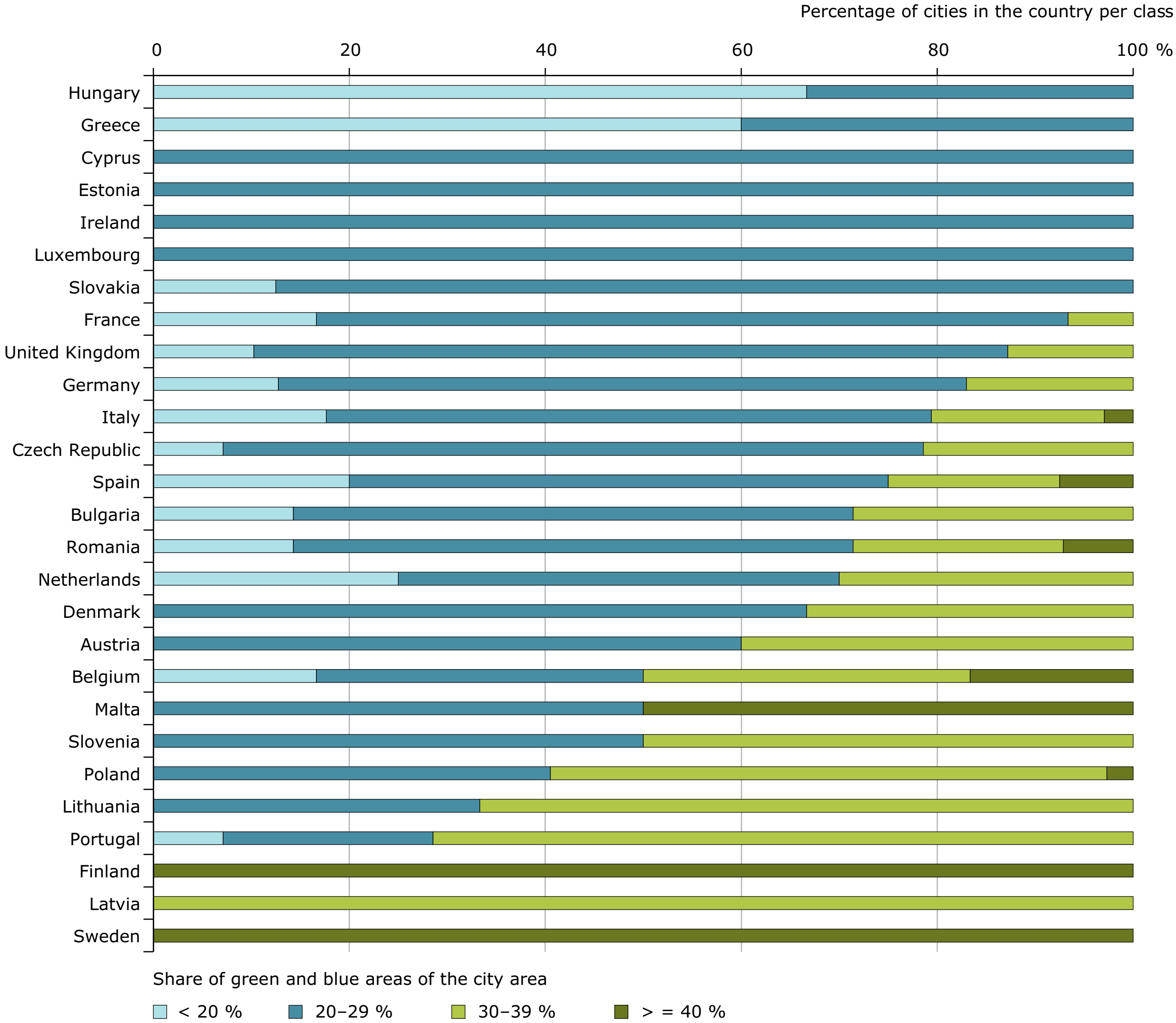
Sources: Greenspace Scotland, 2008b; EEA, 2011c; Naumann, McKenna, et al., 2011; Science for Environment Policy, 2012.

Figure 11.1 Framework linking green infrastructure, ecosystem health and public health



Source: URBAN-NEXUS, 2012 adapted from Tzoulas et al., 2007 and James et al., 2009.

Figure 11.2 The reported and perceived green space in urban areas in Europe



Source: EEA, 2012j.

inequalities related to income deprivation (Mitchell and Popham, 2008). The Strategic Review of Health Inequalities in England post-2010 suggests a social gradient in access to green spaces, with people in lower socio-economic groups accessing green spaces less than those in higher groups (Marmot et al., 2010).

11.2 Contacts with nature improve psychological well-being and social cohesion

Contacts with nature can improve an individual's emotional resilience through stress reduction and recovery from mental fatigue (Velarde et al., 2007). Views of nature can speed up recovery time in hospital patients (Kaplan, 1995; Ulrich, 2002; Hartig and Marcus, 2006), and has a positive effect on recovery from stress and attention fatigue (HCN, 2004). Even brief exposure to a view of nature is beneficial, although less is known about the impact of long-term exposure to nature or the influences of different types of nature (Greenspace Scotland, 2008b; Depledge et al., 2011) such as forests and coastlines, can promote stress reduction and assist in mental recovery following intensive cognitive activities. Settings as simple as hospital window views onto garden-like scenes can also be influential in reducing patients' postoperative recovery periods and analgesic requirements. This paper reviews the evidence supporting the exploitation of these

Figure 11.2 The reported and perceived green space in urban areas in Europe (cont.)

Source: EEA, 2009.

restorative natural environments in future healthcare strategies. The paper also describes early research addressing the development of multisensory, computer-generated restorative environments for the benefit of patients with a variety of psychologically related conditions (including depression, attention deficit disorder, pain, and sleep deficit. Access to safe green-spaces and contacts with wildlife has been shown to be particularly beneficial for exploratory, mental and social development of children and young people, both in urban and rural settings (Munoz, 2009; Louv, 2008).

In many cases, socially-deprived people are disadvantaged with respect to access to green and open spaces in an urban setting. In Scotland, people most satisfied with their local green space tended to be more affluent survey respondents, who used their local green space more, whilst the lowest levels of satisfaction were noted amongst respondents in lower socio-economic groups and living in more deprived areas. However, the relationship between green space and deprivation is complex and not easy to interpret (SNIFFER, 2005).

Green spaces are closely associated with neighbourhood identity, and can encourage social contacts, particularly for low-income people. Studies suggest a positive correlation between the proximity of trees and vegetation and residents' perceptions of well-being and security. Safe and accessible green spaces encourage activities across different social groups and increase the satisfaction of the residents with the local area; there is also evidence of reduced violence and antisocial behaviour (Urban Green Spaces Task Force, 2002; HCN, 2004; Faculty of Public Health, 2010). Community engagement is critical in the development and management of green spaces; if ignored, it can lead to a mismatch with local needs and limited use.

Community gardens, parks and other common areas provide space for recreation, facilitate neighbourhood improvement, and strengthen a sense of community and connection to the environment, thus contributing to an improved sense of health and well-being (Hanna and Oh, 2000). The role of urban allotment gardens in food provision should not be ignored, especially in the context of current discussions on food sustainability and promotion of locally-grown food. There is also a value in (re)connecting urban citizens with nature, and increasing awareness of the value of nature and ecosystems services, such as provision of food or clean water.

The management of green areas can itself enhance relationships and social cohesion in local communities; it should also foresee and prepare for the impacts of climate change. Planting trees and greening the urban environment should be central to local and regional spatial planning.

aiming to exploit the health benefits of time spent in coastal environments (Depledge and Bird, 2009; Wheeler et al., 2012).

11.3 Easy access to green spaces encourages physical activity outdoors

Insufficient physical activity is linked with greater vulnerability to cancers, heart disease, stroke, diabetes, and mental and physical disability (AICR, 2009); Chief Medical Officers, 2011); therefore intense efforts are needed to increase physical activity in the general population to help reduce the burden of chronic disease and morbidity in Europe. According to a Eurobarometer survey, some 27 % of EU citizens report engaging in regular physical activity (at least five times a week), while overall 65 % declare getting some form of exercise at least once a week, with big differences between Member States (Eurobarometer, 2010a).

Parks or other outdoor environments are popular places to exercise. While relationships between green space and physical activity are complex and it is very difficult to reveal cause-effect mechanisms in the observed associations, the attractiveness of green space is likely to provide additional incentives to continue exercising. Efforts are underway to develop tools for the evaluation of green exercise activity (Natural England and the National Institute for Clinical Excellence (Greenspace Scotland, 2008b).

In a European study of eight cities, people living in areas with high levels of greenery were three times more likely to be physically active and the chance of being overweight and obese was about 40 % lower than in people living in similar areas with low levels of greenery. However, people living in areas with high levels of anti-social activities were less likely to be physically active and more likely to be overweight or obese (Ellaway, 2005).

Interest in using green space for exercise is increasing, as physical activity in an outdoor natural environment may bring additional positive effects on mental well-being compared to similar activity indoors (Thompson Coon et al., 2011). In the United Kingdom, more than ten years of experience with Green Gym, a programme developed to encourage people to be more active by engaging in gardening or nature conservation activities, has been successful in increasing people's physical activity. Building on that experience, the Blue Gym programme has been developed

11.4 Improving local environmental quality is an effective way of reducing hazards

Green space can alleviate health-related environmental burdens through improved local environmental conditions, including increased biodiversity and protection against air pollution, noise, soil erosion, flooding, heat, etc. It plays an important role in regulating the micro-climate by providing shade, thermal isolation, and moisture and wind protection. Trees and woodlands can filter and absorb a range of air pollutants, including particulates, heavy metals and gases, and absorb CO_2 (Freer-Smith et al., 2004; Marmot, Allen, et al., 2010). Under certain conditions, green space may amplify the effects of pollution by creating an enclosed space. Vegetation can also contribute to attenuating the effects of noise. The perceived 'better' availability of nearby green areas has been shown to reduce long-term noise annoyance and the prevalence of stress-related psychosocial symptoms, and to increase the use of outdoor spaces (Gidlöf-Gunnarsson

and Öhrström, 2007) 24 h = 60–68 dB. Trees, grass and other urban vegetation have a potential to reduce the risks of flooding as they facilitate the infiltration of rainwater into the ground and can reduce the amount of water run-off. According to some estimates, 1.3 million trees could catch around seven billion tonnes of rain water each year (McPherson et al., 2005).

Green areas can lower the urban 'heat island' effect ([36]); for example in Zaragoza, Spain, differences in urban density and vegetation cover account for 37 % of the thermal variation between the city and its surrounding rural areas (Cuadrat-Prats et al., 2005). That role becomes even more important given current climate change and demographic projections.

11.5 There is a need for adequate tools and methods

While access to natural green environments can offer multiple benefits to health, social well-being and improved quality of life, the mechanisms of these interactions remain unclear. To enhance the use of green infrastructure to foster health and well-being and alleviate inequities, tools and methods are needed to adequately value these benefits, and to improve understanding of the multiple links between biodiverse, resilient ecosystems, and human health and well-being (NCI, 2009; Zaghi et al., 2010).

Evidence is scattered and methods are lacking to quantify the beneficial role of the environment to support and enhance human health and well-being. Substantial knowledge gaps remain in assessing and addressing the multiple functions of green space/infrastructure. A complex process is involved, involving qualitative and quantitative approaches and interdisciplinary work, including environmental psychology, landscape planning, epidemiology, and ecology (Science for Environment Policy, 2012; Sandström, 2002).

Recognition and better appreciation of the benefits can make strong arguments supporting calls to halt biodiversity loss and reduce pressures on ecosystems (and natural capital) to maintain ecosystem services.

11.6 Policy frameworks in relation to green space are largely lacking

There is no dedicated policy framework addressing the human health and well-being benefits of green space/natural environments. There are, however, efforts to integrate green infrastructure into different policy sectors and to promote this concept to support both environmental and non-environmental policy goals. Opportunities are being explored to use existing legislation to promote green infrastructure, for example through the White Paper on Adaptation to Climate Change, Habitats and Birds Directives, Water Framework Directive, Floods Directive, Marine Strategy Framework Directive, and the EIA and the SEA Directives (EEA, 2011c).

Development of a Green Infrastructure Strategy (Action 6) is foreseen in the Biodiversity Strategy, adopted by the European Commission in May 2011, as one of the actions to achieve the Strategy target of halting the loss of biodiversity in the EU by 2020. The Commission work 'to promote the deployment of green infrastructure in the EU in urban and rural areas, including through incentives to encourage up-front investments in green infrastructure projects and the maintenance of ecosystem services, for example through better targeted use of EU funding streams and Public Private Partnerships' (EC, 2011f) was concluded with the adoption of the Green Infrastructure Strategy (EC, 2013a).

In the WHO European Environment and Health process, ensuring access of children to '*healthy and safe environments*', including access to green spaces '*to play and undertake physical activity*' is one of the commitments of the Parma declaration of the 5th Ministerial conference on Environment and Health.

([36]) An urban area which has significantly higher average temperatures than the surrounding (rural) areas; occurs mainly due to the predominance of materials covering the land surface which retain heat.

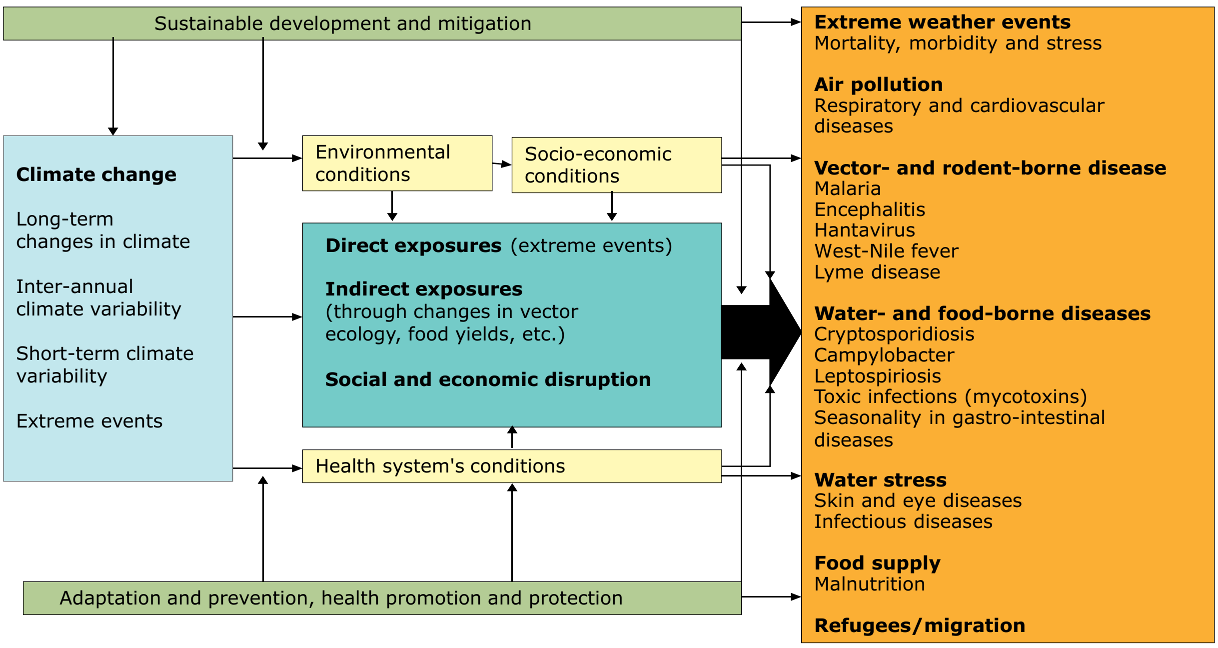
12 Climate change

Climate change may directly or indirectly affect human health via changing weather patterns and extreme events; impacts on ecosystems, agriculture, and livelihoods; exacerbation of existing environmental problems, such as poor air quality, water scarcity and deterioration of water quality; and damage to infrastructure, for example water and energy supplies (Figure 12.1). Climate change is already contributing to the global burden of disease and premature deaths (IWGCCH, 2012; McMichael et al., 2012). In Europe, health effects are related mainly to extreme weather events, changes in the distribution of climate-sensitive diseases, and changes in environmental and social conditions. Current understanding of how climate change could interact with other existing and future environment and health issues remains limited.

In a recent EEA report on climate change impacts, vulnerability and adaptation in Europe (EEA, 2012b), a dedicated chapter, developed jointly with WHO Europe and the European Centre for Disease Prevention and Control (ECDC), provided an overview of climate change-related health issues in Europe, including those linked with extreme weather events, in particular floods and extreme temperatures, air pollution by ozone, and climate change-related vector-, water-, and food-borne diseases. This chapter builds extensively on the information presented in that report (EEA, 2012b).

Climate change can increase or reduce existing health risks, and may introduce new health risks to previously unaffected regions. Globally, adverse impacts are projected to outweigh beneficial ones; in Europe, the health and welfare costs are estimated to be substantial (Kovats et al., 2011; Watkiss and Hunt, 2012). Climate change-related health effects depend largely on population vulnerability and its ability to adapt, linked to ecological, social, economic and cultural factors. Vulnerable population groups include the elderly and children, the urban poor,

Figure 12.1 Impact pathways of climate change on human health



Source: Wolf, 2011, adapted from Confalonieri et al., 2007, in EEA, 2012b.

traditional societies, subsistence farmers, and island and coastal populations (WHO, 2011c). Also some regions, such as the Arctic and the Mediterranean, are particularly vulnerable to climate change.

The links between climate change and health are the subject of intense research in Europe ([37]). Attribution of health effects to climate change is difficult due to the complexity of the interactions, and possible modifying effects of other factors, such as land-use changes, public health preparedness, and socio-economic conditions; uncertainties also need to be carefully considered. The completeness and reliability of available data differs between regions and/or institutions, and may change over time. Quantitative projections of future climate-sensitive health risks are difficult due to the complex inter-linkages between climatic and non-climatic factors, climate-sensitive disease and other health outcomes.

Extreme weather events, such as heat waves, floods, droughts, windstorms, precipitation and storm surges, projected to be more frequent and intense in some regions of Europe, will continue to have impacts on human health and well-being (IPCC, 2007; EEA, 2011e). However, as underlined in a report on managing extreme risks and disasters (IPCC, 2012), factors that shape human vulnerability to extremes are highly complex. While the number of reported extreme weather events in Europe has increased between 1980 and 2011, explanation of trend patterns in weather-related disaster burden, in terms of people affected and economic loss, is difficult, since several interlinked factors play a role. A direct attribution of changes in disaster burden to one specific factor, such as climate change, should be avoided (Visser et al., 2012).

12.1 Flood risk is increasing

River and coastal flooding affect millions of people in Europe each year; health and well-being impacts can occur immediately (e.g., through drowning and injuries), as well as a long time after the event (e.g. through the destruction of homes, water shortages, displacement, disruption of essential services and financial loss), especially through the stress to which flood victims are exposed (Ahern et al., 2005; Paranjothy et al., 2011; Stanke et al., 2012). Estimates for the WHO European Region indicate that floods killed more than 1 000 people and affected 3.4 million others in the period 2000–2009 (WHO, 2013b).

With the projected changes in extreme precipitation and with sea level rise, health risks associated with river and coastal flooding are likely to increase in many regions of Europe. Available estimates indicate that in the absence of adaptation, river flooding could affect 250 000 to 400 000 additional people per year in Europe by the 2080s (WHO, 2008b). For coastal flooding, projections based on different emissions scenarios ([38]) indicate that climate and socio-economic change would lead in the EU to 185 to 650 deaths per year by the 2080s; adaptation measures can substantially reduce these numbers. Uncertainties in those projections need to be carefully considered (Kovats et al., 2011; Watkiss et al., 2012).

12.2 Heat waves and cold spells are a threat to vulnerable population groups

Both heat waves and cold spells have public health impacts in Europe, especially in vulnerable population groups; adverse health outcomes are also linked to temperatures above and below local and seasonal comfort temperatures, with different temperature thresholds throughout Europe.

The heat wave of summer 2003, with around 70 000 heat-related deaths (June–August), mainly in western and central Europe, has probably been the most extensively studied (Robine et al., 2008). However, between 2001 and 2010, several other 'mega-heat waves' were reported, likely to break 500-year-long temperature records over more than 50 % of Europe. In 2010, the summer was exceptionally warm in Eastern Europe and large parts of Russia, with extremely high reported temperatures: daytime (38.2 °C in Moscow), night-time (25 °C in Kiev), and daily mean (26.1 °C in Helsinki). Preliminary estimates for Russia indicate a death toll up to 55 000 (Barriopedro et al., 2011). The probability of a summer with a mega-heat wave may increase by a factor of 5 to 10 within the next 40 years (Barriopedro et al., 2011).

([37]) For example: cCASHh — Climate change and adaptation strategies for human health in Europe; EDEN — Emerging Diseases in a changing European eNvironment; EDENext — Biology and control of vector-borne infections in Europe; Climate-TRAP — Training, Adaptation, Preparedness of the Health Care System to Climate Change; CIRCE — Climate change and Impact Research: the Mediterranean Environment; IMPACT2C — Quantifying projected impacts under 2 °C warming.

([38]) The IPCC Special Report on Emission Scenarios, SRES.

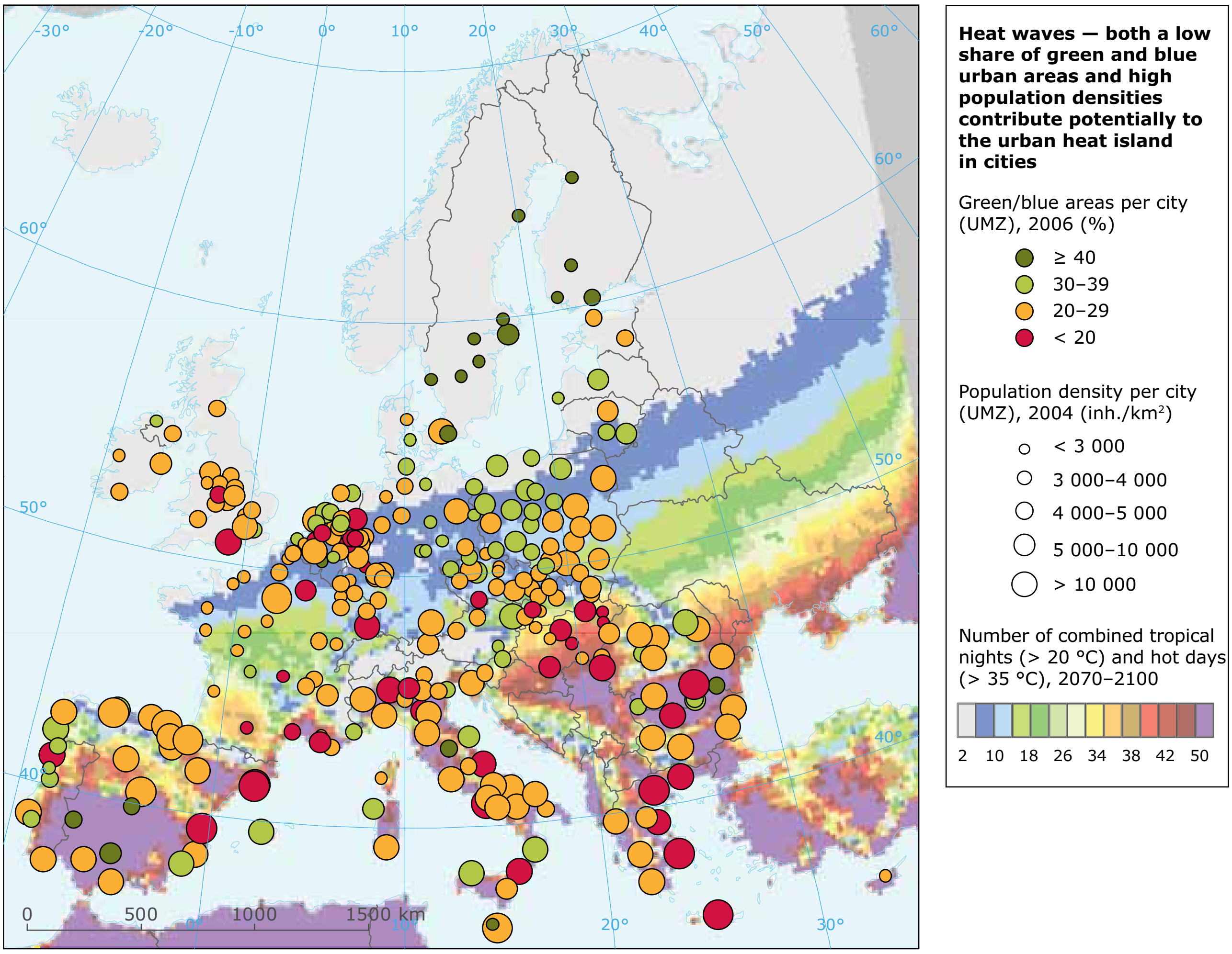
On average, 2 % of deaths during summer can be attributed to heat exposure. In a study of 15 European cities, the largest impact was observed among older people; however, in some cities, an important impact was found for younger adults (Baccini et al., 2011). People with cardio-respiratory diseases are also at higher risk; and deprived population groups are more vulnerable.

In the urban areas with high soil sealing and heat-absorbing surfaces, effects of heat waves can be exacerbated due to insufficient nocturnal cooling and poor air exchange; many factors, including spatial planning and urban green infrastructure, are relevant for the urban heat island effect (Map 12.1). Projected changes in the occurrence of heat waves call for adaptive strategies to efficiently protect the health of the ageing European population.

Extreme cold spells are expected to continue to be a health challenge, even though winter mortality is decreasing in some European countries due to better social, economic and housing conditions. Excess winter mortality in Mediterranean countries is higher than in northern European countries, and deaths often occur several days or weeks after the coldest day (Analitis et al., 2008; Healy, 2003).

The projected progressive change in the seasonality of maximum monthly mortality from winter to summer, as well as an increase in the frequency of warm extremes and in the number of uncomfortable days, could lead (without adaptation) to a reduction in human lifespan of up to 3–4 months by the 2080s (Ballester et al., 2011). Future climate change is very likely to increase the frequency, intensity and duration of heat waves, with marked increase in heat-attributable

Map 12.1 Heat waves — both a low share of green and blue urban areas and high population densities can contribute to the urban heat island effect



Source: EEA, 2012j.

deaths, unless adaptation measures are undertaken (Baccini et al., 2011). Depending on the scenario ([39]), between 69 000 and 127 000 additional heat-related deaths per year in the EU are projected by the 2080s, without adaptation. With acclimatisation, the estimated numbers declines substantially (Kovats et al., 2011). Application of the SRES scenarios to city specific mortality functions in 15 European cities provided estimates of attributable deaths per year, ranging from 2 (Dublin) to 429 (Barcelona), under the 'hottest year' scenario (Baccini et al., 2011).

12.3 Climate change affects health issues related to air quality

Hot weather may exacerbate air pollution through increased formation of ground-level ozone; also more particulate matter remains in the air due to dry conditions. Evidence for synergistic effects of high temperatures and ozone on mortality is increasing (Bell et al., 2005; Medina-Ramón et al., 2006).

Over the past 20 years, no clear trend in the annual mean concentration of ozone was recorded; there was a slight decreasing tendency since 2006 in rural stations, and a slight tendency towards increased concentrations close to traffic. Attribution of observed ozone concentrations and/or changes to individual causes, such as climate change, is difficult. However, a modelling study suggests that climate variability and change have contributed to increased ozone concentrations during the period 1979–2001 in large parts of central and southern Europe (Andersson et al., 2007).

Climate change is expected to affect future ozone concentrations due to changes in meteorological conditions, increased emissions of specific precursors (e.g. increased isoprene from vegetation under higher temperatures) and emissions from wildfires. Projected climate change may affect regions in Europe differently, by increasing average summer ozone concentrations in southern Europe and decreasing them over northern Europe and the Alps (Andersson and Engardt, 2010; Langner et al., 2012). Preliminary results indicate that in a long-term perspective (2050 and beyond), envisaged emission reduction measures of ozone precursors will have a much larger effect on concentrations of ground-level ozone than climate change (Langner et al., 2011).

In addition to 'traditional' chemical air pollutants, biological particles, including pollens, may pose bigger health threats. Climate change is already affecting the quantity, temporal and spatial distribution, and allergenic properties of pollen, with impacts on allergic diseases (Box 12.1). Higher temperatures and CO_2 concentrations facilitate earlier and longer vegetation and pollination seasons. For example, in 2002 British plants were flowering 4.5 days earlier than ten years earlier (Shea et al., 2008). Higher quantities of pollen are produced by many plants in response to rising CO_2 concentrations and temperature (Corden and Millington, 2001; Wayne et al., 2002).

12.4 Diseases may spread more easily as a result of climate change

Climate change is likely to affect the spread of water-borne, food-borne and vector-borne ([40]) diseases in Europe, as many pathogens, vectors, and non-human reservoir species are climate-sensitive. Nearly half of over 50 infectious diseases currently reportable in the EU can be directly or indirectly affected by climate change; several other climate-sensitive diseases are considered to be emerging infectious diseases due to climate change (Lindgren et al., 2012) (Figure 12.2). Recently, TBE was included in the list of notifiable diseases in the EU (Amato-Gauci and Zeller, 2012).

In addition to climate change, other drivers affect the transmission and emergence of infectious diseases in Europe. These include social, demographic, and economic conditions; globalisation of trade and travel; ecological changes in terms of land-use patterns and biodiversity; access to health care, human immunity, early detection systems and adaptive capacities.

Climate change may shift the distribution range of ticks, vectors of the Lyme disease and tick-borne encephalitis (TBE) towards higher latitudes and altitudes; range shifts have already been reported in Sweden, the Czech Republic, Norway and Germany (Lindgren et al., 2000; Daniel et al., 2003; Semenza and Menne, 2009). Lyme borreliosis is the most common vector-borne disease in the EU, with almost 85 000 cases reported annually; some 2 900 cases of TBE are reported every year in the EU. However, these numbers need to be considered with care due to difficulties in diagnosis and case definition

([39]) The IPCC Special Report on Emission Scenarios, SRES.

([40]) Diseases transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, sandflies, etc.

Box 12.1 Allergenic pollens pose additional health threats in a changing climate

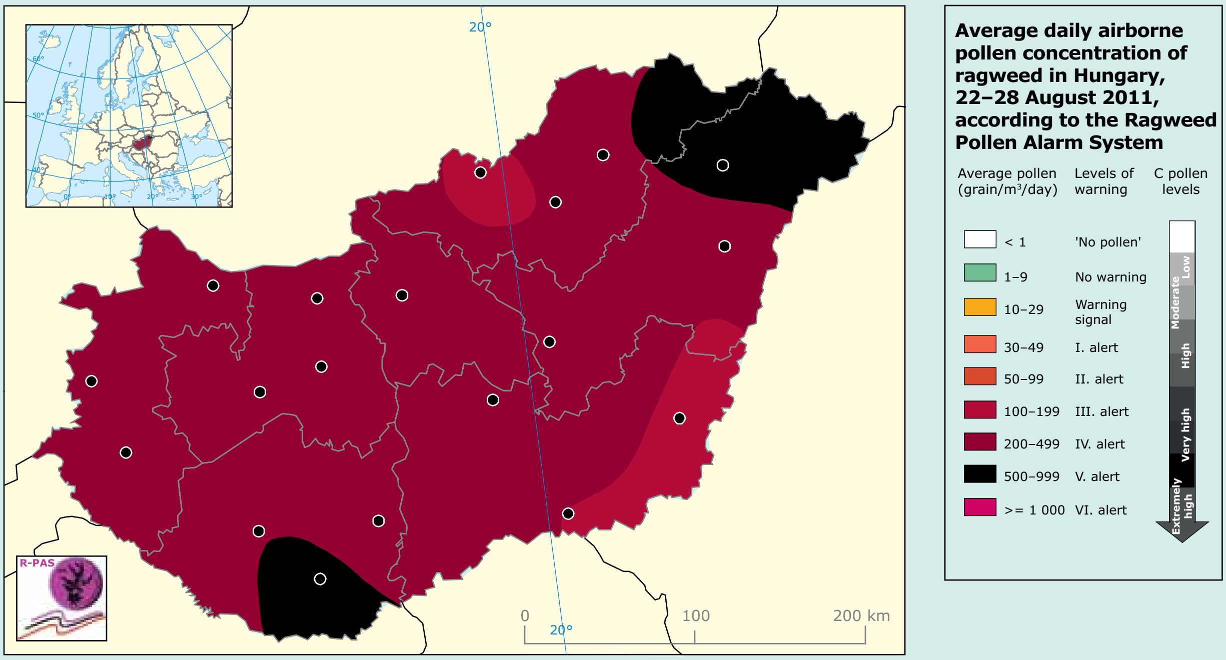
Changing climate is likely to affect the distribution and pollen season of allergenic plants, such as the common ragweed (*Ambrosia artemisiifolia* L.). This invasive plant, found in the temperate zones of Europe, produces enormous amounts of very small, highly allergenic pollen grains, which can be transported over long distances by wind.

Ragweed, introduced to Europe in mid-1800s, started its expansion in 20th century. It is spread mainly due to anthropogenic activities; most affected are agricultural fields with intensive cultivation, fallow lands, ruderal and seminatural habitats, industrial areas, roadsides and river banks. The most abundant country is Hungary, but large masses are also found in Ukraine, Romania, some parts of Croatia, France, Italy, Serbia, Slovakia, Slovenia, and more recently in Austria. The climatic conditions are likely to play a role in this spread.

In Hungary, land use changes following the political change in 1989 affected the spread of ragweed. It is currently an important environment and health issue; every fifth person is estimated to be sensitised to ragweed pollen. Besides direct health impacts, ragweed negatively affects crop yields, tourism, and can pose a risk for food security. Since 1992, the airborne pollen concentration is monitored by the Hungarian Aerobiological Network (HAN). The Hungarian Ragweed Pollen Alarm System (R-PAS) of the National Public Health Service issues weekly warnings during the season, depending on the estimated average daily airborne concentrations of ragweed pollen. The daily concentrations of ragweed pollen may exceed even 1 000 grains/m^3 in the peak days of the season, which results in the 'very high' concentration categories (≥ 100 grains/m^3), typical, on average, during these weeks. This is especially the case in the north-eastern and the south-western parts of the country, where the Pannonian climatic character mixes with the Continental and sub-Mediterranean effects (Map 12.2).

Source: Mányoki, G.; Apatini, D.; Novák, E.; Magyar, D.; Elekes, P. and Páldy, A. National Institute of Environmental Health, Hungary.

Map 12.2 The estimated distribution of the average daily airborne pollen concentration of ragweed in Hungary, 22–28 August 2011, according to the R-PAS



Note: The colours on the map specify the three alert levels of 'very high' concentration category: from the 'III. alert' (claret) to the 'V. alert' (black). Considering that each allergic person exhibits symptoms at a concentration of ragweed pollen grains 30/m^3, the magnitude of the problem caused by the concentrations above 100 and 500 grains/m^3, respectively, is obvious. The III. alert means: *worsening symptoms with the note that in some cases the daily concentration is extremely high, which can produce serious symptoms*. The level V. means: *significant impairment of quality of life associated with acute symptoms*.

Source: Ragweed Pollen Alarm System (R-PAS/ PPRR) by the National Public Health Service of the Hungarian National Institute of Environmental Health (NIEH) and the Hungarian Aerobiological Network (HAN).

Figure 12.2 Weighted risk analysis of climate change impacts on infectious diseases in Europe

Probability of an outbreak; strength of climate change-disease relationship	Low	Medium	High
High		***Vibrio* spp.** (except *V. cholerae* O1 and O139) **Visceral leishmaniasis**	**Lyme borreliosis**
Medium	Crimean-Congo Hemorrhagic fever (CCHF) Hepatitis A Leptospirosis Tularaemia Yellow fever	Campylobacteriosis **Chikungunya fever** Cryptospiridiosis EHEC/VTEC Giardiasis Hantavirus **Rift Valley fever** Salmonellosis Shigellosis	**Dengue fever** **Tick-borne encephalitis (TBE)**
Low	Anthrax Botulism Listeriosis Malaria Q fever Tetanus	Cholera (01 and 0139) Legionellosis Meningococcal infection	

Severity of consequence for society/risk group

Source: ECDC, 2012.

(ECDC, 2011). There has been a marked upsurge in TBE in recent years, but it is impossible to assess the relative importance of climate change and of other factors influencing disease incidence, including vaccination coverage, tourism patterns, public awareness, distribution of rodent host populations, and socio-economic conditions (Randolph, 2008). There is limited evidence that two other tick-borne diseases may be sensitive to climate change, but demographic factors and land-use change may be more important drivers. Further expansion of ticks to higher altitudes and latitudes is projected, provided the natural hosts (deer) of ticks also shift their distribution (Jaenson and Lindgren, 2011). A future rise in TBE could be offset by vaccination programmes and improved surveillance. Warmer winters may facilitate the expansion of Lyme borreliosis to higher latitudes and altitudes, particularly in northern Europe (Semenza and Menne, 2009).

Mosquito-borne diseases have not been a substantial concern within Europe; however recent years have seen small but locally transmitted outbreaks of Chikungunya, Dengue, West Nile fever, and even malaria (ECDC, 2011, 2012d). Also periodical outbreaks of leishmaniasis, a sand-fly transmitted disease, have been reported in the south of Europe. The Asian tiger mosquito (*Aedes albopictus*), an important vector transmitting viral diseases, including Chikungunya and Dengue, has substantially extended its range in Europe since 1990s. It is present in several EU Member States and in some neighbouring countries; even larger parts of Europe are climatically suitable (ECDC, 2009). Some parts of Europe are currently climatically suitable to Aedes aegypti, a primary vector for Dengue. Mosquito habitats are influenced by temperature, humidity and precipitation levels. The climatic suitability for *A. albopictus* is projected to increase in central and western Europe and to decrease in southern Europe (Fischer et al., 2011). the risk of Chikungunya may also increase, particularly in those regions in Europe where the seasonal activity of *A. albopictus* matches the seasonality of endemic Chikungunya infections abroad (Charrel et al., 2008). There could be a small increase in risk of Dengue in Europe; however further modelling studies are needed to assess whether climate change would increase or decrease the climatic suitability for *A. aegypti* in continental Europe (ECDC, 2012b, 2012c).

The risk of reintroducing malaria into Europe is very low and determined by variables other than climate change. Several other vector-borne diseases may also be influenced by climate change, but the evidence is limited. The evidence of an impact of climate change on the distribution of sandfly, a vector transmitting leishmaniasis, in Europe is scarce (Ready, 2010). Future climate change could impact on the distribution of leishmaniasis by affecting the abundance of vector species and parasite development. The risk of disease transmission may decrease in some areas in southern Europe where climate conditions become too hot and dry for vector survival.

12.5 Climate change is likely to affect food and water safety

Climate change could affect water- and food-borne diseases in Europe through higher air and water temperatures, heavy rainfall episodes, and extreme events such as flooding, which can lead to contamination of drinking, recreational and irrigation water and to disruption of water supply and sanitation systems (WHO, 2011a; ECDC, 2012a). Potential health impacts will be modulated by the quality of safety measures throughout the food chain, the capacity of water treatment systems, human behaviour, and a range of other conditions. While a range of water- and food-borne diseases is climate-sensitive, attribution of past disease trends or individual outbreaks to climate change is not possible (Semenza et al., 2012).

Salmonellosis is an important food-borne disease in Europe. Ambient seasonal temperatures are suspected drivers of reported salmonellosis cases, but an influence of higher temperature might be attenuated by public health interventions (Lake et al., 2009). Salmonellosis has continued to decline in Europe over the past decade, in part due to control measures; thus, health promotion and food safety policies should be able to mitigate public health impacts. By the 2080s, climate change could result in up to 50 % more temperature-related cases than would be expected on the basis of population change alone. However, these estimates need to be interpreted with caution, due to high uncertainty (Watkiss et al., 2012).

Viral food-borne diseases, such as norovirus have been linked to climate and weather events. The magnitude of rainfall has also been related to viral contamination of the marine environment and peaks in diarrhoea incidence (Miossec et al., 2000). The predicted increase of heavy rainfall events under climate change scenarios could lead to an increase in norovirus infections. High ambient temperatures and relatively low humidity have been linked with increased incidence of campylobacteriosis (Patrick et al., 2004; Lake et al., 2009). With the projected increase in heavy rainfall events in northern Europe, the risk of surface and groundwater contamination is expected to rise. Climate change might also increase the use of rainwater during times of drought in certain locations; in such circumstances, *Campylobacter* in untreated run-off water might contribute to an increased risk of both animal and human disease (Palmer et al., 1983; Savill et al., 2001). Heavy rainfall has been associated with the contamination of water supplies and outbreaks of cryptosporidiosis (Aksoy et al., 2007; Hoek et al., 2008). The concentration of *Cryptosporidium* oocysts in river water increases significantly during rainfall events. A rise in precipitation is predicted to lead to an increase in cryptosporidiosis, although the strength of the relationship varies by climate category (Jagai et al., 2009).

There is evidence of a link between elevated summer (water) temperatures, extended summer seasons and non-cholera *Vibrio* sp. infections, but the disease or increase is projected to be modest due to low current incidence rates. The recent analysis of the long-term sea surface temperature data revealed an unprecedented rate of Baltic Sea warming (0.063–0.078 °C per year from 1982 to 2010), and found strong links between the temporal and spatial peaks in sea surface temperatures and the number and distribution of *Vibrio* infections in the Baltic Sea region (Baker-Austin et al., 2012).

Complex relationships between climate change and other drivers of infectious diseases call for new approaches to diseases surveillance, including better linking of the notification systems of human infectious diseases with those on animal and plant diseases, as well as with relevant environmental monitoring and reporting systems (Lindgren et al., 2012; ECDC, 2012a).

12.6 Climate change mitigation has co-benefits for health

Many actions to reduce climate change can yield benefits for health and environment, as well as for the economy and society. For example, improving access to public transport and encouraging walking and cycling would greatly reduce CO_2 emissions, and reduce the health impacts of outdoor air pollution and deaths from traffic accidents, and of physical inactivity. Measures to reduce greenhouse gas emissions through cleaner fuels and improved energy efficiency can affect emissions of health-relevant air pollutants such as nitrogen oxides, sulphur dioxide and fine particles.

A systematic analysis of potential health co-benefits of climate change mitigation, as well as of health risks and trade-offs from strategies to reduce climate change across sectors, is not yet available. However, a number of dedicated studies exploring the health co-benefits is growing. WHO analysed the health co-benefits of climate change mitigation in the transport, health, and household energy sectors (WHO, 2011b). In the EU, reducing Europe's greenhouse gas emissions by 20 % by 2020 was estimated to result in health savings worth up to EUR 52 billion per year (HEAL/HCWH, 2010).

Emission reductions and the associated improvements in air quality could by 2050 extend average life expectancy in the EU by 1 month, under the mitigation scenario (E1). In addition, ozone-related deaths in the EU could decrease by 3 400 per year, and the annual number of cases of chronic bronchitis and hospital admissions could be reduced by 27 000 and 20 000 respectively (Holland et al., 2011).

The health and environmental benefits of reduced consumption of red and processed meat were recently assessed. The modelling study from the United Kingdom (using a counterfactual population with higher proportion of vegetarians and low meat-consumption pattern) concluded that reduced dietary intake of meat would reduce the incidence of coronary heart disease, diabetes mellitus and colorectal cancer in the UK population by 3–12 %; the predicted reduction in food-and drink-associated GHG emissions would reach almost 28 million tonnes of CO_2 equivalent/year across the population (Aston et al., 2012).

In 2009, a set of international studies examined the health implications of actions in both high-income and low-income countries designed to reduce emissions of carbon dioxide and other greenhouse gases, focusing on several sectors: household energy use, urban land transport, electricity generation, and food and agriculture (Friel et al., 2009; Haines et al., 2009; Markandya et al., 2009; Smith et al., 2009; Wilkinson et al., 2009; Woodcock et al., 2009). Health co-benefits of actions to address climate change were shown to offset at least some of the costs of climate change mitigation. Several examples relevant to Europe include:

- improvements in household energy efficiency could have modest health benefits in the United Kingdom, mainly through improved indoor temperature and air quality;

- reduction of motor vehicle use through more walking and cycling would not only diminish emissions of GHGs but also contribute to reducing the rates of obesity and chronic diseases caused by physical inactivity, lessen the health-damaging effects of air pollution, and make the roads safer for the users;

- in London, more active travel (walking and cycling) could result in a 10–20 % fall in heart disease and stroke, reductions in breast cancer (12–13 %), dementia (8 %), and depression (5 %). Combining increased active travel with low-emission vehicles would bring greater benefits by further reducing air pollution;

- a 30 % fall in the adult consumption of saturated fat from animal sources would reduce heart disease in the population by around 15 % in the United Kingdom. If additional health outcomes such as obesity and diet-related cancers are considered, the health gains would be even more substantial.

When assessing climate mitigation and adaption measures, health aspects should be considered from an early stage of planning in order to maximise the co-benefits for health and prevent potential trade-offs.

12.7 Global mitigation measures are accompanied by regional and national adaptation strategies

At the global level, climate change is being addressed by the United Nations Framework Convention on Climate Change (UNFCCC). As assessed by (IPCC, 2007), emissions of carbon dioxide and other greenhouse gases (GHGs) must be halved by 2050 (as compared with 1990 levels) to keep global warming below 2 °C. In 2009, an agreement was reached to limit the global mean temperature increase since pre-industrial times ([41]) to less than 2 °C (UNFCCC, 2009 ([42])). The '2° C target' will be reviewed in 2015, to consider a possible goal of limiting global temperature increase to 1.5° C. The EU supports an objective to reduce GHG emissions of developed countries by 80–95 % by 2050.

The UNFCCC's Kyoto Protocol from 1997 set legally binding emission targets for the developed countries that have ratified it, such as the EU Member States, for the first commitment period from 2008 to 2012. The EU is on track to achieve its target ([43]). In 2011, the UN climate conference ([44]) agreed a roadmap towards a new 'protocol, another legal instrument or an agreed outcome with legal force' by 2015, applicable to all Parties to the UN climate convention, foreseeing also a second commitment period of the Kyoto Protocol, starting in 2013.

([41]) Pre-industrial being defined as 1850–1899.
([42]) UNFCCC, 2009. Copenhagen Accord, 18 December 2009, UNFCCC secretariat, Bonn.
([43]) http://www.eea.europa.eu/pressroom/newsreleases/higher-eu-greenhouse-gas-emissions.
([44]) http://unfccc.int/meetings/durban_nov_2011/meeting/6245/php/view/decisions.php.

Box 12.2 The European Climate Adaptation Platform

Climate-ADAPT ([45]) is a publicly accessible, web-based platform, designed to support policy-makers at EU, national, regional and local levels in the development of climate change adaptation measures and policies.

Launched in March 2012, it helps users to access, disseminate and integrate information on:

- expected climate change in Europe;
- the vulnerability of regions, countries and sectors now and in the future;
- information on national, regional and transnational adaptation activities and strategies;
- case studies of adaptation and potential future adaptation options;
- online tools that support adaptation planning;
- adaptation-related research projects, guideline documents, reports information sources, links, news and events.

Climate-ADAPT is hosted and managed by the EEA, in collaboration with the European Commission and supported by the European Topic Centre on Climate Change impacts, vulnerability and adaptation; it is linked to other European information platforms on water (WISE) and biodiversity (BISE).

Source: EEA, 2012b.

Since the publication of the Adaptation White Paper by the European Commission (EC, 2009) on how the EU and its Member States should adapt to climate change, a range of initiatives have been taken to integrate and mainstream adaptation into EU sectoral policies, including on human health. An overview of the main policy developments is available through the European Climate Adaptation Platform (Climate-ADAPT) (Box 12.2).

The EEA has supported the development of EU and national adaptation policy, among others, by co-developing the Climate-ADAPT and by publishing several reports (EEA, 2011e, EEA, 2012b, EEA, 2012j, EEA, 2013c).

In April 2013, the European Commission released the *EU Strategy on adaptation to climate change* (EC, 2013a), with the following objectives:

- Promoting action by Member States through:
  - encouraging all Member States to adopt comprehensive adaptation strategies;
  - providing LIFE funding to support capacity building and adaptation action in Europe;
  - introducing adaptation in the Covenant of Mayors framework.
- Better informed decision-making through:
  - bridging the knowledge gap and
  - further developing Climate-ADAPT as the 'one-stop shop' for adaptation information in Europe.
- Climate-proofing EU action by promoting adaptation in key vulnerable sectors through:
  - facilitating the climate-proofing of the Common Agricultural Policy, the Cohesion Policy and the Common Fisheries Policy;
  - ensuring more resilient infrastructure;
  - promoting insurance and other financial products for resilient investment and business decisions.

The Strategy (EC, 2013b) is accompanied by a Commission *Staff Working Document Adaptation to climate change impacts on human, animal and plant*

([45]) http://climate-adapt.eea.europa.eu.

health (EC, 2013c) that addresses a range of direct and indirect human health impacts, including:

- extreme weather events;
- food- and vector-borne diseases;
- feed and food safety issues;
- water-related issues;
- air quality;
- allergies;
- ultraviolet radiation;
- health inequalities;
- vulnerable groups; and
- environmentally induced migration.

Sixteen EEA member countries to date have developed national adaptation strategies, most of which include considerations of human health; some of them already have action plans in place (EEA, 2013a).

Mainstreaming of climate change is also a critical element of the draft 2014–2020 Multi-annual Financial Framework, which includes a proposal for increasing the share of climate-related expenditure (i.e. for climate change mitigation and adaptation as a whole) to at least 20 % of the EU budget ([46]).

At the pan-European level, activities on climate change and health are part of the WHO Environment and Health process. WHO has developed guidance on heat–health action plans, and issued public health advice on preventing the health effects of heat, which can be adapted to a particular national or regional context (WHO, 2011c). The Regional Framework for Action aiming to protect health, promote health equity and security, and provide healthy environments in a changing climate was welcomed in the 2010 Parma Declaration on Environment and Health. Support to global WHO efforts aimed to eradicate food-, water-, and vector-borne diseases in equatorial and sub-equatorial countries also plays a role.

([46]) http://ec.europa.eu/budget/reform.

Part III Final reflections

13 Analytical and policy considerations

13.1 Complex environmental and health challenges require systemic policy approaches

The increasing complexity of environment and health issues hampers policy responses that need to address a wide range of sectors in a consistent way. Policies in the environment and health domain have traditionally been motivated from an environmental angle, using health concerns as an argument for improving environmental quality. Sectoral policies in the areas of, for example, air quality, water quality or chemicals, all have some human life quality aspects as ultimate motives. Overall, however, these sectoral policy responses to health issues tend to be fragmented, addressing individual substances and issues separately. The limitations of this approach become particularly apparent in the chemicals area, where literally thousands of potential stressors would have to be examined and dealt with separately.

The current, predominantly hazard-focused and compartmentalised approach to environment and health is clearly insufficient to address interconnected and interdependent challenges such as climate change, depletion of resources, ecosystem degradation, the obesity epidemic, and persistent social inequality (Morris, 2010). There is a clear need for an integral perspective on environment and health, focusing not so much on 'end-of-pipe' solutions for individual substances, but rather on systemically reducing human exposure to multiple environmental stressors. Our needs and consumption patterns drive resource use, whereas our trade and settlement patterns largely determine the extent to which we are exposed to the environmental consequences. The policy focus therefore needs to be widened to social and other policy domains, such as consumption, resource efficiency, natural capital, ecosystem services and spatial planning.

13.2 An ecosystem perspective is helpful in analysing complex system interactions

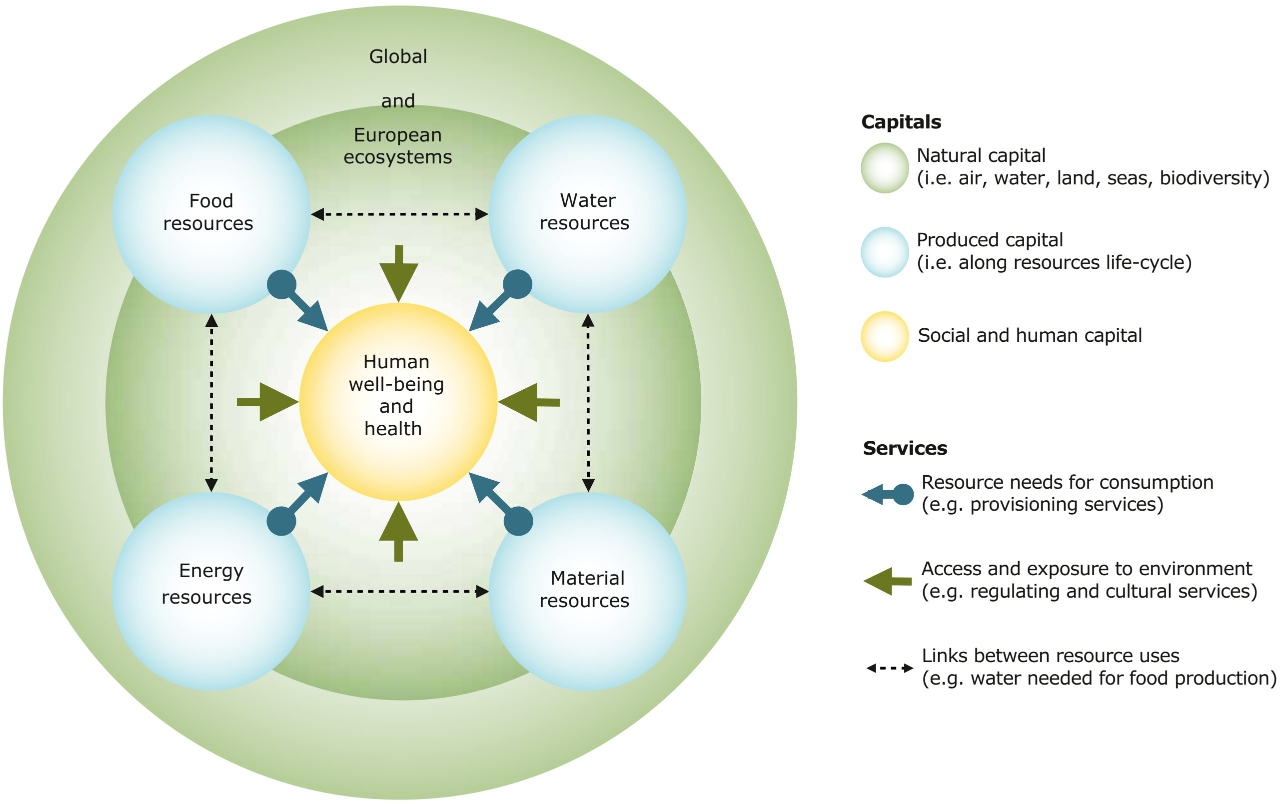
As argued convincingly in the Millennium Ecosystem assessment (MA, 2005), human health and well-being ultimately depend on well-functioning ecosystems and the way we use our natural resources. These resources can be roughly classified into four major categories: food, water, energy and (other) materials. All affect human well-being **directly**, and their supply is therefore subject to strong (sectoral) policy interventions (EEA, 2010d, 2012c). The exploitation of these different resource categories is highly interdependent. These interdependencies lead to synergies and trade-offs that **indirectly** affect human health and well-being, often through impacts on the environment (Figure 13.1).

Food production, for example, requires, water, energy and, increasingly, chemicals such as pesticides and herbicides. Measures to boost agricultural productivity — to meet growing food demand — may have negative effects on water resources, both in qualitative and quantitative terms. Irrigation adds to water stress, particularly in southern European regions, potentially jeopardising water security. Pesticide residues end up in surface water and groundwater bodies, threatening drinking water safety. Similar trade-offs exist in other policy areas, such as energy and climate change mitigation.

13.3 Synergies and trade-offs of policy measures need to be considered...

Climate mitigation is an area where the complex synergies and trade-offs of policy initiatives are particularly obvious. Mitigation polices are high on the European agenda, nursed by two other priority areas, the Energy Efficiency Strategy and the Resource Efficiency Roadmap. These initiatives are in principle synergetic, but implementing them in a consistent way across policy domains is far from straightforward. A shift towards renewable (bio-based) energy, for example, may

Figure 13.1 The key natural resources supporting human health and well-being



Source: EEA, 2012c.

have consequences for food security and human well-being, as energy cropping increasingly competes with food production. Where it replaces extensive farming systems, a negative side-effect on biodiversity and landscape amenity values can also be expected, for example affecting recreation opportunities.

The promotion of fuel-efficient cars through tax incentives is another example of a climate change mitigation initiative with unintended side-effects on the environment and on human health and well-being. Diesel cars are relatively fuel-efficient in terms of CO_2 emissions per km, but they emit considerably more NO_2 than petrol cars equipped with catalytic converters. There are indications that the rapidly increased share of fuel-efficient diesel cars in the car fleet — driven by tax incentives increasing from about 15 % in the early 1990s to 50 % now — has increased NO_2 emissions from traffic (ACEA, 2012; EEA, 2012g). This has repercussions for human health, as current NO_2 concentrations found in cities of Europe and North America can be associated with reduced lung function (Krzyzanowski, 2008). Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase with long-term exposure to NO_2.

In the case of energy-efficient lamps there is a potential trade-off with human exposure to mercury, as these lamps contain mercury that is emitted to the environment when a lamp breaks or is disposed of inappropriately. Traditional light bulbs have been phased out since 2009 and are currently subject to a marketing ban. By 2020 this measure is estimated to save enough energy to power 11 million extra households and reduce carbon dioxide emission by 15 million tonnes per year (EC, 2009a). Coal burning for energy production is also one of the main emission sources of mercury. The impact assessment of an implementing measure under the framework eco-design directive estimated that the reduction in coal-produced electricity with low-energy lamps would lead to a reduction in mercury emissions to the environment that outweighed the additional exposure introduced with the lamps themselves. What the assessment did not account for is that mercury emission from power production is a point source emission that could be abated with technology. By contrast, low energy lamps in all private homes, workplaces and public places pose a considerable diffuse pollution risk that will be hard to mitigate.

13.4 …and global aspects of resource use need to be addressed

Matching natural resource use with human demands and avoiding risks to human health and well-being is thus a complex puzzle, with many interdependencies and environmental feedbacks. Particularly challenging is the external perspective: the global footprint of our resource use, and our vulnerability to global feedbacks. Our dependence on fossil fuels, mining products and other imports contributes to environmental pressures outside Europe. Between 20 and 30 % of the resources used in Europe are imported. Conversely, trends in other parts of the world are increasingly felt closer to home through, for example, climate change and intensified socio-economic pressures (EEA, 2010b).

Household consumption, particularly in the areas of food and drink, housing and transport, is an important driver of environmental pressures. In 2007, approximately 74 % of greenhouse gas emissions, 74 % of acidifying emissions, 72 % of tropospheric ozone precursor emissions and 70 % of the direct and indirect material input globally were caused by private consumption in the EU-27 Member States. Resource efficiency gains have been made, but they have been partly offset by an absolute consumption increase. Since 2000, for example, energy efficiency of housing has improved, but this trend has been largely offset by an increase in housing space per person. A similar development can be seen in transport, where increased fuel efficiency of cars is more than compensated for by increased mobility (EEA, 2012f).

From an environment and health perspective, waste generation is a major issue. While total waste volumes in the EU have fallen slightly and recycling rates of municipal waste have more than doubled since 1995, each citizen still generates on average 5 tonnes of wastes per year. Waste from electrical and electronic equipment (WEEE) is of growing concern, since it may contain hazardous chemicals, especially heavy metals, flame retardants and ozone-depleting compounds (Wäger et al., 2012). Possible adverse impacts result mainly from the poor management of WEEE and occur mainly outside Europe (Zheng et al., 2008; Tsydenova and Bengtsson, 2011). There is evidence that WEEE contaminants may be present in some agricultural or manufactured products for export, suggesting that there are also problems inside Europe (Robinson, 2009). Chemicals from hazardous wastes may be a relevant source locally, via contaminated soil or water.

The extensive use of antibiotics in human and veterinary medicine is another area of concern, as it promotes the development and spread of multi-resistant bacteria world-wide. Releases into the environment of high concentrations of antibiotic substances from drug manufacturing site are reported from China and India (Kristiansson et al., 2011; Li et al., 2010). In India, the effluent from a drug production unit contained up to 31 mg/L of antibiotics (ciprofloxacin), leading to unprecedented contamination of surface, ground and drinking water (Larsson et al., 2007). Adverse developmental effects were observed in tadpoles and zebrafish embryos exposed to effluent concentrations equivalent to those in river water downstream of the plant (Larsson and Fick, 2009). These findings raise concerns for the local wildlife and ecosystems, as well as for little-studied potential effects on human health. Due to the risk of development and rapid global transmission of resistant pathogens, the ultimate consequences of high environmental releases of antibiotics need to be thoroughly addressed (Kristiansson et al., 2011). More open supply chains are needed to ensure that consumers in developed countries know whether or not medicines are made in an environmentally sustainable way (Larsson et al., 2009).

13.5 Governance strategies will critically depend on sound and accessible information

To protect and sustain human health and well-being, future efforts to improve the quality of the environment will need to be complemented by other measures, including significant changes in lifestyles, human behaviour, and consumption. This also implies a stronger need for a multidisciplinary and multi-stakeholder dialogue to take account of values and attitudes. Tensions might occur between the available evidence and societal values and perceptions of relevant environmental challenges, especially in the context of human health. Perception and attitudes of people matter, as they underpin behaviour, which may in turn impact both the environment and health (NCI, 2009).

A broader framing of environment and health also requires a change in traditional governance approaches. It can no longer focus either solely on protecting ecosystems from people or protecting people from environmental threats. Instead, people need to be considered in the context of their ecosystems, and the key should be interactions between ecosystems and society, including positive aspects. This might affect the way people interact with their environment, and help to move *from passive engagement (people receiving benefits from ecosystem services) to active (people getting involved)* (NCI, 2009). Recognition of mutual interactions between humans and ecosystems is the core of the 'eco-health' concept, which argues that human health and well-being do not only depend on ecosystems, but are also important outcomes of effective ecosystem management (Parkes et al., 2010). These considerations call for integrated spatial planning approaches, such as the green infrastructure concept, that focus on maintaining ecosystem resilience and securing multiple and sustainable ecosystem services to human society.

The increasing complexity of environmental and health interactions requires further improvements and adaptation of the information systems underpinning integral assessments. The EEA maintains over 200 environmental indicators across 12 environmental themes, ranging from noise, air and water pollution to vector-borne diseases (EEA, 2012c). Their framing follows the DPSIR logic (Drivers, Pressures, State, Impact and Response) and they use Member State data, compiled by EEA, as well as statistics from other international organisations. Several EEA indicators are directly health-relevant and have been incorporated in the WHO pan-European Environment and Health Information System ([47]). This uses the rather similar DPSEEA framework (Driving force, Pressure, State, Exposure, Effect, and Action) (Corválan et al., 1996; WHO, 2010b). Different modifications of, and alternatives for, the DPSEEA framework are currently being explored (Morris et al., 2006), taking account of multi-causality, complexity, and uncertainty in environment and human health interactions.

Several initiatives at the European level are aimed at improving the accessibility and use of data/information, notably the process of establishing the Infrastructure for Spatial Information in the European Community (INSPIRE) and the Shared Environmental Information System (SEIS). The INSPIRE directive (EU, 2007) adopted in 2007, aims to create a spatial data infrastructure in Europe, addressing 34 environmental themes, including human health and safety ([48]). SEIS builds on a set of data management principles that improve access to datasets, prevent unnecessary duplication of data collection, and allow decentralised quality control (EC, 2008b). While originally developed for environmental information, these principles also apply to information systems in environment and health, though certain limitations in data sharing in this domain have to be acknowledged and carefully addressed (Pearce and Smith, 2011).

The Eye on Earth initiative — a 'global public information network' for creating and sharing information — is an example of implementing the SEIS principles. It comprises on-line interactive datasets such as WaterWatch (water quality data from 28 countries), AirWatch (near real-time air pollution data from 32 European countries), and NoiseWatch. Through the Watches, users can provide feedback and personal ratings of environmental quality at specific locations (e.g. beaches). In future, user involvement is to be extended, and the citizens will be able to provide their own data to the Watches through citizen science activities.

13.6 Final reflection

With the EU2020 strategy, and particularly its focus on smart growth and resource efficiency, European environmental and environment and health policy moves into a more systemic direction. This is clearly underlined in the proposal for the EU 7th Environment Action Programme (EC, 2012f) in which health and well-being aspects is one of three key thematic priorities, with the others being 'Natural Capital' and 'Resource efficient low-carbon economy'. As human demand for the world's natural resources increases and the environmental consequences become more and more manifest, it is imperative that we increase our understanding of the intricate links between environmental conditions and human health and well-being. Effective governance in this policy domain relies critically on awareness of the complex systemic interactions, feed-backs and trade-offs involved.

The EEA will contribute to a more systemic approach to environmental and health issues by further developing the analytic framework outlined

([47]) Environment and Health Information System, WHO Regional Office for Europe.
([48]) Data Specification on Human Health and Safety available at: http://inspire.jrc.ec.europa.eu/index.cfm/pageid/2.

earlier. It is the intention to place human health and well-being concerns much more centrally in an integral narrative on environmental change, to be developed in support of the 2015 State and Outlook Report. Such a narrative would acknowledge that our lifestyles, consumption, trade and settlement patterns determine the pressures on the environment, but in turn also largely determine our individual exposure to them. Integrating data from the social, economic and environmental domain will be the major challenge, and depend critically on the further development of the underpinning data-infrastructure.

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