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Science Advisory Council

The imperative of climate action to protect human health in Europe

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Science Advice for the Benefit of Europe

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

The EASAC Council has 29 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

To find out more about EASAC, visit the website – www.easac.eu – or contact the EASAC Secretariat at secretariat@easac.eu

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The imperative of climate action to protect human health in Europe

Opportunities for adaptation to reduce the impacts, and for mitigation to capitalise on the benefits of decarbonisation

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Foreword

'*Climate change is the defining issue of our time and now is the defining moment to do something about it*'[1]. Previous work by the European Academies' Science Advisory Council (EASAC) has addressed a wide range of issues for climate change action in Europe, for example the role of forests in providing ecosystem services and the potential contribution to be made by Negative Emissions Technologies in mitigation. An EASAC report published in March 2019 on decarbonisation of transport emphasised the needs for drastic societal change and decisive political action and proposes a set of concrete actions to policy makers.

In the present report, we focus on the detrimental effects of climate change on human health in Europe: describing the evidence for current effects and projected impacts according to different scenarios, and reviewing the options for adaptation and for mitigation where that brings co-benefits for health. Our analysis draws on diverse evidence in European populations: we identify increasing risks, particularly in vulnerable groups but we also emphasise the cardinal point that we are all affected by climate change.

The adverse health effects of climate change have been relatively neglected by policy makers until recently, but that is beginning to change—and requires an increasingly robust scientific evidence base to guide the choices between policy options. The threats must drive decisive action by the scientific and health communities in Europe and by public policy makers, to protect the health of future as well as current generations and as a major part of the concerted efforts for reaching targets set in the Sustainable Development Goals (SDGs) for people and the planet. Broadly, evidence is accruing to indicate a falling behind in attaining SDGs and there is need to be more ambitious. Detailed discussion is provided in the following chapters of our report but I want to use this opportunity to highlight the great relevance of the findings to understanding inter-connectivities between the SDGs, for example between SDG 13 (climate action), SDG 2 (zero hunger) and SDG 3 (good health). This project, like all EASAC projects, can itself be seen as a good example of SDG 17 (international partnership).

Our objectives can briefly be summarised as follows.

- Make best use of the current evidence base to inform development of a coordinated EU policy framework for urgent action on climate change adaptation and mitigation, raising the visibility of concerns for human health as a major consideration.
- Fill present knowledge gaps by research in all relevant disciplines.
- Improve health risk communication, including the countering of misinformation.

Our conclusions reinforce points made by other groups, including UNFCCC, WHO and the Lancet Commissions—these and other sources are discussed extensively in the following chapters. We aim to add value to what has already been done by focusing on scientific opportunities. The knowledge base is currently fragmented and we draw on multiple scientific disciplines, with perspectives from across Europe, capitalising on the core values of academies in being free of vested interests, open in processes and accountable. We show where there is consensus and where further work is required to clarify and resolve differing views.

The interlinkages between climate change and health are, of course, of vital importance worldwide and our recommendations are scalable in many regards. EASAC is planning, together with colleagues in the InterAcademy Partnership to extend the assessment of climate change and health issues globally. We in EASAC also acknowledge our continuing responsibility to help catalyse further discussion and action among the academies, the wider scientific community, other stakeholders and policy makers at national and EU levels. Therefore, we greatly welcome the engagement in these issues by the European Commission's Scientific Advice Mechanism and the Group of Chief Scientific Advisors[2].

The present report has been prepared by consultation with a group of experts nominated by their national science academies. I thank them and the Working Group co-chairs, Professors Volker ter Meulen and Andy Haines, for their considerable efforts, and I thank our colleagues in the Federation of European Academies of Medicine (FEAM) for nominating Professor Haines. I also thank the independent peer reviewers, and our EASAC Biosciences Steering Panel for their guidance and Council members and their academies for continuing assistance in communicating our messages at the national level as well as to the EU Institutions.

We welcome discussion of any of the points raised in our report or on other related issues that merit attention.

Thierry Courvoisier
EASAC President

[1] UN Climate Action Summit 23 September 2019, on www.un.org/en/climatechange.
[2] Minutes of the sixteenth plenary meeting of the European Commission's Group of Chief Scientific Advisors, https://ec.europa.eu/research/sam/pdf/meetings/hlg_sam_012019_minutes.pdf#view=fit&pagemode=none.

Summary

The pace and extent of recent environmental change, in particular climate change, poses serious challenges to global health gains made over recent decades.

In previous work, the European Academies' Science Advisory Council (EASAC) has covered several significant challenges relevant to climate change across Europe, for example in assessing the potential of negative emissions technologies in meeting emission targets, and monitoring trends in extreme weather events. In the present report, EASAC focuses on climate change and health. Although the European Union (EU) is very actively engaged in collective efforts to reduce Greenhouse Gas emissions and to identify how best to adapt, the impacts of climate on health have been relatively neglected in EU policy. This must change. Our concern is motivated by the risks to health in the near future.

EASAC's main messages are the following.

- Climate change is happening on a global scale and is attributable to human activity.
- Climate change is adversely affecting human health and health risks will increase over time.
- Rapid and decisive action, to cut GHG emissions sufficiently to keep temperature increase below 2°C above pre-industrial level, could greatly reduce risks to health.
- There are major near term health benefits arising from decarbonising the economy as a result of reduced air pollution and other co-benefits of climate change mitigation.
- Climate change can have effects on health within the boundaries of the EU and also through its effects on the health of populations outside these boundaries.
- Solutions are within reach and much can be done by acting on present knowledge, but this requires political will.
- The scientific community has important roles in generating new knowledge and countering misinformation on the health effects of climate change, on factors increasing vulnerability, and on the effectiveness of adaptation and mitigation strategies, in close collaboration with decision makers.

While recognising the uncertainties in attribution and extrapolation of data, the academies, independent and free of vested interests, are well placed to make an objective and transparent evaluation of the evidence base. The systems are complex but we emphasise that the policy actions required will bring benefits to health now and for future generations whatever the extent of the contribution made by climate change in the mix of risk factors. The focus in the present report is on the EU but climate change effects in other regions have tangible consequences for Europe, and the EU has roles and responsibilities that can help address problems in the rest of the world.

EASAC objectives in this project are to advise on the following:

(1) using the evidence already available to inform coherent health policy development for climate change mitigation and adaptation strategies and their connection to other policy initiatives, for example for Sustainable Development Goals (SDGs), the Common Agricultural Policy, the circular economy and air quality; and
(2) the priorities for filling knowledge gaps by new research, increasingly transdisciplinary and intersectoral. Generation and use of the evidence base is urgently required to clarify risks. What are the major health effects? Who is most vulnerable and over what timescale? Are there tipping points (sudden, irreversible changes in health and environment)? And how could choice of socio-economic development pathway influence alternative futures? In preparing for, and responding to, climate change, better use of the evidence base is also needed to explore the following questions: What are the determinants of systems resilience? What are the most effective mitigation and adaptation strategies for health? How should different strategies be integrated? What are the barriers to, and unintended consequences, synergies and trade-offs of different actions?

Climate change is already contributing to the burden of disease and premature mortality. Without prompt and effective action, the problems are forecast to worsen considerably. Impact is a function of hazard, exposure and susceptibility. Mechanisms by which climate risk affects health can be categorised as direct, indirect via ecosystem effects and indirect via societal system effects. Resultant health effects comprise both communicable and non-communicable diseases (including mental illness) and injuries. Among the most vulnerable groups are the elderly, children, those with pre-existing medical conditions, migrants and other marginalised groups.

Pathways for health effects are complex with many factors interacting, and climate change will

intersect with other major trajectories, for example in urbanisation, population ageing and human behavioural change. There may be divergent trends and there are challenges in attributing specific health effects to specific climatic trends. Nonetheless, there is growing evidence that climate change is already having effects on health in EU countries, and that these health effects are associated with high temperatures, wildfires, flooding, changes in infectious disease transmission and in allergens. Mental health consequences can arise from a range of causes. Climate change is likely already affecting agricultural productivity in some parts of Europe and in regions that trade with Europe, with potential implications for EU and global food and nutrition security.

The European territories most vulnerable to the environmental effects of climate change are the Arctic and the Mediterranean region; and changes in these regions also have potential consequences for the rest of the EU.

For the future, projected effects on health depend on the magnitude of climate change and the adaptive responses made. There is uncertainty on scale but projections are becoming more robust on temporal and spatial scales and the balance of effects on health is increasingly negative over time. Climate change will also affect the ability of health systems to function effectively; these effects, and the consequences for public health, will vary according to the socio-economic pathway chosen.

Responding to climate change requires connected strategies for mitigation (reducing greenhouse gas (GHG) emissions) and adaptation (adjusting to what cannot be avoided). Certain mitigation actions will also bring ancillary (co)-benefits to health, additional to those effects mediated by reductions in projected climate change. For example, a zero-carbon economy, characterised by the extensive use of clean renewable energy technologies, would potentially avert hundreds of thousands of premature deaths annually from air pollutants emitted when fossil fuels are burnt.

Although many adaptation and mitigation plans have been compiled across the EU, concrete objectives for health – and links with SDGs – are often weak. Plans to promote system resilience and to progress cost-effective adaptation measures and mitigation synergies are often based on fundamental principles and simulations but empirical evidence to support options can be improved. There is need to do much more in ensuring that health impact assessment is part of all proposed initiatives and of the monitoring of implemented plans.

This report presents case studies on mitigation health co-benefits: opportunities for European city sustainability and for action on agricultural systems and consumer dietary choice. A case study on adaptation examines progress made in tackling the increasing threat of infectious disease. Optimisation of individual initiatives requires adoption of systems thinking to identify potential for synergies, inadvertent consequences and trade-offs. Furthermore, a strategic disconnect in policy should be addressed: there is significant EU collaboration in dealing with some aspects of climate change but most health policy is decided at the national level. Opportunities should be taken for increasing EU-level action on health where appropriate, alongside the specific actions at country-level that need to be taken by EU Member States.

The economic benefits of action to address the current and prospective health effects of climate change are likely to be substantial but there is need for more work to be done on methodologies for economic valuation of costs and benefits. There is also need for further work on identifying alternatives to gross domestic product as a measure of societal progress.

Tackling the barriers to action is also a matter of urgency and requires new commitment to engage with and inform EU citizens about the pressing issues for climate change and health. It is vital to counter misperceptions that may be fostered by the deliberate actions of those with vested interests intending to mislead.

Some messages demand repetition. For the overarching recommendation, we reaffirm the top priority to stabilise climate and accelerate efforts to limit GHG emissions with the aim of achieving a zero-carbon economy before 2050. Collectively, we must also build better strategic links between the adaptation and mitigation communities, those working on climate change and on pollution, and between other sectors. There must be continuing engagement to resolve what is EU-level and what is Member State responsibility and how there can be effective integration of roles. Continuing exploration of the issues for the EU must also take account of the effects of decisions by the EU on neighbouring countries and the rest of the world, and the implications of changes elsewhere on EU decisions.

The priorities for linking research outputs and policy development are described in the following paragraphs according to the precepts:

- Elucidating and quantifying climate change effects on health and improving methods for attribution of health effects to climate change.
- Improving understanding of the multiple benefits for health of policies to mitigate climate change.
- Clarifying the challenges to, and effective policies for, adaptation.
- Evaluating unintended consequences of policy action and proposing effective approaches to minimise them.

Our recommendations pertaining to health can be summarised as follows.

Health in all policies

Making best use of the current evidence base to develop coherent and coordinated EU policy frameworks to encompass health as a major consideration, including the following:

- Reform of the EU Adaptation Strategy to ensure increased focus on health consequences of climate change.
- Health impact assessment in all climate change adaptation and mitigation strategies, for example for transport, energy, and housing sectors.
- Development of healthy, climate-smart food systems at both national and city levels to improve health, with corresponding modifications of for the Common Agricultural Policy.
- Development and promotion of dietary guidelines for sustainable healthy diets, with implications for whether and how the EU and Member States should use health or environmental criteria to influence food system policies.
- Linkage of climate change and health objectives into all other key EU domestic policies, and into neighbouring country and international development policy initiatives: for example for migration, air quality, circular economy and bioeconomy.
- At global level, continue to build links between EU climate and health policies with World Health Organization (WHO), Group of Seven (G7) and Group of Twenty (G20) initiatives and with collective action on SDGs.

Filling knowledge gaps by research

This includes continuing commitment to basic research to understand mechanisms of impact; longitudinal (long-term observational) data collection, with focus on vulnerable groups; research and modelling to characterise alternative scenarios and tipping points for impact assessments and co-benefits modelling; developing and improving indicators of exposure and vulnerability, evaluation of adaptation processes, resilience and GHG mitigation strategies; encouraging global collaboration on research priorities; and supporting implementation research to identify approaches to accelerate uptake of research findings particularly where these are based on rigorous syntheses of evidence.

Improving integration of data sets

To strengthen understanding of the links between hazard, exposure, sustainability and outcomes. Better surveillance and linkage between environmental, socio-economic and health data with exploration of the potential for global observatory or other monitoring system options.

Health risk communication

As part of the urgent need to raise awareness of current and potential effects of climate change on health, the scientific community must do more: to understand individual and institutional behaviour; counter misinformation and polarisation; and strengthen the response of health services and EU agencies.

We conclude by re-affirming that there are significant opportunities now for action at the EU level to reduce the risks to health in the near future and gain multiple benefits to health of "zero-carbon" policies. To realise these opportunities the EU must ensure integration of climate and health policy options with other policy, in particular for the circular economy; for delivery of sustainable, healthy diets; for tackling air pollution; and for ensuring that development aid focuses on climate change adaptation and mitigation priorities. Pursuit of integrated policy objectives requires rethinking of subsidies, incentives and other financial instruments operable at the EU level. Concomitantly there should be EU strengthening of monitoring and surveillance to link health and environmental trends, and initiatives for informing public awareness of the current and future risks. EASAC recognises its continuing responsibility to collect and interpret evidence, foster interaction between disciplines, sectors and countries and inform all in the science and policy communities about the matters raised in our report. We are committed to supporting further analysis, engagement and action.

1 Introduction to challenges for the shared global agenda and its relevance to the EU

1.1 Sustainable development, climate change and health

By most metrics, human health is better today than at any time in history. Yet there is an apparent paradox: the improvements in life expectancy are being experienced at a time when many natural systems are degrading at unprecedented rates (Whitmee *et al.* 2015). There may be various explanations for this paradox but the most probable is that the health of future generations has been mortgaged to realise economic and development gains in the present. And that improvements in higher-income countries have been made at the expense of the rest of the world. The pace and extent of recent environmental change suggest that it will not be possible to continue to exploit nature according to this same development and behavioural paradigm to provide for a growing world population. Changes in the environment, including climate change, air pollution, ocean acidification, land degradation, water scarcity, over-exploitation of fisheries and biodiversity loss pose serious challenges to the global health gains made previously. There is significant effort now being made to define the environmental limits within which humanity can safely operate, to support the new paradigm that integrates continued development of human societies and maintenance of the Earth system in a resilient and accommodating state (Steffen *et al.* 2015). Climate change is one of the most important global environmental changes that define the Anthropocene epoch.

In this report, the European Academies' Science Advisory Council (EASAC) focuses on critical issues for climate change and health in Europe. We explore where there is consensus on key questions, identify where further assessment of the issues is required and clarify options for policy development. During the past years there have, unfortunately, been vested interests generating misinformation leading to confused understanding of climate change (examples are discussed by Oreskes and Conway 2010) and of associated health effects. Digital technologies and social media platforms can mean that false information circulates and gains traction rapidly (Royal Society and Academy of Medical Sciences 2018). The academies, independent and free of vested interests, are well placed to make an objective and transparent evaluation of the evidence base. While recognising the uncertainties, it is urgent to make decisions and act to avoid greater negative implications for health in the future.

Health aspects must be taken into account in all policies and, as we discuss later, action on climate change and health must also be integrated into other current European Union (EU) policies, especially for a circular economy and for Sustainable Development Goals (SDGs). The present work takes a broad perspective on climate change and human health. It has been initiated in response to the significant interest expressed by the national academies of science of the EU Member States in these issues, and to convey the urgency of the policy actions required. Details of the Working Group and project procedures are in Appendix 1.

The climate is changing, primarily because of emission of greenhouse gases (GHGs), and short-lived climate emissions pollutants such as methane and black carbon, from human activities (EEA 2017a). The perception that climate change impacts are something that happens to other countries is still prevalent among some European politicians. There is increasing evidence that the severity and frequency of some extreme weather events worldwide can be attributed to climate change (Schiermeier 2018)[3].

The EU accounts for approximately 9% of global emissions of carbon dioxide (CO_2)[4]. The EU collectively is at the forefront of international efforts to reduce GHG emissions (Klugman 2018)[4] but climate change preparedness and responsiveness must be brought into the mainstream in all sectors concerning human health. The recent persistently high temperatures across Europe (and elsewhere) emphasise the need for urgent action. There is now the imperative '*to place health at the centre of decision-making about climate change, to recognise that threats to health, like heatwaves, are shared internationally, to build more resilient communities, and, most importantly to limit further emissions of greenhouse gases*' (Anon. 2018a).

[3] International collaboration to adopt standardised statistical procedures and increasingly robust models on inferring causality from observational data are improving the capacity to assess and assign attribution of extreme events to climate change: see www.worldweatherattribution.org.
[4] Global comparison 2014 data from World Resources Institute (www.wri.org). According to Eurostat data for the EU Greenhouse Gas Emissions inventory submitted to UNFCC, absolute emissions declined by 22% during the period 1990–2014. There has been little net change 2014–2016 (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emissions_statistics&redirect=no). See also the leadership position taken in COP24: European Commission 12 December 2018, 'COP24: EU and allies in breakthrough agreement to step up ambition', https://ec.europa.eu/clima/news/cop24-eu-and-allies-breakthrough-agreement-step-ambition_en. Latest data worldwide on GHG emissions is provided by the Global Carbon Budget, www.globalcarbonproject.org.

1.2 Managing the global commons: what are the prospects for climate change and health?

The Paris Agreement can be seen as a political triumph and 196 signatories have committed (up to 2030) to reduce GHG emissions and limit climate change to well below a global temperature rise of 2°C above pre-industrial levels, with an aim of limiting increases to 1.5°C. However, current projections show that these objectives are unlikely to be met and intended nationally determined contributions fall short of the necessary reduction to meet the 2°C pathway (IPCC 2018). In the recent Intergovernmental Panel on Climate Change (IPCC) analysis (Ebi *et al.* 2018a), lower risks are projected at 1.5°C than at 2°C for various health effects and in the European Commission's Joint Research Centre (JRC) analysis (Ciscar *et al.* 2018) the responses to greater than 2°C rise are contrasted with those from lesser increases in temperature; these projections will be discussed in further detail in subsequent chapters.

Whereas the risks to health from climate change have attracted global political attention recently, the potential for vulnerability has been known for some time (see, for example, IPCC 1996; McMichael *et al.* 1996; Haines *et al.* 2006). Health impacts may have been relatively neglected in the initial adaptation and mitigation policies of national governments because of various barriers to focusing on the achievement of health benefits, relating to awareness, efficiency, vested interests and structural challenges (Workman *et al.* 2018). Nonetheless, the avoidance of a high level of immediate mortality in some heatwaves might be considered an example of increasingly effective adaptation planning[5]. The past relative neglect of multiple health consequences is now being reversed and considerations of impact of climate change on health play an increasing but still relatively peripheral role in the ongoing discussions at the Conference of the Parties of the Paris Climate Agreement and the SDGs. Recent analysis of progress made by the EU and Member States in tackling the SDGs, covering issues for climate action, has been published by the European Commission (2019), drawing on the data by Eurostat[6]. An introduction to some interactions between the SDGs for climate action (SDG 13) and health (SDG 2) has been made by the International Science Council (2017)[7].

Climate change poses increasing challenges for health in Europe and worldwide (EEA 2017a; WHO Europe 2017a). As will be discussed in detail in the following chapters reviewing representative literature, the effects of climate change on human health are manifold. These effects may be direct, for example heat-related excess morbidity and mortality; indirect, for example mediated by vector-borne disease, water extremes (floods and droughts), pollutants, food supplies; or socially mediated, for example via effects on vulnerable groups. In all cases, there will be multiple factors involved. Although the focus on health effects has often been on infectious disease (see, for example, EASAC 2010), the effects on non-communicable diseases are just as important and involve multiple direct and indirect mechanisms (Friel *et al.* 2011; Frumkin and Haines 2019). While health effects are already manifest, their increase in the absence of climate change mitigation will greatly amplify existing health challenges and inequalities (Smith *et al.* 2014).

There is substantial international consensus, on the scope of climate change effects on human health, among those who advise on policy in this area (Appendix 2), but less evidence on the magnitude of the effects. On the basis of the sources presented in Appendix 2, the balance of health effects is clearly negative[8]. Nonetheless, the scientific evidence for quantification remains tenuous in some respects, partly because of lack of exposure–response and longitudinal data and partly because of uncertainty in attributing specific health effects to climate amidst many other variables in the complex systems linking environmental change and human health.

1.3 The role of this EASAC report in addressing scientific and societal aspects for the EU

EASAC has already covered several significant issues relevant to climate change in Europe, particularly through the work of the Environment and Energy Programmes. Recent EASAC publications have examined the potential of negative emissions technologies to remove CO_2 from the atmosphere (EASAC 2018a), the role of ecosystem services provided by forests in mitigating climate change (EASAC 2017a), the difference in GHG emission patterns between different

[5] For example, the increasing preparedness by Public Health England as evidenced by their Heatwave Plan for England, www.gov.uk/government/publications/heatwave-plan-for-england, published May 2018. See also Chapter 3.
[6] Eurostat 2018 report on progress on SDGs, https://ec.europa.eu/eurostat/web/sdi/overview. Earlier OECD analysis (June 2017) is on www.oecd.org/sdd/OECD-Measuring-Distance-to-SDG-Targets.pdf and there is further assessment by the Sustainable Development Solutions Network on www.sdg.org.
[7] EASAC is currently participating in a project of the InterAcademies Partnership (IAP) focussing on SDGs, http://www.interacademies.org/36061/Improving-Scientific-Input-to-Global-Policymaking-with-a-focus-on-the-UN-Sustainable-Development-Goals, and IAP is also developing as an open access resource, a database of academies' work on SDGs, www.interacademies.org/35255/SDG.
[8] In many European countries, there is an excess number of deaths in winter months. For example, in the UK, there were approximately 50,000 excess winter deaths in 2017–2018, mainly in women and the over-85s, perhaps partly because of the cold weather but also probably because of the relative ineffectiveness of the influenza vaccine during that season (www.ons.gov.uk, 30 November 2018). The extent to which climate change might decrease the number of excess winter deaths is not clear, particularly if development of more effective influenza vaccines reduces that burden and if there is also an increasing frequency of extreme weather events in the winter.

sources of oil (EASAC 2016) and provided continuing analysis of trends in extreme weather events (Norwegian Meteorological Institute in cooperation with EASAC 2013; EASAC 2018b). Previous work by the EASAC Biosciences Programme on climate change and infectious disease (EASAC 2010) and on food and nutrition security (EASAC 2017b) will be discussed subsequently.

Why are we now publishing this new report? The issues are urgent and we aim to highlight how to respond to, and prepare for, climate change from the health perspective, taking account of the growing evidence base to guide decisions and support the implementation of appropriate interventions. Effective policy-making requires better understanding of the acute and chronic health effects, what drives them and what mediates them. The report will also indicate where knowledge gaps need to be filled to generate a robust evidence base. It is not our purpose to duplicate analysis of the rapidly accumulating evidence base that is covered so well in other work (for example, those sources cited in Appendix 2) but we provide links to those detailed assessments, to systematic reviews, and to more recent publications to highlight key points for policy-makers and other stakeholders in the EU. Our objectives are the following:

- Use the transdisciplinary strengths contained in the academies to review mechanisms and implications and evaluate policy tasks.
- Extend the discussion on climate and health across Europe and generate greater understanding of the health effects resulting from climate change and the health co-benefits of decarbonisation—evidence for health effects can be persuasive in stimulating the decisive action that is necessary to reduce GHGs.
- Identify immediate opportunities for sharing good practice in sustainable frameworks relating to both adaptation and mitigation—clarifying where the primary responsibility lies at Member State level or should be an EU competence.
- Provide advice to inform sustained, coherent and coordinated policy development and decisions across a broad front; this includes strengthening research and surveillance together with monitoring of implementation activities and their impact.
- Support efforts to improve public engagement—including follow-up by the member academies of EASAC to use this report as a resource to engage with civil society.

The issues are of global concern and we hope that the present report will also serve as a resource to inform other inquiry globally, and provide a basis to support EU involvement in discussions between policy-makers and the academies of science worldwide.

EASAC messages are directed to the following groups:

- Those who make or influence policy in the European Commission (including the DGs Health and Food Safety, Clima, Environment, Research and Innovation, and Employment and Social Affairs), European Parliament and Council of Ministers.
- Those who make or influence policy at the EU Member State level.
- Other opinion leaders at the European regional level, for example WHO Europe.
- Inter-governmental and other bodies operating at the global level, particularly those involved with progressing SDGs.
- Member academies of EASAC, other academies of science and of medicine in the European region and worldwide. Others in the scientific community, including individual researchers and research funders.
- Through our member academies, to the lay public and public health authorities.

In the following chapters we emphasise transdisciplinary and cross-sectoral issues with particular reference to the scientific opportunities in Europe and the choice of policy options. This is an important time for informing and renewing strategic priorities to ensure that current and potential health effects of climate change are taken into account across a broad front of European Commission policy work (see discussion of current initiatives in Appendix 3) and we return to these priorities in Chapter 5 for urgent attention in the EU.

2 Starting points for this project

Summary of emerging points from Chapter 2

Many academies of science and medicine have already actively engaged in the issues for climate change and health. The regional focus in the present report is on the EU but climate change effects in other regions have tangible consequences for Europe, and the EU has roles and responsibilities that can help address problems in the rest of the world.

EASAC's objectives in this project are to advise on (1) using the evidence already available to inform coherent policy development for climate change mitigation and adaptation strategies and their connection to other policy initiatives, for example for SDGs, the circular economy, and air quality; and (2) the priorities for filling knowledge gaps by new research, increasingly transdisciplinary and intersectoral.

Generation and use of the evidence base is urgently required to clarify risks. What are the major health effects? Who is most vulnerable and over what timescale? Are there tipping points (sudden, irreversible changes in health and environment)? And how could choice of socio-economic development pathway influence alternative futures?

In preparing for, and responding to, climate change, better use of the evidence base is also needed to explore the following questions. What are the determinants of systems resilience? What are the most effective mitigation and adaptation strategies for health? How should different strategies be integrated? What are the barriers to, and unintended consequences, synergies and trade-offs for, different actions?

2.1 Previous academy publications on climate change and health

Many academies worldwide are interested in the effects of climate change and health, and our report draws on some of this previous work (Table 2.1); our quotes from academy work highlight general points that will permeate all our analyses and several of these sources are discussed further in Chapters 3 and 4, where appropriate. Previous EASAC work covering issues for climate change and health will be reviewed and updated in Chapters 3 and 4.

2.2 Geographical and policy scope

The remit of EASAC is to focus on the EU. As will be discussed in the following chapters, there are direct effects and many indirect effects of climate change on

Table 2.1 Examples of previous academy work on climate change and health worldwide

Academy source	Published output
InterAcademy Medical Panel (IAMP) 2010	The health co-benefits of policies to tackle climate change: '*Since some degree of climate change is now inevitable, countries will have to adapt to the associated health risks … the health benefits are more local and can be realised more quickly, making them tangible and attractive to policy-makers and the public.*'
German National Academy of Sciences Leopoldina 2015	The co-benefits of actions on climate change and public health: '*… health and environmental sciences share a common culture of responsibility under uncertainty. This should be explored together as intensified dialogue.*'
Swiss Academies of Arts and Sciences 2015	Health and global change in an interconnected world: '*The complex nature of climate change and its environmental and societal manifestations results in diverse threats to human health.*'
Pontifical Academy of Science 2017	Declaration of the health of people, health of planet, and our responsibility climate change, air pollution and health: '*The time to act is now.*' See also Ramanathan *et al.* (2018).
US National Academies of Science 2017	Protecting the health and well-being of communities in a changing climate. Proceedings of a workshop: '*… the health effects of climate change are real, they are here now, they are unfair and inequitable and, most important, they are preventable.*'
Australian Academy of Science 2016	Climate change challenge to health: risks and opportunities
Royal Society of New Zealand 2017	Human health impacts of climate change for New Zealand
EASAC 2010	Climate change and infectious diseases in Europe
EASAC 2017b	Opportunities and challenges for research on food and nutrition security and agriculture in Europe
EASAC in collaboration with Norwegian Meteorological Institute 2013 (EASAC 2018b)	Extreme weather events in Europe: preparing for climate change adaptation. Includes coverage of health within sector-focused adaptation strategies

European health and economies. The complexity of the interconnected variables and the intersections between climate change and globalisation testifies to the importance of the task. Although some parts of Europe will be more vulnerable to particular effects, local–global interconnections bring implications for their neighbours and all of the EU will be affected.

2.2.1 Global context

Policy-makers in Europe need to appreciate both (1) that climate change in other regions has consequences that will affect Europe and (2) that Europe has roles and responsibilities in helping to deal with problems elsewhere. These responsibilities encompass action both to support actions in low middle income nations to rapidly decarbonise their economies and to help adaptation actions. Although our messages are directed predominantly to European audiences[9], we emphasise that EU policy-makers must take account of developments relevant to climate change and health in the rest of the world and their influence in Europe. Understanding and tackling climate change globally is critically important to addressing the SDGs collectively, in supporting EU international development aspirations and for promoting the security of European populations[10]. In making this case, we note the following.

- Climate change effects on health, to be discussed in detail in the following chapters, transcend geographical and political boundaries.

- There is growing evidence that the effect of climate change on populations, for example in Africa and Asia, increases population movement and forced migration (see section 3.10). Europe has a moral responsibility to help tackle the problems but it is also seen to be in European self-interest to manage and reduce migration into Europe. Although some of the evidence is controversial, an association of climate change with conflict and regional unrest has additional implications for global geopolitical risks and stability, also affecting Europe.

- The EU is also vulnerable to climate effects elsewhere with regard to disruption of trade, food supplies and other, non-agricultural commodities and raw materials needed for manufacturing in goods. This makes the reduction of climate risks to trade with other nations a priority.

- Attending to climate-smart adaptation and mitigation worldwide brings opportunities for entrepreneurial activity, innovation, employment and economic development in the EU and linkages to other EU policy priorities, for example for the circular economy, bioeconomy and for low-carbon technologies.

- In addition to the consequences of global changes impacting on Europe, European citizens and companies affect people living elsewhere: that is, we export our lack of sustainability. For example, a study on Switzerland for the period 1996–2011 (Swiss Academies of Arts and Sciences 2015) showed that the total environmental impact caused within Switzerland significantly decreased but was largely offset by Switzerland's growing environment impact and induced health burden abroad. Swiss livestock, for example, are fed with imported fodder from arable land abroad (necessitating deforestation and land conversion) equivalent to 60% of the arable land in Switzerland. Similar concerns have been raised in Finland (Sandstrom *et al.* 2017). Analysis of trade and countries of origin with respect to the GHG emission footprint of human diets (Sandstrom *et al.* 2018) provides further support for the conclusion that the EU displaces far more environmental pressures to the rest of the world, compared with pressures displaced to the EU by the rest of the world.

2.2.2 Framework for EASAC's inquiry

Throughout this report, we will focus on using the evidence available to inform policy options although we will also, where appropriate, indicate where research gaps need to be filled to generate better evidence. We concentrate on human health but mention animal and plant health issues where relevant.

Much of the recent thinking is this broad area derives from the work of McMichael *et al.* (1996, 2006, 2008), whose pioneering publications directed attention to the damaging effects of climate change and other human pressures on health as well as on the biophysical and ecological systems. This insight highlighted the resultant inequitable effects on health (McMichael *et al.*, 2008) and set out strategies to help prevent or lessen the harm, encompassing four relevant policy foci:

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[9] The literature that we cite usually takes a pan-EU or pan-European region perspective but there is also increasing discussion of evidence at the national level, reflecting growing political attention (for example, in the UK (McKibbin and Cave 2017)). We cite literature from outside the EU where it is necessary to make a particular point that is also of European relevance.

[10] The EU (in 2016) spends more on development cooperation than the rest of the world put together (EASAC 2018c). The EU's 'New European Consensus on Development' stresses the need for the EU and its Member States to work better together, using joint programming in partner countries and combining traditional development aid with other resources (including leveraging private sector investment).

Box 2.1 Key questions on the health effects of climate change: to be answered in Chapter 3

What are the major health effects?
Who is vulnerable and where do they live?
Are there tipping points beyond which major and perhaps catastrophic effects could occur?
Over what time period will major effects take place?
How will development pathways modify effects?

Box 2.2 Key questions on the main adaptation and mitigation policy options to safeguard health: to be answered in Chapter 4

Which policies increase resilience?
Which is the best (combination of) adaptation strategies, in which contexts?
What are the trade-offs and synergies?
What are the most important health benefits of mitigation strategies in the key sectors—energy, housing, urban, planning, food and agriculture, industry, etc.?
Are there unintended consequences?
What are the wider economic and development consequences?
What are the barriers to implementation and how can they be overcome?

- impact of climate change on health, livelihoods and social stability;
- benefits of moving to a low-carbon economy;
- effects of adaptation – and its limits;
- unintended health effects of policy actions including what trade offs may have to be made.

This framework, together with the impetus generated by the Lancet Countdown initiative (Watts *et al.* 2018a,b) and other international initiatives (Appendix 2 and IPCC 2018a,b), provides the baseline for our work, within the broad EU policy context (Appendix 3).

The following two chapters address two sets of questions (Boxes 2.1 and 2.2), with Chapter 5 bringing together our conclusions and recommendations.

3 What are the major health effects?

Summary of emerging points from Chapter 3

There is growing evidence that climate change is already contributing to the burden of disease and premature mortality in the EU. Without prompt and effective action, the problems are forecast to worsen considerably.

Effects are a function of hazard, exposure and vulnerability. Pathways by which climate change can affect health can be categorised as direct, indirect via ecosystem effects and indirect via societal system effects. Health effects comprise both communicable and non-communicable diseases (including mental illness) and injuries. Among the most vulnerable groups are the elderly, children, those with pre-existing medical conditions, migrating and marginalised populations/groups.

Pathways for eliciting health effects are complex with many factors interacting, and climate change will intersect with other major trajectories, for example in urbanisation, population ageing and human behavioural change. There may be divergent trends and there are challenges in attributing specific health effects to specific climatic variables. Nonetheless, there is now a significant body of evidence documenting current health effects in EU countries associated with high temperatures (direct and indirect effects), wildfires, flooding, infectious disease (vector-, water- and food-borne), air pollution and allergens, and from forced migration. Mental health consequences can arise from exposure to extreme events,population displacement, increased poverty and through other pathways. Climate change is already affecting agricultural productivity in parts of Europe, and is projected to worsen global food and nutrition security with potential implications for the EU.

The European territories most vulnerable to the environmental effects of climate change are the Arctic and the Mediterranean region; and changes in these regions also have potential consequences for the rest of the EU.

For the future, projected effects on health depend on the magnitude of climate change and the adaptive responses made. There is uncertainty on spatial and temporal scales but projections are becoming more robust and the balance of effects on health is clearly negative. Climate change will also affect the ability of health systems to function effectively. These effects, and the consequences for public health, will vary according to the socio-economic pathway chosen.

3.1 Introduction to scope and scale

As noted previously, our bibliographic listing in this report is not intended to be exhaustive: guided by Working Group expert discussion and our peer reviewers, we cite particular references to exemplify particular issues but also refer to systematic reviews. Systematic literature reviews (e.g. Mora *et al.* 2018) describe the numerous pathways by which human health, water, food, economy, infrastructure and security are affected by climate hazards (Figure 3.1). It is important to understand that GHG emissions pose a broad threat by intensifying multiple hazards and variations in adaptive capacity will result in different types and magnitudes of effect. However, it should also be appreciated that systematic literature reviews can only reflect the amount of literature available on the particular topic rather than, necessarily, the effect of a particular hazard on society—in our report we attempt impartially to explore those effects on health.

Our focus is on climate change and health but it is sometimes also necessary to consider the evidence available for climate variability and health because the effects of variability give important insights into the potential effects of changes in climate. Climate change will act partly by exacerbating health problems that already exist and the largest risks will apply in populations that are currently most affected by climate-related disorders (EEA 2017a), as will be discussed subsequently. Projections of future health effects depend, of course, on expectations of future GHG emissions (and see also the point about excess winter deaths[8]). The published work to be discussed in this report is based on various scenarios for climate change. For the Fifth Assessment Report of the IPCC, the scientific community has defined a set of four Representative Concentration Pathways (RCPs). They are identified by the approximate total warming effect in the year 2100 relative to pre-industrial 1750. The maximum, RCP 8.5, was regarded as an extreme pathway with very high GHG emissions (resulting in a projected global temperature increase of, on average, 4.8°C above pre-industrial levels) but it is still possible, depending on the policies implemented; potential effects of high-end climate change in Europe are discussed in detail by Berry *et al.* (2017).

Epidemiological research can make an important contribution in improving assessment of exposure and quantifying disease burdens arising from environmental change, and in the rigorous evaluation of potential solutions, both adaptation and mitigation (Haines 2018)[11]. There are challenges in inferring causation (Bradford Hill 1965) and it is important to understand the potential for confounding factors while methods of detection and attribution have evolved in recent years, greater refinement may be possible in future. While it may be difficult to collect dose–response data to satisfy one of the principles of causality, because populations can adapt up to a point to changing climate, epidemiological data should be available to satisfy other principles (consistency, temporality, plausibility and

[11] The WHO European Regional official guidance for epidemiological research (WHO Europe 2000) differentiates and provides guidelines and principles for addressing health hazard identification and health impact assessment.

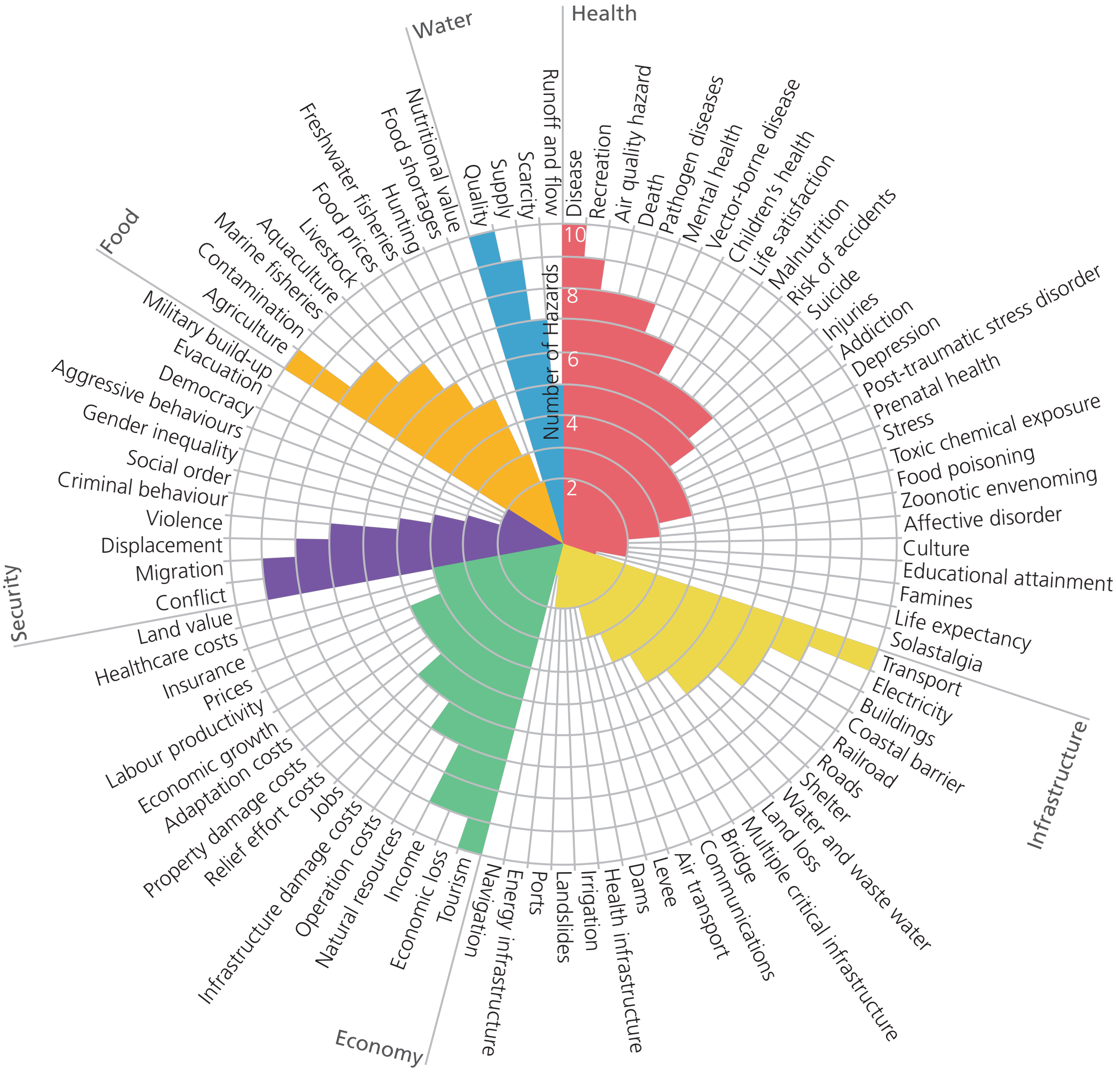

Figure 3.1 Observed effects on humanity from climate hazards. Hazards included warming, heatwaves, precipitation, drought, floods, fire, storms, sea-level rise and changes in natural land cover and ocean chemistry. Six different aspects of human systems are shown (health, food, water, infrastructure, economy and security), with their subcategories for which effects were observed. The heights of the bars indicate the number of hazards implicated in the impacts. Reprinted by permission from Springer Nature, Nature Climate Change, Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions, Mora et al., © 2018.

coherence). The life course perspective of impact takes account of possible cumulative risk, and life course studies explicitly encompassing climate parameters should be conducted. Research encompassing the ability to adapt and self-manage in the face of social, physical and emotional challenges is needed (Huber *et al.* 2011).

There is a need, and a considerable opportunity, now to link atmospheric, environmental, socio-economic and health datasets to develop new insights into potential causal relationships between climate change and human health (Fleming *et al.* 2014). Comprehensive information will also be needed to answer future research questions, and more can be done to link health data into objectives for regional and global observatories (see, for example, Kulmala 2018), to be discussed subsequently. Not only the relatively direct effects of climate change on health but also those indirect effects arising from systems' changes need to be elucidated and examples will be discussed in the following sections. Advances from basic research provide the resource with which to pursue yet further directions. For example, there is increasing realisation that microbial activity is shaping the dynamics of ecosystems in various ways and fundamental research can explore how the impact of climate change will influence the relationship between microbial communities and the built environment (Gilbert and Stephens 2018) and the natural environment, with implications for human health (Anon. 2018b).

We recognise that the systems and pathways are complex. Systems approaches are needed to understand how human health outcomes emerge from complex interactions and feedbacks between natural and social systems, and to incorporate stakeholder engagement and values (Whitmee *et al.* 2015; Pongsiri *et al.* 2017; Haines 2018). The systems approach requires scientific analysis of complexity and dynamic interactions among economic, social and environmental systems on the basis of transdisciplinary collaboration.

Quantifiable and comprehensive projections are becoming more robust. For example, an analysis (Forzieri *et al.* 2017) of most probable extreme weather hazards in Europe for periods up to the year 2100 finds that weather-related disasters could affect two-thirds of the European population, compared with 5% during the reference period (1981–2010, largely excluding the effect of heatwaves). As will be discussed subsequently, projections of future effects show a prominent geographical gradient, increasing towards southern Europe, but also with greater effects at the highest latitudes (Arctic). Although there remains uncertainty in documenting and quantifying effects, we emphasise that many of the policy actions to be discussed are relevant for public health now and for future generations, whether or not climate change is a predominant influence among the mix of risk factors.

It is also important to understand reasons for divergent trends. Although the frequency and intensity of extreme weather events is increasing globally (accompanied by increasing financial impact), death rates from climate-related disasters in some locations are relatively stable, or even decreasing (Watts *et al.* 2018a). For example, in Spain, summer temperatures increased by nearly 1°C on average between 1980 and 2015 (Achebak *et al.* 2018). Yet there is a mostly downward trend in heat-attributable mortality, presumably because of societal adaption and/or socio-economic development, changing population vulnerability (a systematic review is provided by Boeckmann and Rohn 2014). However, some recent conclusions from individual countries in Europe (for example Poland, see section 3.2) infer heat-related vulnerability increasing. Furthermore, it is not known whether the decline in heat-related deaths because of adaptation, where it is seen, would continue at higher levels of climate warming. Therefore, in extrapolating for future effects on health, there is need for more data on regional, temporal and other variation to clarify potentially offsetting beneficial effects of other changes on health, such as housing quality, effectiveness of early warning systems, and accessibility to health care.

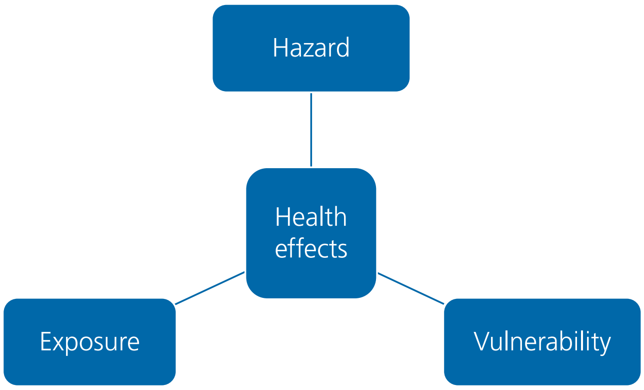

Figure 3.2 The determinants of harm.

Understanding the social determinants of health and of adaptive capacity and their limits – and learning from lessons of good practice – will help to improve future preparedness and responsiveness.

There are various mechanisms mediating climate-related drivers of harm. These include rising temperature, rising sea levels, changing precipitation intensities and frequencies, and increasing levels of CO_2 and levels of hazardous pollutants. Magnitude of the health effects depends on the nature of the hazard, exposure to that hazard and individual vulnerability as outlined in Figure 3.2.

We summarise examples of specific health effects in Figure 3.3.

We now consider points from Figures 3.2 and 3.3 in further detail in the remainder of this chapter. Before doing so, however, we observe that it is challenging to ascertain the net contributions made by climate change to the total burden of diseases although a global attempt is made by the WHO[12]. It is also important to realise that the balance of future effects may be different from the balance of current effects, and that the propotion of deaths attributable to climate change may be difficult to ascertain within broader analysis of the number of deaths from extreme events. As will be discussed, the balance of effects in the EU is likely to be different from the global one, with disability adjusted life year (DALY)[13] effects greatest for non-communicable diseases and mental health disorders. One particular assessment of health effects of extreme weather in Europe is summarised in Table 3.1 to exemplify some of the data available. Several caveats limit interpretation

[12] Analysis of partial health impacts, assuming continued economic growth and health progress, calculated that between 2030 and 2050, climate change would cause approximately 250,000 deaths per year worldwide: 38,000 heat exposure in the elderly, 48,000 from diarrhoea, 60,000 from malaria and 95,000 from childhood undernutrition ('Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s' 2014, on https://apps.who.int/iris/handle/10665/134014). However, such analyses count only a limited number of direct effects; there are likely to be large premature mortality and morbidity consequences also from indirect effects. See also WHO (2018) for a summary of the issues for COP24.

[13] DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences; see https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en.

Pathways of risk

Direct	Indirect (ecosystems)	Indirect (societal)
Increasing temperature and frequency of heatwaves. Increasing drought. Increasing riverine flooding. Sea level rise. Increasing frequency of wildfires. Other extreme weather events.	Air pollution. Allergens. Water availability and quality. Food and nutrition security. Infectious disease threats (host, vector, pathogen).	Migration. Damage to infrastructure and health services. Economic effects of declining labour productivity. Conflict.

Health effects

Communicable diseases: vector-borne, water-borne and food-borne.
Non-communicable diseases: especially cardiovascular, cerebrovascular, respiratory, including allergies.
Mental health effects.
Undernutrition.
Hazard-related and violent injuries and death.
Health outcomes due to harmful algal blooms.

Vulnerable groups

Children.
Elderly people.
Expectant mothers.
Persons with pre-existing medical conditions.
Outdoor workers.
Migrants and other marginalised groups.

Figure 3.3 Summary of implications of climate change for health in Europe.

Table 3.1 Mortality per one million people attributed to extreme weather events for 1991–2015

Region of Europe	Heatwave	Cold	Flooding and landslides	Storm	Wildfire[14]
Eastern	11.4	28.3	8.6	1.7	0.54
Northern	11.2	1.7	1.0	2.5	0.01
Southern	178	0.9	6.8	1.2	0.97
Western	192	0.9	2.1	2.8	0.04

Table is adapted from EEA (2017a), using data from EM-DAT (http://www.emdat.be/database), Eurostat (http://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-data) and WHO (http://www.euro.who.int/en/data-and-evidence). Country groupings are listed in EEA (2017a) and include, for example, Balkan States in the southern region as well as EU Member States.

of the significance of this data set, including concern on lack of comparability in collecting data over time and the impact of single events on cumulative data. Furthermore, many heat- and cold-related deaths are not classified as being due to extreme events. Therefore, the total climate-induced burden of disease will represent much higher premature mortality than the particular effects of individual extreme weather events presented in Table 3.1. It should also be noted that data on premature deaths do not give information as to how premature and thus cannot give information on life-years lost. The focus in our report is on climate change but this exploration must be set into the context of the existing evidence base on climate and health. Further information on heat- and cold-related deaths in European countries is provided in the literature (for example, Ciscar *et al.* 2014; Gasparrini *et al.* 2015) and will be discussed in the following sections. There are many more cold- than heat-related deaths but it is unclear whether and, if so, by how much, cold-related deaths will decline in Europe with climate change.

3.2 Direct heat-related health effects

Heat waves and cold spells are associated with increases in premature mortality and morbidity, especially in vulnerable groups. The main effects are on cardiovascular, respiratory and cerebrovascular disease. Among groups particularly susceptible to heat are the elderly, infants and young children, those with pre-existing health problems and those in hospitals, nursing homes or who are bedridden. The size of the hazard

[14] The mortality from wildfires is conservative because it does not include air-pollution effects.

will also be variable. 'Usual' heatwaves affect those who are already vulnerable whereas extreme, prolonged heatwaves will also affect those who were relatively healthy. Although there will be variability between population groups and between regions, there is need for action everywhere. The latest Lancet Countdown worldwide analysis (Watts *et al.* 2018b) indicates that populations in the WHO European region and eastern Mediterranean are particularly at risk because of the high proportions of elderly living in urban areas.

3.2.1 Current situation

Impacts of climate change intersect with other societal changes, for example population ageing and urbanisation (heat island effects). The interaction between heat exposure and other factors such as drought, with the potential for exacerbated impacts on health, is now receiving detailed attention, including in Europe (Anon. 2018c). Heat extremes have substantially increased across Europe in recent decades[15], particularly in cities. For example, in a study of the 10 largest cities in Poland for the period 1989–2012 (Graczyk *et al.* 2018), the mortality observed during heat waves indicates a serious threat, particularly in older people and those with cardiovascular disease. However, as noted in other studies (Spain, see section 3.1), the overall effects will also depend on adaptation and other developments.

According to European Environment Agency (EEA) analysis[16], there have been many tens of thousands of premature deaths in Europe since 2000, with association between temperature and mortality documented for example in London, Stockholm, Rome and Madrid. The record hot summer of 2003 was associated with an estimated premature mortality of 70,000 in Europe (Robine *et al.* 2008). According to a study using publicly-donated computing to perform many thousands of climate simulations of a high-resolution regional climate model, in summer 2003, anthropogenic climate change increased the risk of heat-related mortality in Central Paris by ~70% and by ~20% in London, which experienced lower extreme heat. Across the EU region, the strongest trend for the number of hot days has been over the Iberian Peninsula and southern France. According to these analyses, additive effects are found between high temperature and air pollution (e.g. particulate matter of sub-2.5 µm and sub-10 µm size ($PM_{2.5}$ and PM_{10}) and ozone (O_3)) resulting in increases in hospital admissions for cardiovascular and respiratory diseases. Extreme situations can result from a combination of several weather variables. Heat stress depends not only on high temperature but also on high humidity.

A detailed analysis of excess mortality in the 2003 heatwave in Portugal showed that it was gender dependent—greater for women than men, especially for ages above 45 (Trigo *et al.* 2009). Analysis of heatwaves of 2003 and 2015 in Slovenia also emphasised the contribution of social factors to excess heat deaths in the elderly, particularly in those with previous circulatory disease, and in women up to the age of 75 (gender-related effects could not be compared for 75+ because this age group was predominantly women) (Percic *et al.* 2018). Clarification of particular vulnerabilities helps to define target populations, although other factors playing a major role in net risk must be acknowledged, for example housing quality and access to air conditioning (Trigo *et al.* 2009). From analysis in Portugal it was concluded that heat-related mortality is likely to be the highest public health concern for climate change but the relative contribution to the total burden of disease is difficult to quantify because of knowledge gaps, uncertainties and the influence of other factors, such as ageing (Casimiro *et al.* 2006).

3.2.2 Projections

For the future, it is virtually certain according to EEA analysis that length, frequency and intensity of heat waves will increase and lead to substantial further rises in premature mortality unless adaptation measures are taken. In other, comprehensive global evaluations, the extent of the effects predicted depended on the IPCC scenario used (Gasparrini *et al.* 2017; Hansen and Bi 2017), and reinforced the conclusion that for Europe the impact on mortality will be greatest in the south. There are also rises projected in hospital admissions for heat-related respiratory disease, with the largest increases expected in southern Europe (Åstrom *et al.* 2013). The European Commission (2013) initially concluded that if no further adaptation measures were taken, there would be an additional 26,000 deaths per year from heat by 2020, rising to 90,000 extra deaths per year by 2050. Recent modelling of heat-related mortality under Paris Agreement goals (Mitchell *et al.* 2018) indicated that stabilising climate warming at 1.5°C would decrease extreme heat-related mortality by 15–22% per summer in London and Paris compared with stabilisation at 2°C. Recent further analysis by the European Commission's JRC (Ciscar *et al.* 2018) suggests that

[15] Initial analysis is appearing relating to the high temperatures experienced in much of Europe in 2018. For example, in presentation of mortality statistics for England it was observed (Office for National Statistics, Quarterly mortality report, England: April to June 2018, on https://www.ons.gov.uk) that '*there were specific instances of increased mortality that coincided with periods of increased temperature in England …*'. The latest UK ONS report confirms that the exceptionally hot weather experienced in late July coincided with a sharp increase in the daily death count, which substantially exceeded the 5-year average on those days (https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/quarterlymortalityreports/apriltojune2018).
[16] EEA Extreme temperatures and health, 20 December 2016, www.eea.europa.eu; see also EEA (2017a).

for a temperature rise greater than 2°C above pre-industrial levels, by the end of the century there would be an additional 132,000 yearly heat fatalities in the EU, with this total reduced at temperature rises less than 2°C. Other recent assessment of effects worldwide (Vicedo-Cabrera *et al.* 2018) concludes that limiting warming below 2°C could prevent large increases in mortality in most regions but that the comparison of differences between 1.5 and 2°C is more complex and characterised by higher uncertainty. Modelling to extrapolate trends and project future impacts is an important part of the composite information base but it is important to exercise caution on individual predictions because the uncertainty surrounding assumptions on scenarios may amplify the implications of lack of robustness in starting data sets. There is need for more modelling and for more systematic review.

Worldwide, extreme heat exposure will be particularly pronounced in cities (Milner *et al.* (2017), analysing projections for the hottest months for the period up to 2050–2100 for RCP 2.6 and RCP 8.5, relative to 2017). From this assessment, the greatest changes are anticipated in those cities of mid- to high latitude with large seasonal variations in temperature—indicating significant implications for Europe with regard to the challenges for adaptation and health protection. For some cities, the projected temperature increases are much higher than the computed global average. Under RCP 8.5, by the end of the century, in the hottest months, many cities are likely to experience increases of 4–7°C or above: for Europe, these include Bucharest, Madrid and Zagreb (Milner *et al.* 2017). Modelling of summer climate indices for Brno in the Czech Republic (Geletič *et al.* 2019) shows that projected changes are significantly influenced by the locality within the urban environment, for example whether forested or not, drawing attention to the importance of urban planning for moderating heat stress.

In aggregate, relatively large temperature and premature mortality changes are forecast for cities in southern Europe by the end of the century in the scenario of high warming. In northern and eastern Europe, a reduction in cold-related excess mortality[8] (and see Table 3.1) may offset the likely rise in heat-related excess deaths: comparative projections indicate that mortality from cold is expected to decrease for the period up to 2050–2080 while mortality from heat increases (Hajat *et al.* 2014; Vardoulakis *et al.* 2014). However, these extrapolations tend to assume that the current relationship in trends between climate and cold-related mortality persists. The previously cited international study of Gasparrini *et al.* (2015), which included studies from Italy, Spain, Sweden and the UK, quantified the historically observed mortality in terms of relative contributions from heat and cold and from moderate and extreme temperatures. More research is needed to explore the issues for non-optimum ambient temperatures and, in particular, the causes of cold-related excess winter deaths and the impact of extreme events on cold-related deaths in projecting future effects. Research is also needed to support the development of more effective vaccines to protect against seasonal influenza.

In addition to direct effects, heat may also affect health through multiple pathways, discussed in the next section.

3.3 Indirect heat effects

3.3.1 Sleep disturbance

A survey of US respondents, for the period 2002–2011, found an association between night-time temperature and self-reported sleep disturbance, a risk factor for cardiovascular disease (Obradovich *et al.* 2017), with the biggest effects among lower-income and elderly respondents.

3.3.2 Kidney disease

Kidney stone formation varies with temperature (Tasian *et al.* 2014), perhaps as a result of relative dehydration and urinary concentration.

3.3.3 Criminal activity

A US study of 30-year crime and weather data found that temperature has a strong positive correlation with criminal behaviour, including violent crimes, with little evidence of lagged impact (Ranson 2014). Systematic literature review confirms the link between high temperatures and crime (Mora *et al.* 2018).

3.3.4 Labour productivity

Even small increases in temperature may reduce cognitive and physical performance and hence impair labour productivity and earning power, with further consequences for health. Earlier analyses had concentrated on the effects of heat on rural labour capacity, but now it is appreciated that many occupations may be affected. For example, recent analysis by the French Agency for Food, Environmental, Occupational Health and Safety (ANSES 2018) concludes that productivity and health of workers in most business sectors will be affected in European countries by 2050. The effects of indoor high temperatures in terms of altered circadian rhythms were recently reported (Zheng *et al.* 2019) as part of a broader discussion of the literature on indoor high temperatures and human work efficiency. For temperature rises greater than 2°C, labour productivity could drop by 10–15% in some southern European countries (Ciscar *et al.* 2018). Meta-analysis of the global literature confirms that occupational heat strain has important health and productivity outcomes (Flouris *et al.* 2018).

Climate change will increase the risk of environmental conditions that exceed human thermoregulatory capacity. About 30% of the world's population is currently exposed to climatic conditions exceeding the threshold beyond which daily mean surface air temperature and relative humidity are associated with increased mortality rates (Mora *et al.* 2017). By 2100, this percentage is projected to increase to about 48% under a scenario with drastic reductions in GHGs and 74% under a scenario of growing emissions. Other modelling on workability and survivability, indicating the nonlinear dependency of heat exposure risks on temperature, highlights the importance of understanding thresholds in coupled human–climate systems. With 1.5°C global temperature change, about 350 million people worldwide would be exposed to extreme heat stress sufficient to reduce greatly the ability to undertake physical labour for at least the hottest month in the year; this increases to about one billion people with 2.5°C global temperature change (Andrews *et al.* 2018).

3.3.5 Other physical exercise

Comparison of countries worldwide shows that many of the hottest countries have the lowest proportion of the population taking a healthy level of exercise. Climate change will extend these regions and times of year at which outside temperatures are too high for physical exercise, with anticipated further impact on population health and well-being. However, net effects may be difficult to predict. From analysis of a US survey of reported participation in recreational physical activity 2002–2012, it was predicted that warming may decrease activity during the summer in southern States but increase activity in winter in northern States (Obradovich and Fowler 2017). Changes in physical activity may affect mental health as well as physical health, in various ways (Mammen and Faulkner 2013; Stubbs *et al.* 2017) (and see section 3.11).

3.4 Forest fires

Climate change (increasing temperature and decreasing precipitation) is likely to be a significant factor in the origin of forest and heathland fires in Europe following extended periods of soil dryness, heat waves and extreme winds: recent data support this association although the evidence base for cause-and-effect is still relatively weak.

From 1 January to 6 August 2018 there were 496 wildfires of 30 hectares or larger across the EU[17]. That is 130 more fires than the 10-year average for this period. Wildfires are increasingly occurring outside of the traditional fire season and in countries where they were previously rare, although the most devastating fires occurred in the Mediterranean region. Catastrophic impacts may accrue during summer months in southern Europe if extended drought and massive fires are exacerbated by failures of governance, for example in maintenance and repair of electricity grids and water supplies. 2017 was one of the worst years on record for fires in Europe: over 800,000 hectares of land burnt in Portugal, Italy and Spain. As Europe's land gets drier, the risk of fires will worsen and not just for the hottest countries around the Mediterranean (de Rigo *et al.* 2017). Projection of fire risk in Mediterranean Europe under 1.5, 2 and 3°C global warming scenarios suggests that impacts will be much less if warming were to be limited to well below 2°C (Turco *et al.* 2018).

Wildfires and their effects on air pollution can be associated with significant health effects additional to the accidental fatalities (see, for example, Shaposhnikov *et al.* 2014; Liu *et al.* 2015; Reid *et al.* 2016; Kollanus *et al.* 2017). A study in Athens for the period 1998–2004 disclosed an immediate effect on cardiovascular and respiratory mortality, especially in older people (Analitis *et al.* 2013). More must be done in the EU[18] to quantify the health and economic impacts to inform policy and action. Among environmental research initiatives on wildfires in the USA (Reardon 2018), a study of how wildfire smoke affects human health is examining the inventory of chemicals released by wildfires (including nitrogen oxides (NO_x), carbon monoxide, volatile organic compounds and PM) to assess the potential effects of longer-term smoke exposure on public health (Cornwall 2018). There is also need for more work to understand the connections between natural hazards, such as wildfires, and other climate change effects that may combine to cause disasters (AghaKouchak *et al.* 2018).

3.5 Climate and flooding

There are multiple mechanisms for flooding in consequence of climate change. These include sea level rise, increasing intensity of precipitation and melting glaciers in parts of Europe.

3.5.1 Current situation

River and coastal flooding in the EU resulted in more than 2,500 deaths and affected more than 5.5 million people during the period 1980–2011 (European Commission 2013). Risk of inundations is not only related to the rising frequency and amplitude of heavy precipitation but also to land-use change (such as urbanisation and increase in impermeable

[17] European Forest Fire Information Service (EFIS) data 22 August 2018, on https://ec.europa.eu/jrc/en/news/jrc-supports-wildfire-monitoring-eu.
[18] For example, it is important to build on the resource provided by the European Commission's EFIS, https://effis.jrc.ec.europa.eu, which aims to support protection of forests against fires and provide harmonised information on wildland fires in Europe.

areas, resulting in increase of runoff). EASAC recently published a report on sustainable soils where relevant issues are considered further (EASAC 2018d).

Detailed analysis by the EEA[19] lists the main health effects of flooding as cardiovascular events, injuries, infections (see section 3.6 for further discussion on water-borne diseases), exposure to chemical hazards and mental health consequences. The associated disruption to services, including health services, safe drinking water, sanitation and transport, may increase vulnerabilities. According to Eurostat data and EEA analysis, the largest effects of flooding to date have been observed in south-eastern, eastern and central Europe. Floods now usually cause relatively few deaths in most of Europe (see Table 3.1 for response to extreme weather events) and mental health problems are estimated to account for the majority of disability adjusted life years attributed to floods (Tong 2017); see section 3.11.

3.5.2 Projections

For the future, the expected increases in heavy precipitation and coastal water levels increase the risks of river and coastal flooding in many European regions with attendant health impacts. For temperature rises greater than 2°C across the EU, sea level rise may result in fivefold increase in coastal flooding damage and threefold more people exposed to river floods (Ciscar *et al.* 2018). However, flood projections are subject to considerable uncertainty and should be interpreted with caution (Kundzewicz *et al.* 2017, 2018).

3.6 Infectious disease threats

The association of climate change with increasing infectious disease has been found worldwide, including Europe and the eastern Mediterranean (WHO regional analysis in Watts *et al.* (2018a)), but there are many determinants of infectious disease threats with interaction, for example, between climate change, globalisation and human behavioural change. There are significant threats from zoonotic, vector-borne and water-borne and food-borne diseases.

In 2010 EASAC published a Statement drawing attention to the current and potential effects of climate on transmission and distribution of human and animal infectious diseases in the EU (EASAC 2010). We now reiterate what we concluded then: '*There is still much to be done to clarify and quantify the impact. There is difficulty in assessing the net public health consequences, because there are uncertainties in the current and projected assessments of change in climate. Furthermore, this difficulty is compounded by gaps in the evidence base, by a weak integration of human-animal interfaces in research and surveillance, and by uncertainties about the impact of climate and other environmental change on human behaviour.*' Our previous work covered a wide range of vector-borne (mosquito, sandfly and tick) and rodent-borne infections and, broadly, the observed trends documented expansion of distribution of many vectors to higher latitudes and altitudes in Europe. Infectious disease knows no borders and it is important to respond to developments worldwide (some of the earlier EASAC recommendations for action are discussed in section 4.6).

Since publication of the earlier EASAC work, climate has been reaffirmed as a significant driver of infectious disease threats in Europe (Semenza *et al.* (2016a), analysis of the period 2008–2013), together with the drivers travel/tourism, food and water quality, natural environment and global trade. Climate and natural environment tend to cluster together as drivers. In addition to the evidence for effects on specific pathogens and vectors, there is also now ecological evidence (MacFadden *et al.* 2018) to suggest that increasing temperature is associated with increased antibiotic resistance for pathogens such as *Escherichia coli*, *Klebsiella pneumoniae* and *Staphylococcus aureus*. There are many other factors implicated in the increasing threat of antibiotic resistance but these data indicate that current forecasts of the public health burden of antibiotic resistance could be underestimated in the face of climate change.

3.6.1 Vector-borne diseases

Comparing the 1.5°C and 2°C scenarios, risks from some vector-borne diseases are projected to increase more at the higher temperature, partly because of shifts in geographical distribution (Ebi *et al.* 2018a). Warmer temperatures enable vectors both to spread to new locations and to survive the colder seasons (Antonio *et al.* 2018). For example, an epidemiological update on West Nile virus transmission[20] indicated increases in Romania compared with the previous year, with Italy, Greece and France reporting cases, including in areas where none had previously been reported. The unprecedented increase in West Nile fever in south-eastern Europe in 2010 was preceded by extreme hot spells in the region and was probably related to those high-temperature anomalies. Surveillance data (ECDC

[19] EEA, Floods, 20 December 2016, www.eea.europa.eu/data-and-maps/indicators/floods-and-health-1/assessment.
[20] ECDC (2018a): 'Epidemiological update: West Nile virus transmission season in Europe 2017' from 28 February 2018, on https://www.ecdc.europa.eu/en/news-events/epidemiological-update-west-nile-virus-transmission-season-europe-2017. The 2018 surveillance data show even higher case numbers, on https://ecdc.europa.eu/west-nile-fever/surveillance-and-disease-data/historical.

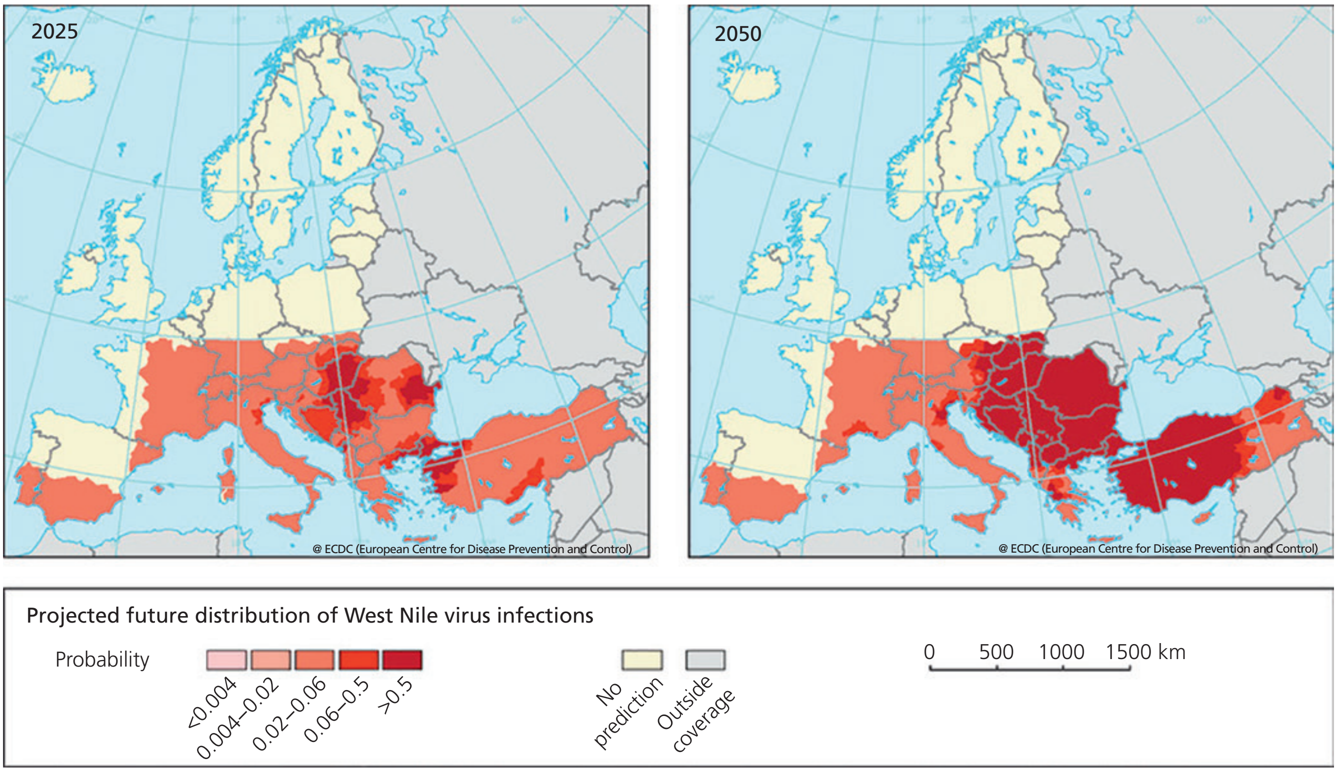

Figure 3.4 Projected future distribution of West Nile virus infections. Source: EEA (2017a), adapted from Semenza et al. (2016b); based on July temperatures for medium–high climate change scenario. Further historical data available on https://ecdc.europa.eu/en/west-nile-fever/surveillance-and-disease-data/historical

2018a) indicate an early start to the transmission season in 2018 for West Nile virus infections in the EU (Italy, Greece, Hungary and Romania) and neighbouring countries (particularly Serbia), likely to be associated with the observed weather pattern of increased temperature and early spring season in south-eastern Europe. West Nile virus transmission is dependent on other variables such as bird migration, also affected by climate change. An estimate of future changes, forecasting expanding distribution, is summarised in Figure 3.4 to illustrate the magnitude of future dissemination that may be expected in southern and eastern parts of the region.

Broadly analogous changes in distribution might be anticipated for some other vectors and pathogens. The distribution of *Aedes albopictus* mosquitoes (a known vector for chikungunya, dengue and dirofilariasis) is expanding in Europe and is implicated in chikungunya virus transmission in Italy and France and in dengue transmission in France and Croatia. Populations have also been established in Slovenia, Switzerland, Bulgaria and Romania: projections suggest that Greece and Portugal will be likely habitats in the future and that western Europe will also provide favourable climactic conditions within the next decades[21]. The distribution of *Aedes aegypti* (vector for chikungunya, dengue, yellow fever and zika) is currently restricted by intolerance to temperate winters but dissemination worldwide has increased during the past three decades. It could soon become established in the Mediterranean region and future climate change may result in northern expansion[21]. For chikungunya (*A. albopictus* and *A. aegypti* as vectors), modelling projections under RCP 4.5 and 8.5 climate change scenarios suggest moderate expansion in continental Europe, particularly France and Italy, and northwards expansion in the coming decades (Tjaden *et al.* 2017).

A European dengue outbreak, caused by changing urbanisation, globalisation and climate trends, occurred in Madeira in 2009, resulting in more than 2,000 local cases and 80 cases exported to continental Portugal (Lourenco and Recker 2014). Assessment of dengue epidemic potential using vectorial capacity on the basis of historical and projected temperatures indicates that vectorial capacity is currently sufficient for commencement of seasonal dengue outbreaks in southern Europe if sufficient populations of *A. aegypti* or *A. albopictus* were active and the virus introduced

[21] ECDC mosquito factsheets are on http://www.ecdc.europa.eu/en/disease-vectors/facts/mosquito-factsheets/.

(Liu-Helmersson *et al.* 2016). Increasing globalisation and trade will probably intensify the importation of dengue virus and vectors.

Given the historical distribution of malaria in Europe, there has been considerable interest in modelling the potential for recurrence. A comprehensive study (Caminade *et al.* 2014) compared different models under the four emission scenarios, RCP 2.6 to RCP 8.5 for the period 2050–2080. Generally, malaria modelling simulates an increase in climate suitability for endemic malaria transmission in Europe in the future, although it is acknowledged that there will be other important socio-economic factors involved. The presence of effective health care systems should be sufficient to prevent malaria from becoming re-established.

At the country level, analysis confirms the complexity of interactions and difficulty of generalising. For example, in Portugal, malaria and schistosomiasis[22], currently not endemic, are more sensitive to introduction of vectors than to temperature change (Casimiro *et al.* 2006). However, higher temperatures may increase the transmission risk of zoonoses that are endemic, such as leishmaniasis, Lyme disease and Mediterranean spotted fever.

The connection between the environment and helminth parasitic diseases is also not straightforward but climate change has the capability to drive incidence and prevalence, via the increased distribution of parasites, their vectors and host species (Short *et al.* 2017). Efforts to inform disease management plans need to include clarification of a particularly strong linkage of helminth parasites in humans to wildlife in temperate Europe (Wells *et al.* 2018). A climate-dependent introduction of the helminth *Dirofilaria repens* has been shown in Germany (in dogs (Sassnau *et al.* 2014)) and the first autochthonous human case has been described (Tappe *et al.* 2014).

There are also continuing changes in other disease threats to animals, both livestock (EASAC 2010) and domestic. For example, the brown dog tick *Rhipicephalus sanguineus*, the most widespread tick worldwide (Dantas-Torres 2010), has increased in Europe by approximately 700% since the 1960s. African swine fever was eradicated in most of Europe in the 1950s (although it remained endemic in Sardinia), but it reappeared in eastern Europe Member States in 2014. Recently, there have been reports of African swine fever in the wild boar population in Belgium[23], potentially very near to the most important western Europe centres of EU pigmeat production and export. Although there may be many factors responsible for the new spread of African swine fever across Europe[24], climate change may be resulting in wider distribution of *Ornithodorus* tick species as a virus reservoir for African swine fever[25]. The emergence of bluetongue disease of sheep in northern Europe with high impact on animal health and high costs has also been attributed to climate change, and modelling indicates the likelihood of further extension northwards, a longer transmission season and larger outbreaks (Jones *et al.* 2019). Because of the complexity of mechanisms involved, disease transmission uncertainty is greater than climate uncertainty but similar transmission processes apply to other vector-borne animal diseases such as epizootic haemorrhagic disease, African horse sickness and Schmallenberg infections (Jones *et al.* 2019).

3.6.2 Water-borne diseases

Water-borne pathogens often act in concert through two major exposure pathways: drinking water and recreational water use. Determining the role of climate in water-borne infections is another priority for public health research and surveillance. A literature review (Herrador *et al.* 2015) combined epidemiological and meteorological data (including for Europe although there are few such studies here) to analyse associations. A majority of studies identified a positive association between increased precipitation or temperature and infection, but not all did. Another systematic review of literature worldwide (including European studies) reveals two areas of agreement in the evidence base: an association between ambient temperature and diarrhoeal diseases and an increase in diarrhoeal disease following heavy rainfall and flooding events (Levy *et al.* 2016). The relationships are complex and there is need for more research to analyse variables, for example type of microorganism, geographical region, type of water supply and its treatment.

There has been a substantial increase in *Vibrio* infections, which can be life threatening, primarily to people with immunodeficiency, unless a proper diagnosis is made with the right treatment given in time. The infection is associated with an increase in sea surface temperature exceeding 16°C (Daniels 2011). In 2014, which was an unusually hot summer in the Baltic, the highest number of cases so far was reported in the northernmost parts of the Baltic Sea (Semenza *et al.* 2017), associated with *Vibrio* blooms in marine waters (EEA 2017a). Mechanisms for the global distribution of *Vibrio cholerae*, including in European waters, have been reviewed in terms of water blooms and the propensity for biofilm formation on biotic and abiotic surfaces (Lutz *et al.* 2013).

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22 Schistosomiasis has been recently introduced into Corsica (Boissier *et al.* 2016).
23 https://ec.europa.eu/food/animals/animal-diseases/control-measures/asf_en.
24 https://www.efsa.europa.eu/en/topics/topic/african-swine-fever.
25 https://www.epizone-eu.net/en/Home/show/African-swine-fever.htm.

Legionnaires' disease is caused by *Legionella* species. Bacteria found in fresh water and contaminating man-made water systems. The burden of Legionnaires' disease is growing in Europe (Beaute 2017); there may be various explanations for this observation of increased risk – including improved surveillance – but some studies have found an association with wet and warm weather (Brandsema *et al.* 2014).

Further detailed discussion of water-borne diseases can be found in ECDC (2012) and EEA (2017a).

3.6.3 Food-borne infections

The relationship between climate change, food-borne pathogens and illness in higher-income countries is also complex (Uyttendaele *et al.* 2015; Lake and Barker 2018). There is more to be done to explore which pathogens, with what effect and over what timescale are the highest priority. This requires improved surveillance and integration of plant, animal and human surveillance systems. Tackling food-borne infections also depends on improving the coherence between different policy objectives—such as those for food safety and for increasing the recycling of food waste.

One priority is *Salmonella* species where, because of its thermophilic nature, an increase in temperature will increase pathogen multiplication and spread in food, water and contaminated environments (WHO Europe 2017a; Mora *et al.* 2018). Further evidence to document the increasing threat from *Salmonella* and other food-borne infections such as norovirus, campylobacteriosis and cryptosporidiosis is summarised by EEA (2017a). Other detailed discussion of food-borne pathogens can be found in ECDC (2012), and in 2018 the European Food Safety Authority initiated a relevant new project[26]. A summary of some of the effects of climatic variables on water- and food-borne pathogens (bacteria, viruses and parasites) is provided in Table 3.2 but it is emphasised that the resultant impact on health will also depend on other variables.

3.7 Food and nutrition security and agriculture

Globally, there has been a recent increase in the numbers of people suffering undernutrition—this may already be attributable in part to climate change (FAO *et al.* 2018). Future productivity of food crops, particularly in the tropics and sub-tropics, will decline according to most climate scenarios and this problem will be compounded in poorer countries if there are heat-induced declines in labour productivity the income of outdoor labourers, including subsistence farmers, is reduced (see Andrews *et al.* (2018) for further discussion of workability and survivability, and links with poverty). As a generalisation for Europe, climate change is expected to improve the suitability of northern Europe for growing crops, such as cereals but to reduce crop productivity in large parts of southern Europe although the growing season there might shift into the winter in partial compensation. An estimate of aggregated future projections in crop production, taking account of temperature, precipitation and CO_2 is summarised in Figure 3.5. In addition to drought, yield performance may be impaired by excessive rain in parts of Europe (Kahiluoto *et al.* 2019).

At temperature increases of greater than 2°C across the EU, changes in agricultural productivity and habitat suitability are projected to lead to potential doubling of the arid climate zone (Ciscar *et al.* 2018). Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming—in central Europe as well as in other regions (IPCC 2018). Cereal crop yields in Mediterranean countries may be particularly vulnerable (Figure 3.4) because of the increasing temperature coupled with water shortages: southern Europe is likely to experience significant food production losses (up to 25% at the 5.4°C temperature increase scenario (WHO Europe 2017a)). Further detailed information on European regions and crop characteristics are in EEA (2017a) (and see discussion below). The consequences will not only be local: declining crop productivity in southern Europe will affect the export of food supplies

Table 3.2 Demonstrable links between climate and distribution and/or incidence of some pathogens

	Campylobacter	*Salmonella*	*Listeria*	*Vibrio*	*Cryptosporidium*	*Norovirus*
Temperature	+	+	?	+	+	+
Precipitation	+	+	?	+	+	?
Humidity	+	+	+	?	?	?
Ultraviolet radiation	+	+	+	+	+	?
Recreational activities	+	+	?	+	+	+

Table adapted from EEA (2017a), where further variables are included, using data from Semenza *et al.* (2012). +, Impact on basis of current knowledge; ?, impact unknown. See Semenza *et al.* (2012) for further description of variables.

[26] 'Climate change and emerging risks for food safety', www.efsa.europa.eu/en/press/news/180221.

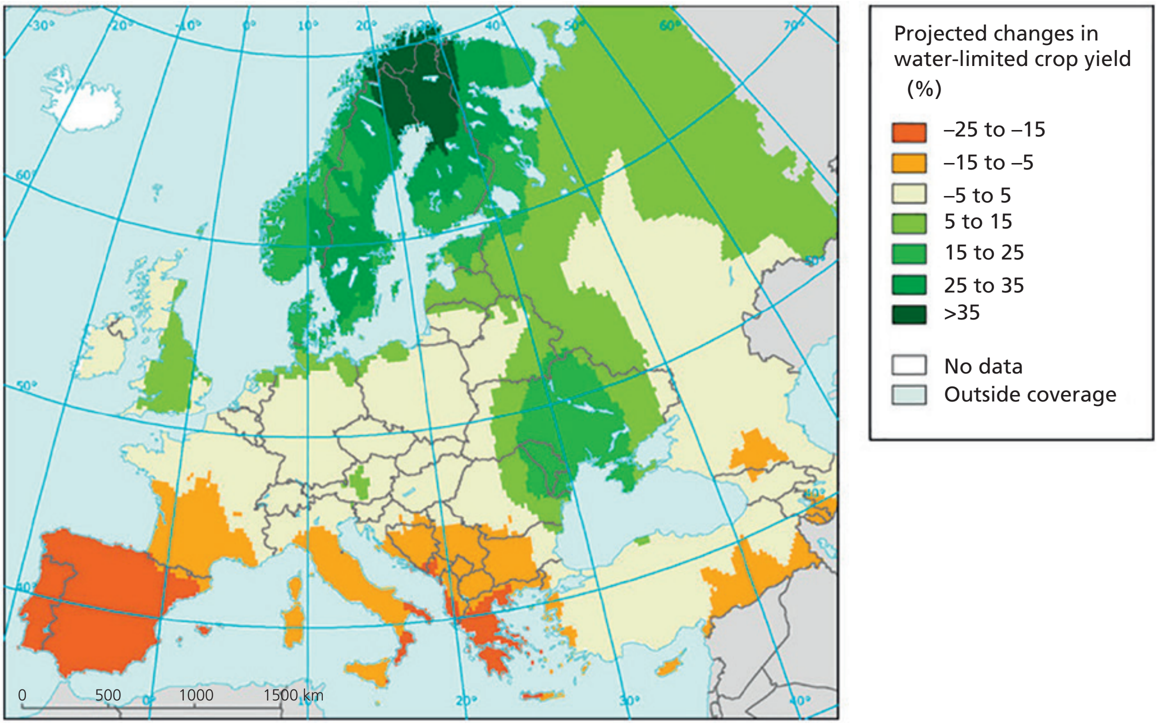

Figure 3.5 Projected changes in water-limited crop yield. Source: EEA 2017a, using data from Ciscar et al. (2011) and Iglesias et al. (2012). This map compares relative changes for the 2050s with the period 1961–1990 for a medium–high climate change scenario. The simulation assumes that the irrigated area remains constant: the results combine the impacts on the key crops wheat, maize and soybean, weighted by their current distribution.

to central Europe. And effects of climate change on agriculture and food systems worldwide will have consequences for availability of food imports into the EU (FAO 2018). If food costs rise, the EU can probably still satisfy its food and nutrition security requirements by importation but this will have increasing consequences for the rest of the world.

Climate resilience of crops, for example wheat in central and southern Europe, is currently not receiving the attention it deserves by breeders, seed and wheat traders and farmers (Kahiluoto *et al.* 2019). The climate change impacts on crop productivity will depend on many factors: high temperatures, variation in temperature, precipitation (and soil moisture), other water availability, O_3, direct impacts of CO_2 on levels of key nutrients (such as zinc and iron in wheat and legumes (Myers *et al.* 2016); proteins and micronutrients in rice (Zhu *et al.* 2018)) and effects mediated by increasing numbers of plant and animal pests and pathogens. While much of the literature characterises impacts of climate change on cereal commodity crops, there are also likely to be negative effects on yields of vegetables and fruit, with further nutritional and health consequences (see, for example, Tuomisto *et al.* 2017). Europe's prolonged drought in 2018 has caused the most severe problem to the EU vegetable sector from reduced yields in the past 40 years according to the European Association of Fruit and Vegetable Producers[27], with northern/central European countries (France, Belgium, Netherlands, Germany, UK, Hungary and Poland) most affected. Meta-analysis of the scientific literature (including studies in Europe, mainly southern Europe) on effects of ambient temperature, CO_2, O_3, water availability and salinisation concluded that in a 'business-as-usual' scenario there will be significant reduction of yields of vegetables and legumes (Scheelbeek *et al.* 2018). Previous work by EASAC (2017b) has discussed in detail potential impacts of climate change on agricultural productivity and the implications for European food systems and health. Human health effects can be expected arising from potential reductions in nutrient intake but also because of food safety vulnerabilities (food-borne infections and toxins, see preceding section). Adoption of climate-stabilisation pathways would reduce the projected number of climate-related deaths in Europe, with the degree of impact depending on stringency (Springmann *et al.* 2016).

There will also be continuing negative effects on fisheries worldwide (see, for example, Whitmee *et al.* 2015), on assumption of linear changes in environmental parameters, with temperature effects exacerbated if nonlinear. There may be less decline in

[27] www.euractiv.com/section/agriculture-food/news/extreme-drought-causes-eu-vegetables-most-serious-crisis-in-40-years/.

fisheries in Europe in consequence of fish moving from tropical to temperate latitudes, although the rise in sea surface temperature adjacent to Germany, Greece and Italy fishing basins (Watts *et al.* 2018b) may have local consequences, and ocean acidification will reduce shellfish productivity. The risk of impact to fish and other foods from the oceans also depends on the degree of exposure to over-exploitation. There are opportunities to reduce climate impact through effective fisheries management (Cheung *et al.* 2018).

The impact of climate change on agricultural ecosystems should not be considered in isolation as there are other environmental consequences of the changes in temperature and soil moisture. For example, drought predisposes to risk of forest fires and to increasing dust, both associated with the health effects of air pollution. Increased use of water for irrigation might increase water-borne diseases and exacerbate water scarcity with consequences for ecosystem stability and potable supplies. Climate change will also have implications on food systems more generally: that is, on all the steps from harvesting through to processing, transporting, trading and consuming (EASAC 2017b). A comprehensive global analysis (Fanzo *et al.* 2017) discusses these broader aspects of climate change on food systems and nutrition, highlighting priorities for collecting data and conducting research to construct a robust evidence base to support coordinated action and to evaluate the consequences of those actions.

Effects of climate change on health may also be mediated by changing patterns of agricultural pathogens and use of pesticides. Increases in temperature and changes in precipitation patterns are major determinants of the levels of pests and pathogens in farming. Modelling of the three most important cereal crops worldwide – wheat, rice and maize – suggest yield loss to insects will increase 10–25% per 1°C of warming (Deutsch *et al.* 2018), because of increases in both insect reproductive rate (more insects) and metabolic rate (eating more). Effects are computed to be greatest in the temperate zone, including the EU, for example from the action of the European corn borer. In another example of impact, the codling moth, an apple pest, is projected to shift its occurrence in Switzerland. The risk of developing a third insect generation per season is increasing and implies an intensification and prolongation of control measures (Hirschl *et al.* 2012).

Climate change can be expected to reduce environmental concentrations of pesticides because of increased volatilisation and accelerated degradation, necessitating greater application. Review of the literature (Delcour *et al.* 2015) reveals expectations of increased pesticide use in response to climate change, in the form of higher amounts, doses and frequencies. In consequence, an increased occupational exposure is predicted (Gatto *et al.* 2016), as well as the potential for increased environmental contamination (Landrigan *et al.* 2018a), for example of drinking water. A reduction in the number of pollinating insects will have further implications for food security. All of these effects, for pollinators and on human health, have consequences that need to be taken into account to balance the positive impacts of use of plant protection products on pests and agricultural productivity.

Fungal pathogens pose an additional problem. Research shows that climate change provides more favourable conditions for some agricultural fungal pathogens (Luck *et al.* 2011) and, although projections are subject to various uncertainties, modelling studies are providing new insight on the challenges for modelling microbial interactions, resistance, host shift and new diseases (Newbery *et al.* 2016). Climate change is likely to increase antifungal drug use in agriculture (Jampilek 2016). There is already an unprecedented rise in emerging strains of fungi resistant to common antifungal drugs, associated with overuse of these chemicals (Fisher *et al.* 2018). The particular problem is the dual use inherent in farmers spraying crops with the same drugs (such as azoles) that are used to treat fungal infections in patients. Azoles account for more than 25% of all fungicides in the EU and resistant strains circulate widely in the air. Problems in treating fungal disease in patients are likely to keep increasing if effective action is not taken.

The burden of malnutrition encompasses overweight and obesity as well as undernutrition and micronutrient deficiencies. Review of the literature exploring the relationships between obesity and climate change emphasises the common drivers, for example motorised transport (An *et al.* 2017). However, it is conceivable that climate change may also promote obesity via changing dietary consumption: because of the effects of climate change to decrease production of nutrient-rich foods, inducing higher prices of those foods, there may be increase in consumption of cheaper, energy-dense foods (Drewnowski *et al.* 2013). These effects may be compounded by reduced physical activity at higher temperatures (see section 3.3.5). In this context, it is also worth noting the contribution of obesity as a risk factor for diabetes because of other evidence that both obesity and diabetes carry an increased risk of heat-related illness (Kenny *et al*. 2010) and mortality (Åström *et al.* 2015). The effect of diabetes on the physiological response to thermal stress has been reviewed in detail by Kenny *et al*. (2016).

3.8 Climate change and environmental toxicology: air pollution and other pollutants

Pollution endangers planetary health, destroys ecosystems and is intimately linked to global climate change (Pontifical Academy of Sciences 2017). Current estimates of pollution-related disease and premature death underestimate pollution's full impacts and there is much to be done to quantify the contributions of pollution and climate in contributing to the global burden of disease (Cohen *et al.* 2017; Hu *et al.* 2018; Landrigan *et al.* 2018b)[28]. There are many relevant environmental pollutants besides pesticides (section 3.6), and climate change can mobilise toxins and other pollutants in the environment, for example into water supplies (Landrigan *et al.* 2018a; Mora *et al.* 2018). Climate change will increase dust storms and is also predicted to increase the level of exposure of many environmental chemicals because of direct or indirect effects on the generation, use patterns, transport and fate of chemicals and because of changes in human behaviour (Balbus *et al.* 2013). In addition to air pollution and environmental chemicals, there are risks from various natural toxins, for example mycotoxins and algal toxins, as well as many synthetic contaminants from manufacturing processes, for example polychlorinated biphenyls, pharmaceutical residues, other endocrine disruptors and nanomaterials (Landrigan *et al.* 2018a). In some cases the risks may be increased under climate change.

In the WHO European region annually, outdoor air pollution causes about 500,000 premature deaths (Watts *et al.* 2018b) and household air pollution is responsible for about 120,000 premature deaths (WHO 2017a,b), but it is again important to remember that these data relate to a far wider geographical area than the EU and that many of the deaths are due to pollutants co-emitted with GHGs and short-lived pollutants (Gao *et al.* 2018). On the other hand, previous estimates of the public health and economic effects of air pollution have not measured the full consequences for health. For example, there is emerging evidence for impacts of air pollution on labour market performance and from the *in utero* and early-childhood exposure that will influence later-life outcomes via cognitive ability development (Graffzivin and Neidell 2018). Seven million babies in Europe are living in areas where air pollution exceeds WHO recommended limits and such exposure may affect brain development and cognitive function (Rees 2017). There is also evidence from studies on primary school children, for example in Spain (children 7–10 years old), that exposure to traffic-related NO_2 and $PM_{2.5}$ is associated with acute neuropsychological effects in terms of attention processes (Sunyer *et al.* 2017).

3.8.1 Fossil fuel impacts

Fossil fuel combustion in high- and middle-income countries and burning of biomass in low-income countries accounts for a high proportion of anthropogenic airborne particulate pollution, including black carbon, and almost all pollution by oxides of sulfur and nitrogen as well as, of course, for considerable GHG emissions (see further discussion subsequently in section 4.4). Coal is the world's worst polluting fossil fuel and coal combustion is, therefore, an important cause of both pollution and climate change. For example, analysis of the contribution made by coal power plants in the Western Balkans to EU health impacts and costs demonstrates a significant burden in terms of premature mortality, bronchitis and asthma symptoms in children, hospital admissions and lost working days (Matkovic Puljic *et al.* 2019).

Measures to mitigate emissions of short-lived climate pollutants, together with GHGs (Smith and Mayer 2019), can contribute to attaining multiple SDGs (Haines *et al.* 2017; Landrigan *et al.* 2018b). Doherty *et al.* (2017) conducted a comprehensive analysis of the literature on future effects of mitigation measures on air quality (mainly PM and O_3 but also NO_x and methane) and corresponding health effects, considering different RCPs and projections up to the year 2100. A recent UK modelling case study (Williams *et al.* 2018) also provides detailed mortality projections for different air pollution scenarios (encompassing $PM_{2.5}$, NO_2 and O_3). This study emphasises that mitigation policies need to be carefully designed to avoid undue increases in harmful air pollution emissions by replacement fuels, particularly in view of additional data disclosing effects at levels below WHO guidelines (Burnett *et al.* 2018), which suggest even higher numbers of premature deaths from ambient air pollution than WHO and other estimates, amounting to about 8.9 million worldwide annually.

A very recent publication (Lelieveld *et al*. 2019) provides additional evidence for the importance of taking an integrated approach to tackling the mutual goals of clean air and a stable climate. In this research, the benefits of total anthropogenic emission removal are quantified by modelling public health outcomes attributable to fossil fuel use. The modelling shows that a phaseout of fossil fuels would avoid an excess global mortality rate of 3.6 million (range 3.0–4.2 million) deaths per year at today's population. The global benefit could be up to 5.6 million (range 4.5–6.5 million) fewer deaths per year from ambient air pollution if, additionally, emission of non-fossil fuel anthropogenic sources of ambient air pollution, in particular from agriculture and household air pollution, were controlled. The main causes of death arising from air pollution are ischaemic heart disease, chronic obstructive pulmonary disease, cerebrovascular disease, lung cancer, other NCDs and lower respiratory tract infections.

[28] It is noteworthy that the first WHO Global Conference on Air Pollution and Health was held in late 2018, recognising the many relevant interactions: between climate change mitigation that also reduces air pollution and the efforts to curb air pollution that reduce short-lived climate pollutants as well as long-lived CO_2, thus slowing the pace of climate change.

Table 3.3 Excess mortality rate attributed to air pollution. Data derived from Lelieveld *et al.* (2019)

	All sources: excess deaths ×10³/year	Deaths from fossil-fuel-related sources of air pollution ×10³/year	Deaths from all anthropogenic sources ×10³/year
World	8,793	3,608	5,554
EU-28	656	348	499

Using country-level data presented in the appendix of Lelieveld *et al*. (2019), it is also possible to calculate total effects for the EU-28 countries (Table 3.3). Uncertainty ranges are not shown in this synopsis but the figures can be seen as approximations.

For the EU overall, fossil-fuel-related emissions account for more than half of the excess mortality attributed to air pollution, and total anthropogenic emissions account for 75% of avoidable deaths. The lowest proportional contributions of fossil fuels to human mortality are found in Malta, Portugal, Spain, Ireland, Greece, Denmark and the UK; the highest proportions in Austria, Croatia, Germany, Hungary, Poland and Romania (Lelieveld *et al.* 2019). The remainder of air pollution not arising from anthropogenic sources comes from natural sources such as aeolian dust, the concentration of which varies greatly dependent on location.

There are some complexities to consider in the assessment of the implications for public health and climate because decarbonisation removes cooling aerosols as well as warming pollutants and CO_2. The loss of cooling aerosols has a rapid onset effect but, overall, the net effect is still a reduced temperature rise and it is possible to stay under 2°C warming if fossil fuels are phased out rapidly (Lelieveld *et al.* 2019). Moreover, because aerosols affect the hydrologic cycle such that removing anthropogenic emissions in the model increases simulated rainfall in various global regions, there would be additional health co-benefits arising from increased water- and food- security.

3.8.2 Volatile organic compounds

Many higher plants, and especially trees, are a source of emissions of biogenic volatile organic compounds. These are mostly from the terpene family of compounds and have a high chemical reactivity. As a consequence, they participate rapidly in atmospheric chemical reactions and can make a substantial contribution to the level of toxic air pollutants, most notably ground-level O_3 (Donovan *et al.* 2005) and fine PM, referred to as secondary organic aerosol (Carlton *et al.* 2010). The emissions of volatile organic compounds are highly temperature sensitive (Staudt and Berlin 1998; Tarvainen *et al.* 2005) and even a relatively small increase in atmospheric temperatures can lead to a substantial increase in emissions with a consequence of increased production of toxic secondary pollutants.

3.8.3 Ultraviolet radiation and O_3 concentrations

Challenges are now arising in response to climate change, with complex interactions between the drivers of climate change and those of stratospheric O_3 depletion (Williamson *et al.* 2014; Bais *et al.* 2015).

Thus, changes in climate as well as in stratospheric levels of O_3 are altering exposure to ultraviolet radiation but the consequences are not yet fully ascribed. The nature of the global burden of disease from solar ultraviolet radiation has been discussed in detail by the WHO (Lucas *et al.* 2006): most deaths are from malignant melanoma and skin carcinomas. Mortality rates from malignant melanoma (which has decadal delay between exposure to ultraviolet radiation and death) have increased markedly in Europe (Watts *et al.* 2018b) which, however, are likely to be due to changes in behaviour patterns possibly contributed to by warmer temperatures.

3.8.4 Indoor environment

Factors in the indoor environment that may affect health[29] related to climate change are temperature and air quality; water damage and dampness in buildings may also become more common because of frequent and extreme precipitation and flood events. Household air pollution also contributes to ambient air pollution and is a source of black carbon. An indoor environment that is hot and humid may increase the risk of moisture-related occurrence of mould and higher concentrations of chemical substances. Health risks include respiratory diseases such as allergy, asthma and rhinitis as well as more unspecific symptoms such as eye and respiratory irritation. Asthma and respiratory symptoms have been reported to be 30–50% more common in humid houses (Fisk *et al.* 2006).

Humidity can contribute to higher concentrations of chemical pollutants indoors from building materials: higher moisture content is associated with greater

[29] WHO Guidelines for indoor air quality cover both biological air pollution (2009) and chemical pollutants (2010); see http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/policy/who-guidelines-for-indoor-air-quality.

emissions of DEHP, a phthalate, from PVC wallpaper (Hsu *et al.* 2017). Older people are vulnerable, especially those living alone, as well as people with allergies or asthma, and those who are socio-economically vulnerable (Vardoulakis *et al.* 2015).

3.9 Allergy

The prevalence of allergic respiratory and skin diseases within the general population in Europe has been estimated at 40% and has increased dramatically over the past decades. This includes allergic rhinoconjunctivitis (pollen allergies) and asthma (although not all asthma is allergic). Climate change has been suggested as one factor accounting for the increasing prevalence of allergic disease. However, the influence of climate change and increased CO_2 is complex in affecting the range of allergic species as well as the timing and length of the pollen season and pollen productivity, also affecting the release and atmospheric distribution of pollen. It is not only the classical climatic variables that influence the pollen season. In several experiments that included the most allergenic pollen taxa such as ragweed and grass, it was demonstrated that increasing CO_2 concentrations stimulate plant growth and increase pollen production (see, for example, Singer *et al.* 2005; literature review by Menzel and Jochner 2016). One effect of extreme weather is the occurrence of thunderstorm-associated asthma (systematic review by Dabera *et al.* 2013) whereby an increase in humidity causes fragmentation of pollen, thus enabling it to penetrate into small airways of the lung.

A quantitative case study of the potential effect of climate change upon pollen allergy focused on common ragweed using two GHG scenarios, RCPs 4.5 and 8.5, and different plant invasion scenarios (Lake *et al.* 2017) (see Figure 3.6). This modelling indicates that sensitisation to ragweed will more than double in Europe by 2041–2060 (77 million people). Sensitisation will increase in countries with existing ragweed problems, for example Hungary and the Balkans, but the greatest proportional increases will occur where sensitisation is currently uncommon, for example Germany, Poland and France. Climate, air pollution and aeroallergens interact in a variety of ways. Several studies have shown an influence of air pollution on the allergen content of pollen grains and an increased health risk for allergic diseases, especially in areas with high traffic emissions (see, for example, Kinney *et al.* 2016). Thus, a reduction in air pollution as an effect of climate change mitigation (see Chapter 4) could also be a co-benefit for people suffering from allergies.

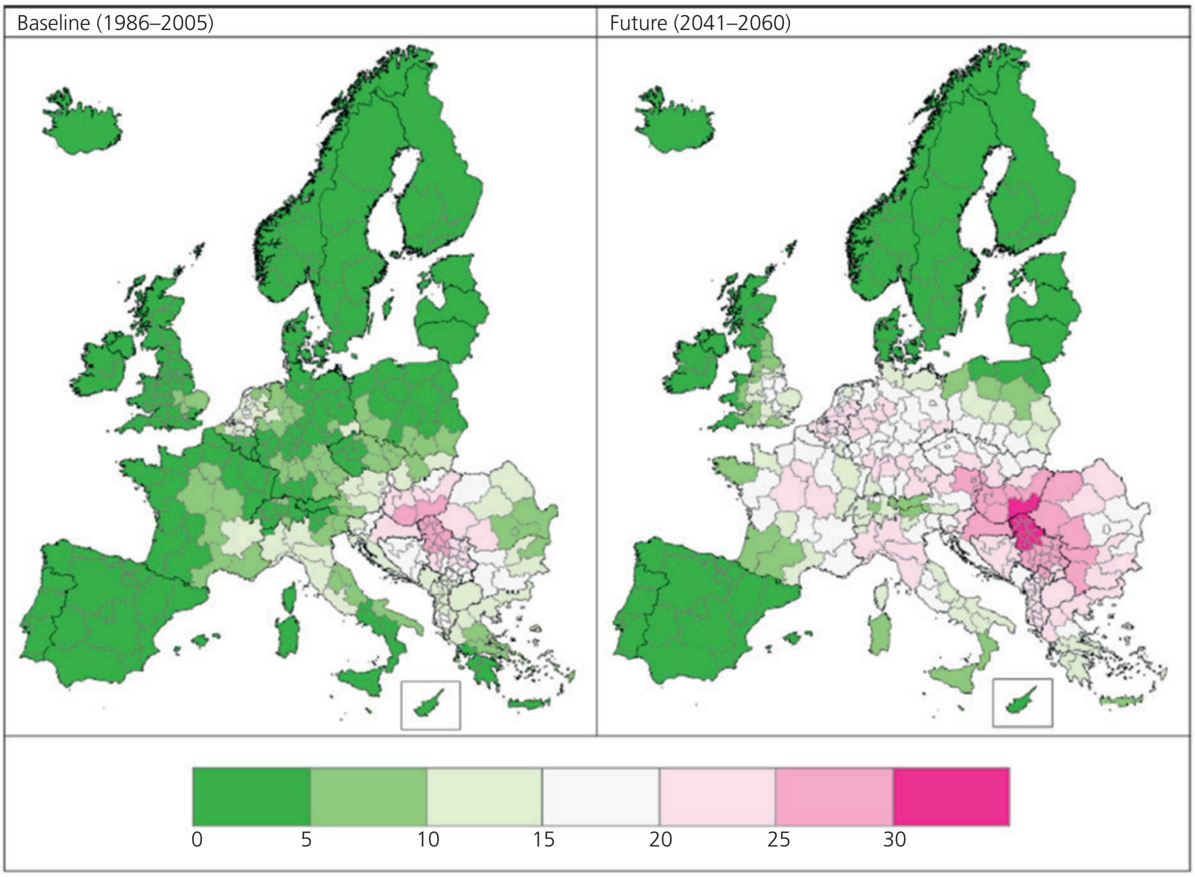

Figure 3.6 Percentage of population sensitised to ragweed pollen at baseline and in the future; averaged results for WRF/RegCM and CHIMERE, RCP4.5, and reference invasion scenario (Lake et al. 2017). © EuroGeographics for the administrative boundaries.

3.10 Forced migration and conflict

The total number of people vulnerable to migration will increase substantially by the end of the century without significant further action on climate change. Among areas likely to be worst affected is the Sahel (Defrance *et al.* 2017), and the EU is likely to continue to be a major receiving area for climate refugees. Climate-change-induced migration can occur through a variety of different social and political pathways, including population displacement by heat, sea level rise, extreme weather events and exacerbation of food and water security issues.

There is some evidence, for example from Syria, that a reduction of national capacity to deliver food and nutrition security in consequence of drought was a factor leading to civil unrest, conflict and forced migration, both internally and to other countries. However, there are scientific and methodological challenges in evaluating the links between climate change and conflict. Recently, such claims have become more controversial because of the suggestion that there is sampling bias in the evidence base: research had focused on regions of violent conflict (Anon. 2018d; Adams *et al.* 2018). Nonetheless, although it is important not to overstate an association, it is reasonable to describe climate as a contributing factor to some conflicts (Whitmee *et al.* 2015; EEA 2017c; WHO Europe 2017a,b; Gleick *et al.* 2018). In understanding the evidence base, there is need to attend to the context in which droughts and other climactic extremes may increase the risk of forced mobilisation. For example, for agriculturally dependent groups in very poor countries, drought during the growing season has been associated with the increased likelihood of sustained conflict (von Uexkull *et al.* 2016).

Other evidence supports the association between climate change and migration. An analysis of weather variations in 103 countries for the period 2000–2014 (Missirian and Schlenker 2017) found that when temperatures deviated from the moderate optimum, asylum applications to the EU increased in a nonlinear fashion. This observation implies an accelerated increase under continued future warming: if everything else is held constant, asylum applications by the end of the century are predicted to increase on average by 28% per year at RCP 4.5 and by 188% under RCP 8.5. The issues relating to climate change and migration are discussed further in the European Commission's JRC publication (Migali *et al.* 2018) and in the latest Lancet Countdown assessment (Watts *et al.* 2018b).

However, the impacts on health are less easily quantified. One significant factor is the living conditions that are allowed for migrants, particularly if there has been declining immunisation coverage in the countries of origin of migrants (Berkley 2017). For example, previous EASAC work on tuberculosis (EASAC 2009), noted that migrants may only be infected after arrival in their host country in consequence of their impoverished socio-economic status. In the past 3 years, the EU has experienced the most significant influx of migrants and refugees since the Second World War. The institutional response, including the health services, has been suboptimal, failing to address specific vulnerabilities (Puchner *et al*. 2018). For example, in Greece the asylum-seekers crisis has led to unmet health needs both for locals and for refugees (see Kotsiou *et al.* 2018)[30]. These growing challenges have to be countered by a sustainable and comprehensive approach to screening and vaccination of migrants (ECDC 2018b) and by integrating all into strengthened national health systems, which must be climate-resilient and migrant-inclusive (Schwerdtle *et al.* 2018).

3.11 Mental health effects

Mental health effects can arise from all of the various impacts described in the preceding sections and are considered here as a cross-cutting issue. From detailed review of the literature worldwide (Hayes *et al.* 2018) it is clear that the specific attribution of mental health outcomes to climate change remains challenging, but the risks of effects are accelerating, disproportionately affecting those who are most marginalised. Policy interventions on climate and mental health need to be coordinated, for example with the SDGs and the Sendai Framework on disaster risk reduction.

Effects on mental health, as on physical health, can derive directly from impacts of floods, storms, wildfires and heatwaves. Other effects are more indirect, for example in response to changing temperature and rising sea levels that cause forced migration (Clayton *et al.* 2017; and see footnote 31). Acute mental health effects include post-traumatic stress disorder, anxiety, substance abuse and depression. Chronic effects include higher rates of aggression, violence and hopelessness. One recent study of long-term data (in the USA and Mexico) has shown an association between higher temperatures and increased suicide rates (Burke *et al.* 2018).

Factors that may increase vulnerability to mental health effects include ageing (Bei *et al.* 2013), pregnancy (Xiong *et al.* 2010), geographical location, pre-existing medical conditions (including mental disorders, Page *et al.* 2012) and socio-economic inequalities. Stress from climate extremes can cause children to experience changes in behaviour, development, memory, executive

[30] See also the publication from the International Rescue Committee (www.rescue-uk.org) 'Unprotected, unsupported, uncertain' documenting mental strain that includes suicide attempts, suicidal ideation, anxiety, depression and post-traumatic stress disorder (section 3.11).

function, decision-making and scholastic achievement (Van Den Hazel 2017).

For example, in addition to the direct effects of heat on cardiovascular disease/heart failure and heat stroke (section 3.2), there are increased risks to mental health and well-being. A significantly increased risk of dying on hot days is reported to be associated with depression and other mental disorders (Michelozzi *et al.* 2005; Schwartz 2005; Bouchama *et al.* 2007; Stafoggia *et al.* 2008; Schifano *et al.* 2009). One of the explanations may be medication with diuretics and psychotropic drugs which, at high temperature, have been associated with an increased risk of mortality and morbidity, especially in the elderly (Martin-Latry *et al.* 2007; Hajat *et al.* 2010).

Systematic literature reviews for the period up to 2014 (Stanke *et al*. 2012; Fernandez *et al*. 2015) provide a significant body of information on mental health outcomes after flooding but there is a relative paucity of longitudinal studies and lack of controls for confounding. An analysis of UK data for the period 2013–2014 (Munro *et al.* 2017) on the association between flooding and mental health outcomes (primarily depression and post-traumatic disorder) observes higher and longer-term impacts (e.g. 1 year after the event) if displacement by flooding occurs without warning. Systematic analysis of the literature on flooding confirms a long-term trend of increasing psychological disease, particularly in poorer socio-economic conditions (Zhong *et al.* 2018).

A systems approach has been recommended to tackle the needs of the emerging field of mental health effects (Berry *et al.* 2018). From this perspective, there is need for more research on the short- and long-term effects of climate change with regard to (1) immediate effects on incidence and severity of mental health outcomes in response to extreme events; (2) focusing on vulnerable communities expressing disruption to social, economic and environmental determinants that promote risk; and (3) understanding how climate change as a global environmental threat may create emotional stress and anxiety about the future[31].

3.12 Vulnerable populations and regions in Europe: differential exposure, differential vulnerability and differential consequences

Climate change will affect everybody but some population groups and settings are more vulnerable than others. Historically, children and the elderly account for most of the death toll during times of severe environmental stress. As discussed previously, individuals may be vulnerable because of particular sensitivity or because of inadequate operation of health and social systems or other infrastructure (IPCC 2014), for example a lack of resilience in the electricity grid, resulting in power failures in time of peak need. There will be differing vulnerabilities in different locations. Among those most vulnerable, and discussed with regard to particular health effects in the previous sections, are the elderly, children, those who are physically very active, migrants and other marginalised groups (Figure 3.2). Evidence for exacerbation of effects in urban areas has been reviewed in previous sections and will be considered further in Chapter 4.

Those who are already vulnerable may be susceptible to relatively small changes in climactic conditions. There is need for more research in both the biosciences and social sciences to identify the basis for vulnerability. Future projections for greater impact of climate change in the elderly (in the USA) have been related to their greater sensitivity to environmental changes including exposure to air pollution, ambient temperature, other toxins and infectious agents, in combination with factors such as urbanisation (Carnes *et al.* 2014). The greater susceptibility of the elderly can be explained by their lower physiological reserve capacity, slower metabolism and more slowly responding immune system. The cardiovascular and central nervous systems may be particularly at risk. Vulnerability in the elderly may be related both to poorer physical health (and their medications) and to their underestimation of heat-related health risk. Twenty-five per cent of the EU population is now 65 or older and the changing European demographics (population ageing) means that the consequences of climate change on health of the elderly will affect a progressively greater proportion of the population.

Children have been considered more vulnerable to climate change for several main reasons[32]: their behaviour exposes them to risks, their bodies respond differently to exposures and they depend on others. Ahead of them, they have a lifetime of exposure to potential harms. More research is needed in the European context. For the mother/foetus, unusually high temperature exposure affects a range of birth outcomes including length of gestation, birth-weight, stillbirth and neonatal stress (Kuehn and McCormick 2017). Recent systematic literature analysis confirms the vulnerability of the pregnant woman/foetus (Mora *et al.* 2018) and

[31] See also the European Climate Adaptation Platform, https://climate-adapt.eea.europa.eu/metadata/publications/climate-change-and-mental-health-in-the-uk-impacts-of-changes-in-temperature-precipitation-and-uv.

[32] Doctors for the Environment Australia 'Protecting children's health in a changing climate', October 2018, www.dea.org.au/protecting-childrens-health-in-a-changing-climate/.

further effort is warranted to establish uniform standards for assessing effects (Kuehn and McCormick 2017).

City dwellers are exposed to higher heat stress because of urban heat islands and other effects; these have been discussed in previous sections and will be considered further in the next chapter. Certain regions within Europe may be more vulnerable than others and the previous sections have also discussed in detail some of the health effect issues for southern Europe, relating in particular to heat, flooding, agriculture, infectious diseases and pollution. We provide further information on specific regional vulnerability in the following sections, but we emphasise that climate change affects all of Europe.

3.12.1 Southern and south-eastern Europe

Changing water quantity and quality will have significant effects (Ciscar *et al.* 2018): for example, an increase in drought makes the Mediterranean Basin regions vulnerable to longer fire seasons and increased risk of fires. Occurrence of water-borne diseases is also related to water quality and, according to WHO Europe (2017a,b), more than 30 infectious diseases are considered climate-sensitive and relevant in the Mediterranean.

In the Mediterranean region, risks associated with increases in drought frequency and magnitude are substantially higher at 2°C than 1.5°C (Ebi *et al.* 2018a). A recent review of the effects of climate change in exacerbating environmental problems in the Mediterranean basin (Cramer *et al.* 2018) identifies a combination of changes in five interconnected domains – water, ecosystems, food, health and security – and provides further assessment of the substantial literature available on food systems and health impacts of climate change in this region.

A Regional Framework for Climate Change Adaptation in the Mediterranean was endorsed by members of the Barcelona Convention[33] in 2016, with the aim of increasing resilience to the adverse impacts of climate variability by 2050.

3.12.2 Arctic

The Arctic region is warming at a rate almost twice the global average, resulting in profound and rapid changes in living conditions and the environment (EEA 2017a,b); these changes are of concern to several of the member academies of EASAC[34]. The relevance of Arctic climate change to health applies both to those living in the Arctic region and to those susceptible to the implications of Arctic changes on the rest of Europe (and the world).

A warming Arctic brings wider European and global challenges to the environment (G7 2018):

- melting ice and sea level rise;
- diminishing snow cover accelerating global warming from albedo loss;
- thawing permafrost resulting in increasing release of GHGs;
- discharge of pollutants and disease strains from melting ice and snow;
- influx of freshwater in the Arctic Basin which could affect the thermohaline circulation that drives the North Atlantic Current and exerts strong influence on European weather (see further discussion in section 3.13).

Changes to the Arctic terrestrial and marine ecosystems will have consequences for the health and well-being of coastal communities in the region (G7 2018). Among the local health issues are those linked to chemical pollution, and research is continuing to characterise this exposure and the health impacts. Other local issues include the implications for infectious disease in humans and animals. Changes in Arctic temperature and humidity may influence the rate of development and survival of pathogens and vectors; this potential needs to be assessed further (Parkinson *et al.* 2014). According to systematic literature review, tick-borne diseases, tularaemia, anthrax and vibriosis were the most researched areas likely to be impacted by climatic factors in the Arctic. The US National Library of Medicine provides collected literature on emerging pathogens relevant to Arctic health[35]. One particular issue of thawing permafrost associated with the potential for anthrax outbreaks (Revich and Podolnaya 2011; Walsh *et al.* 2018) has attracted considerable public interest. The prospect of (re-)emerging infectious disease in the Arctic will have implications for Europe beyond the Arctic region.

3.12.3 Other vulnerable territories

In addition to the Mediterranean and Arctic, other particularly vulnerable European macro-regions are developing legal and policy instruments to address and embed climate change actions. These regions include

[33] The Barcelona convention, dating back to 1976, includes EU States together with other Mediterranean countries (EEA 2017a).
[34] For example the Royal Swedish Academy of Sciences ('Scenarios for a warmer Arctic' 2018, on http://www.beijer.kva.se/Material/Filer/Scenarios%20for%20a%20warmer%20Arctic_180215.pdf) and the Council of Finnish Academies ('Human rights and the Arctic' 2017, on https://www.academies.fi/en/arctic/).
[35] https://arctichealth.nlm.nih.gov.

the Baltic Sea States, and various mountain regions (Pyrenees, Alps and Carpathians). The present and projected climatic changes and impacts in all these vulnerable regions are discussed in detail elsewhere (EEA 2017a) although there is relatively little specific information on health.

It is also relevant to note the situation for EU overseas entities, often characterised by specific climate conditions, rich biodiversity and economic dependence on a small number of products and services (details are in EEA 2017a). There are also regions (overseas countries and territories) that are not part of the EU but are constitutionally linked to an EU Member State (e.g. Greenland with Denmark, the British Antarctic Territory with the UK). The outermost regions have been recognised as particularly vulnerable to climate change impacts and this includes health effects, for example with regard to flooding, saltwater intrusion reducing freshwater quality, an increasing number of invasive species (including pathogens) and consequences for agriculture from soil degradation and drought (EEA 2017a).

3.13 Mapping the future: tipping points and existential risks

Beyond the threshold for discernible effects, many of the projected trends – in climate and health effects – will not be linear (Steffen *et al.* 2018). This creates challenges for the regular monitoring and interpretation of effects. Catastrophic tipping points may also arise from exacerbation of the situation by interaction of multiple factors (natural hazards cascading to cause disasters (AghaKouchak *et al.* 2018)) and by poor governance for preparedness and responsiveness. Climate change tipping points for Europe are discussed in further detail in the JRC's Peseta II project (Ciscar *et al.* 2014; and see previous discussion of the Arctic), and include the following:

- Arctic sea ice melting;
- melting of Alpine glaciers;
- Greenland Ice Sheet meltdown
- persistent blocking events of the jet stream;
- collapse of the Atlantic Thermohaline Circulation.

A recent EASAC statement (2018b) discusses in more detail the latest data on the potential weakening of the Atlantic Thermohaline Circulation (Atlantic Meridional Overturning Circulation) with substantial implications for cooling of the climate of north-west Europe. Although it is not yet possible to resolve the considerable uncertainties on the rate and magnitude of possible future change in temperature and on the health implications, analysis emerging since the 2018 EASAC statement confirms the evidence for the Circulation's weakening (Anon. 2018e).

With regard to warming of the climate, tipping points for health are perhaps most likely where the heat stress is currently high and further increase would impact on survivability, if it exceeds the capacity to maintain core body temperature within safe limits. This will also have significant implications for population movements. Another potential global tipping point, for food and nutrition security, will directly affect the EU if major food exporters stopped exporting at the same time as domestic production declined (Figure 3.4); this risk strengthens the case for improving EU policy coherence in governance of domestic and global food security, at a time when EU policy integration seems to have slowed (Candel and Biesbroek 2018). Worldwide, there may be an increasing frequency of food production shocks, and losses by spillover across multiple food sources on land and sea (Cottrell *et al.* 2019). One of the SDG 2 targets is to strengthen adaptive capacity in face of climate change and extreme events, yet shocks across multiple sectors compromise the options for diversification.

3.14 How will development pathways influence future scenarios?

In addition to affecting health outcomes in a variety of ways, climate change is also likely to affect the ability of health systems to function effectively as a result of changes in demand for services, effects on infrastructure and increased costs in a world impacted by climate change (Sellers and Ebi 2018). The effects of climate change on population health and health systems will vary between countries according to different socio-economic development pathways. That is, different development trajectories (EEA 2017a) will affect the capacity of health services to plan and provide effective services[36] and thus the likelihood of attaining SDG 3 (good health and well-being). Transitioning to a more resilient and sustainable world economy to prepare for, and manage, the effects of climate change is likely to result in better health outcomes whereas prolonged use of fossil fuels will probably result in continued high burden of preventable conditions.

Different determinants of socio-economic change are characterised by strong inter-linkages in an increasingly

[36] The contribution of the activities of the health care sector itself to GHG emissions is not covered in this EASAC report but is an issue that has been extensively discussed elsewhere (e.g. Holmner *et al.* 2014).

Table 3.4 The five shared Shared Socio-economic Pathways (SSPs)

SSP	Characteristic	Socio-economic challenges for adaptation and mitigation	Likelihood of attaining SDG 3 health targets
1	Sustainable development	Low	++++
2	Middle of the road	Moderate	++
3	Regional rivalry	High	+
4	Inequality	High	+
5	Fossil-fuelled development	Low for adaptation, high for mitigation	+++ (except those targets sensitive to fossil fuel use)

Analysis adapted from Sellers and Ebi (2018).

interconnected world. A set of five global pathways describing potential alternative socio-economic futures has been developed and these plausible futures imply a range of challenges for climate change mitigation and adaptation (EEA 2017a). The effects of different Shared Socio-economic Pathways (SSPs) (EEA 2017a; see also Table 3.4) have been explored by Sellers and Ebi (2018) in terms of the various dimensions of health systems and their potential to support attainment of SDG targets. However, these interpretations need further consideration: as noted throughout this EASAC report, our concern is that increasing climate change undermines progress in health and Table 3.4 may be an overly optimistic assessment.

Other SDGs with implications for health such as SDG 2 (zero hunger) and SDG 6 (clean water and sanitation) are likely to be affected in similar ways to SDG 3 (Table 3.4). In terms of SSP impacts on the performance of health systems under climate change, the global analysis of Sellers and Ebi (2018) delineates various essential aspects:

- leadership and governance, for example in responding to infectious disease outbreaks;
- health workforce, for example for training on environmental health and disease impacts associated with climate change;
- health information systems, for example early warning and risk monitoring systems;
- essential medical products and technologies, for example climate-resilient infrastructure and supply chains;
- service delivery, for example managing environmental determinants of health, creating climate-informed health programmes, developing robust emergency preparedness, and adjusting service delivery, including mental health provision, for those particularly susceptible;
- climate and health funding, requiring continued attention of policy-makers and sustaining global partnerships.

Mapping of SSP–climate effects on health and health services needs to be further characterised for the EU region overall (EEA 2017a) and, within the EU region, to compare how different countries fare under different SSPs. Quantifying changes in mortality and morbidity under different SSPs across the EU region could provide essential information for the policy-maker seeking how best to allocate resources under climate change.

The principal dimensions of development pathways that are important to modify to reduce health effects include the following:

- tackling inequality and building social capital;
- increasing resources spent on health protection and social care;
- improving physical infrastructure' for example housing quality and urban design to lessen city heat-island effects.

In the EU, there are relevant issues for linking climate change mitigation with the objectives of a circular economy (Appendix 3): climate change will necessitate progress towards a circular economy, given the large emissions linked to current EU patterns of consumption. This progress will include re-manufacturing, re-use, recycling of products and raw materials, and reducing material flows into the EU economy. The objectives of a circular economy must be operationalised for EU health and for curtailing the export of health problems to the rest of the world, for example through export of toxic waste for processing. Broader issues in support of EU resilience and progress to sustainable prosperity rather than indefinite gross domestic product (GDP) growth will be discussed further in Chapter 4.

4 What are the main adaptation and mitigation policy options?

Summary of emerging points from Chapter 4

Responding to climate change requires connected strategies for mitigation (reducing GHG emissions) and adaptation (adjusting to what cannot be avoided). Certain mitigation actions will also bring direct co-benefits to health, additional to those effects mediated by reduction in GHG emissions.

While many adaptation and mitigation plans have been compiled across the EU, concrete objectives for health – and links with SDGs – are often weak. There are various approaches, based on fundamental principles and simulations, to promote system resilience, to progress cost-effective adaptation measures and mitigation synergies but empirical evidence to support options is also often weak. Health impact assessment must be part of all proposed initiatives and of the monitoring of implemented plans.

Case studies are presented on mitigation health co-benefits: opportunities for European city sustainability and for action on food systems systems/consumer dietary choice. A case study on adaptation examines progress made in tackling the increasing threat of infectious disease. Optimisation and coordination of individual initiatives requires adoption of systems thinking to identify potential for synergies, inadvertent consequences and trade-offs.

The economic benefits of action to address the current and prospective health effects of climate change are likely to be substantial but there is a need for more work on methodologies for the economic assessments of such policies. There is also need for further work on identifying alternatives to GDP as a metric of human progress and well-being.

Tackling the barriers to action is a matter of urgency and requires new commitment to engage with and inform EU citizens about the pressing issues for climate change and health. It is vital to counter misperceptions that may be fostered by the deliberate actions of those with vested interests intending to mislead.

Responding to climate change requires integrated strategies for mitigation (reducing emissions of GHGs) and for adaptation (taking action to support individuals, communities and environments to adjust to those consequences of climate change that cannot be avoided). IPCC defines climate change adaptation as the '*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*' and mitigation as '*an anthropogenic intervention to reduce the sources or enhance the sinks of GHGs.*' Specific opportunities for mitigation and adaptation are described in this chapter in the context of the broader national and EU plans for climate change.

4.1 National adaptation plans for health

A WHO Europe survey published in 2015 (conducted in 2012) on how far European region Member States have progressed in implementing commitments to act on climate change and health identified various areas for technical improvement, including the following:

- overall strengthening of capacities for health-related mitigation co-benefits;
- ascertainment of climate-sensitive disease burdens in populations;
- assessment of adequacy of adaptation measures and their social, environmental and economic consequences;
- development of climate change and health risk communication.

Since then an increasing number of countries worldwide are now producing national adaptation plans, assessing their vulnerabilities to climate change and providing climate information to their health services. In some cases these plans cover mitigation as well as adaptation activities. The adequacy of such measures in protecting against growing risks of climate change to health remains uncertain. In 2017, countries in the WHO Europe region adopted the Ostrava Declaration[37] which commits them to make visible, measurable and equitable progress on environment and health in seven priority areas, including adaptive capacity and resilience to climate change impacts (Box 4.1). In addition to specific objectives identified for climate change and health (#5 in Box 4.1), other actions listed are relevant, e.g. through the effects of clean renewables in reducing air pollution and GHG emissions (#1 and #3 in Box 4.1).

The WHO UNFCCC climate and health country profiles[38] provide country-specific estimates of current and future climate hazards and expected burdens for

[37] http://www.euro.who.int/en/health-topics/environment-and-health/Climate-change.
[38] http://www.who.int/globalchange/resources/countries/en/. See also assessments of EU Member States' adaptation actions in the DG Clima discussion (Appendix 3).

Box 4.1 National portfolios of action encompass the following

1. Improving indoor and outdoor air quality for all.
2. Ensuring universal, equitable, sustainable access to safe drinking water, sanitation and hygiene for all.
3. Minimising adverse effects of chemicals on human health and the environment.
4. Preventing and eliminating adverse effects related to waste management and contaminated sites.
5. Strengthening adaptive capacity and resilience to climate change-induced health risks and supporting measures to mitigate climate change and achieve health co-benefits in line with the Paris Agreement.
6. Supporting efforts of European cities and regions to become healthier, more inclusive, safer, resilient and sustainable.
7. Building the environmental sustainability of health systems and reducing their environmental impact.

human health, identifying opportunities for health co-benefits from climate mitigation actions and tracking national policy responses. Worldwide, there are about 40 of these country assessments, including in the EU, France, Germany, Italy and the UK (see also Watts *et al.* 2018a)[39]. Analysis of patterns of adaptation planning in different parts of the EU (at city as well as country level (Aguiar *et al.* 2018)) found that priorities reflected the main local vulnerabilities, for example for flood protection and water management or for urban planning. The main barriers to adaptation were insufficient resources, capacity, political commitment and uncertainty.

At first sight, the health sector is well integrated into some countries' nationally determined contribution plans addressing mitigation and adaptation opportunities and challenges. However, concrete actions are often missing and links with SDGs are weak (Dickin and Dzebo 2018). It would be highly valuable for specific actions relating to health to be strengthened in the next iteration of the national plans. The perception of weaknesses in health linkages is reinforced by a systematic review of published information on countries in the OECD (Organisation for Economic Co-operation and Development), which notes that there are differing views on what responsibilities and obligations are expressed by national governments regarding climate change and health (Austin *et al.* 2016). These OECD findings suggest that national goals in health are focusing relatively narrowly on infectious disease and heat-related risks posed by climate change, typically emphasising issues for capacity building and information-based initiatives. Further efforts were recommended for cross-sectoral collaboration, vertical coordination and national health adaptation planning, accompanied by evaluation to define what health adaptation looks like in practice so that lessons of good practice can be shared between countries and used to inform policy. The OECD analysis reaffirms a broader point about highlighting the relative importance of non-communicable diseases among the effects of climate change: interest has been previously expressed by various bodies, including EASAC, in extending the remit of ECDC beyond infectious disease to cover non-communicable diseases.

Figure 4.1 Adaptation limits.

4.2 Approaches to adaptation and mitigation

Adaptation has its limits, and various dimensions – exogenous and endogenous (Figure 4.1).

Physical limits (e.g. low-lying islands or other territories), behavioural limits (e.g. populations living in vulnerable areas), technological limits (e.g. nature of flood defences) and financial limits (e.g. deciding who pays and cost–benefit considerations) may all contribute to the constraints to achieving effective adaptation. The contribution of different limits to the overall constraints on adaptation will vary according to the context. For example, a national case study on public water supply in adapting to climate change (Arnell and Delaney 2006) illustrated physical limits (drying up of rivers), economic limits (affordability), socio-political limits (construction of water storage reservoirs may not be acceptable because of effects on the environment) and

[39] Although not specific to health, all current EU national policies and measures on climate change are tracked by the EEA: see their Briefing No 7/2018 'Tracking climate policies in European Union countries', on https://www.eea.europa.eu/publications/tracking-climate-policies-in-european.

institutional limits (for example inadequate capacity of water management agencies). More generally, in addition, strategic limitation may have been self-imposed by lack of ambition in scope, exemplified in the past by the European Commission's climate change adaptation strategy that paid little attention to public health (Appendix 3). This is now beginning to change: the European Commission's forward look on strategy emphasises the need to reinforce links between climate adaptation and public health, for example to improve cross-sectoral cooperation on risk assessment and surveillance, and to increase awareness and capacity of the health sector, including at local level, to address current and emerging climate-related health risks.

In developing better resilience, more can be done to integrate health into the SSPs (section 3.14) and other scenario planning, capturing both relatively predictable changes (e.g. demographics) and critical uncertainties (e.g. migration flows). Comparison of scenarios may be particularly helpful in revealing scientific opportunities and challenges. That is, what should be the research agenda to help understand and influence the trajectories? As described in section 3.14, adaptation of health care systems will need to vary according to SSPs. Although, for example, early warning systems, hospital preparedness and training are needed in all SSPs, their effectiveness may vary in more unequal societies with greater poverty. There will also be relevant implications for health in the adaptation plans progressed by other sectors, for example agriculture and construction.

The Working Group identified some general points to set the overall context for mitigation and adaptation, before exemplifying specific case studies in the following sections.

- It is important to build social capital and resilience in systems and infrastructure, especially where there may be cases of market failure, and to reduce stress and other mental health consequences of climate change (Majeed and Lee 2017).

- Identification and comparison of mitigation and adaptation policy options requires good scientific data, and monitoring of interventions requires good baseline data. Much of the current debate on strategies is based on principles and (cost) effectiveness modelling rather than empirical evidence' although there is some information, for example on strategies for ecosystem protection against climate disasters (Royal Society 2014).

- Improving the practical value of novel approaches, for example early warning or other alert and information systems for air quality[40], infectious disease threats, food insecurity, pollen forecasts, heatwaves and other extreme weather events (Bittner *et al.* 2014; Boekmann and Rohn 2014), requires co-design of systems with the community involved.

- In mitigation objectives, it is important to reduce climate risk to a much lower level as a basis for subsequent establishment of the most cost-effective adaptation measures. Several policy instruments are available for mitigation such as carbon taxes, and a range of options for negative emission technologies several of which are under investigation. It is not within the scope of the present EASAC project to ascertain what more can and should be done to promote negative carbon balances, but we emphasise the point that negative emissions technologies and mitigation technologies have significant potential in supporting human health. Taking account of health impact assessment is a key part of the work on comparing the different technologies' in evaluating carbon pricing reform and in assessing other key EU initiatives, such as for the circular economy and bioeconomy.

- The need to avoid unintended consequences of adaptation or mitigation strategies (see section 4.7). Downstream health impacts of proposals for climate engineering through negative emission technologies are still mainly unevaluated but there are concerns (Carlson and Trisas 2018).
  For example, replacing food crops by bioenergy crops has implications for food and nutrition security, and ocean fertilisation for carbon capture would trigger massive phytoplankton blooms, driving zooplankton blooms, and the potential for cholera outbreaks.

4.3 Mitigation and co-benefits

Research indicates that the main policies proposed to mitigate climate change can also lead to localised improvements in the health of those populations undertaking the mitigation. These health co-benefits are additional to the global health benefits that will flow from mitigation and could help to offset the costs of tackling climate change (IAMP 2010).

There are multiple potential benefits for air quality and climate (Haines *et al.*, 2009; Smith *et al.*, 2014) (see also discussion in section 3.8.1). Working Group discussion noted that some air pollution control measures such as the reduction of sulfur dioxide emissions can adversely affect climate by affecting radiative transfer in the atmosphere and increasing penetration of sunshine to ground level. However, there are also many air pollution

[40] For example, air quality alerts specifically benefit asthmatics and there is potential for increasing public health protection by using personalised alert systems (Ho *et al.* 2018).

control measures that are beneficial for climate change and vice versa (that is, action to mitigate climate change that will also reduce pollution). Two prime examples are the use of renewables for electricity generation, which reduces emissions both of GHGs and of locally acting pollutants from fossil fuel combustion, and modal shifts in transport towards more active and lower emission modes. These examples are discussed further below.

Connecting the climate policy agenda with public health issues can potentially mobilise additional support and enthusiasm for environmental sustainability (German National Academy of Sciences Leopoldina 2015), helping to make the case to policy-makers who want to see impact in the short term. The Leopoldina analysis emphasises the broader priorities for ascertaining health co-benefits, as follows.

- Accelerate the move away from fossil fuels[41] and the move towards clean energy sources.
- Acknowledge the overall climate-health nexus.
- Appreciate the major benefits of reduced air pollution.
- Promote measures that help to mitigate climate change and improve health.

Among the global evidence for specific co-benefits (see, for example, Haines *et al.* 2009; Whitmee *et al.* 2015; Chang *et al.* 2017) are studies on the following.

- Household energy. For example, replacing solid fuels for domestic use with clean fuels could avert many of the 3 million premature deaths annually due to household air pollution worldwide. If the solid fuel is replaced by electricity generated from clean renewable sources it would also contribute to climate change mitigation.
- Electricity generation. For example, reducing coal use would also reduce both GHG emissions and particulate air pollution resulting in near-term health benefits (West *et al.* 2013; Markandya *et al.* 2018). Air quality improvements in high-income countries yield substantial economic gains as well as reducing deaths from cardiovascular and respiratory diseases (and these gains are likely to be underestimates of public health impact (Graffzivin and Neidell 2018)) but see further discussion of the challenges of economic assessment in section 4.8. For example, in the USA, an estimated US$30 in benefits has been returned for every $1 invested in air pollution control since 1970 (Landrigan *et al.* 2018a). Greater health benefits in the future are possible. For example, Shindell *et al.* (2018) examined the human health benefits of achieving a 2°C scenario: the decreased air pollution was calculated to lead to approximately 150 million fewer premature deaths worldwide with about 40% of these prevented deaths during the next 40 years, but the assumptions and extrapolations seem optimistic.
- Urban transport. For example, modelling studies suggest that low-carbon transport and increasing active travel would lead to lower GHG emissions and decrease the burden of disease arising from sedentary behaviour. A broader study on the issues involved in the decarbonisation of transport was recently published by EASAC (2019)[42].
- Agriculture and food systems. For example, reducing consumption of animal source food and increasing fruit and vegetable consumption would be expected to reduce cardiovascular and other non-communicable diseases (see subsequently) and lead to reduced GHG emissions from livestock production.

In the following sections we provide further information on some of these health co-benefits of the low-carbon economy, in the European context.

4.4 Case study in mitigation: sustainability and health gains in European cities

Urban policies are critically important for the future of planetary health because, globally, 85% of GDP and 75% of energy-related GHG emissions are associated with cities. A recent study of data from 25 EU cities estimated that life expectancy could be increased by up to approximately 22 months if long-term $PM_{2.5}$ concentration was reduced to the WHO guideline level in the most polluted cities (WHO Europe 2017a). Ongoing work by WHO Europe is estimating the health benefits of reducing $PM_{2.5}$, sulfur dioxide and NO_x in line with the Paris Agreement: preventable premature mortality from reduced air pollution in 2030 (if all countries implemented their intended nationally determined contributions to mitigate emission levels) could amount to 74,000 fewer deaths in the WHO Europe region, accompanied by 49,000 fewer hospital admissions, 1.9 million fewer asthma attacks, 350,000 avoided cases of bronchitis in children and 50,000 fewer in adults, and 17 million fewer lost work days.

[41] According to Eurostat data, the main EU sources of GHGs are: electricity and heat production > manufacturing industry and construction > transport > residential/commercial > agriculture (EEA 8/2017 'Analysis of key trends and drivers in greenhouse gas emissions in the EU between 1990 and 2015'). The contribution by agriculture will be higher if land use changes are counted as in EASAC (2017b). The agricultural production of ammonia, which contributes to particulate air pollution, and of methane, a precursor of tropospheric ozone, also contributes to human health problems.
[42] https://easac.eu/publications/details/decarbonisation-of-transport-options-and-challenges/.

The Working Group discussed the diverse opportunities available to European cities to achieve health co-benefits. In addition to universal access to clean, low-carbon energy, significant co-benefits would accrue, for example from the following.

- Providing accessible, efficient public transport and encouraging physical activity, if appropriately aligned—the big GHG benefits come from decarbonising transport whereas big health benefits come from more active travel (a relatively low prevalence of cycling persists in many European cities (Watts *et al.* 2018b; Woodcock *et al.* 2009)).
- Safe access to green space and ecosystem strategies for resilience (while avoiding planting those tree species that significantly augment pollen exposure or emit O_3 precursors, see section 4.7).
- Improvements in housing, for example combining insulation and ventilation control improvements in housing to increase energy efficiency of heating/cooling systems and reduce the health effects of moulds.

However, more research is needed, together with integration of disparate data sets. For example, analysis by city authorities and partner academic organisations in five European cities (Kuopio, Finland; Rotterdam, the Netherlands; Stuttgart, Germany; Basel, Switzerland; and Thessaloniki, Greece) and two Chinese cities (Xian, Suzhou) examined health benefits associated with introducing electric cars, reducing private car use, increasing energy efficiency of housing and reducing in-home biomass burning (Sabel *et al.* 2016). It was found that the potential health and well-being impacts of these city policies to mitigate climate change varied and were often rather limited, possibly reflecting the existing relatively high quality of life and environmental standards in most of the participating cities. Also, reducing emissions within cities may not be so effective if high emissions continue from industry around the cities. There is greater potential for future health benefits in lower-income countries. However, the situation is complex and further significant benefits in Europe should certainly not be discounted. Further insight is available from a recent study in Austrian cities on the implementation of low-carbon policies in urban passenger transport which assessed the near-term health co-benefits through increased physical activity and improved air quality (Wolkinger *et al.* 2018). These projections show substantially decreased morbidity and mortality with strong positive welfare effects yet with a slightly negative GDP and employment effects. Further assessment of this work (which is also discussed in section 4.8) and the need to do more research to ensure reliability of conclusions is provided in EEA (2017a). It is vital to take into account co-benefits, substitution effects and related cost reductions in planning and decision processes. The issue of whether there is a disconnect between objectives for decarbonisation of transport and for economic growth is controversial[42].

The EU has set itself the goal of achieving levels of air quality that do not give rise to significant impacts on, and risks to, human health. Across the EU, there are actions to control emissions into the atmosphere, improve fuel quality and integrate environmental protection measures into the transport and energy sectors. Currently the European Commission is performing a 'Fitness Check of the EU Ambient Air Quality Directives' (deadline end-2019) to assess whether the present policy is fit for purpose and continues to provide an appropriate legislative framework. Among other activities of the European Commission (DG Environment) is a collaboration with the US Health Effects Institute to examine the impact of $PM_{2.5}$ and other pollutants in European populations[43].

The European Public Health Alliance, observing that many cities exceed WHO standards for PM (European Public Health Alliance 2017), has called for better implementation and enforcement of EU air pollution standards including the new limits for PM and NO_x set out in the revised National Emissions Ceiling Directive. Furthermore, EU policies for the period up to 2020 can be viewed as relatively weak with unambitious targets (Brunekreef *et al.* 2015). While stronger reductions are promised for subsequent years, these promises are non-binding. A recent assessment by the European Court of Auditors[44] concludes that action taken to date to improve air quality is not sufficiently protecting citizens from pollution: in the cities studied (including Brussels, Krakow, Milan and Sofia), there has been little recent progress in reducing PM or NO_2. It is also relevant to note that recent analysis from the UK Biobank Population Imaging Study (Aung *et al.* 2018) finds, in an asymptomatic population, that past exposure to low levels of $PM_{2.5}$ (and smaller particulates) and NO_2 was associated with cardiac ventricular dilation, a marker of adverse remodelling that often precedes heart failure development. That is, even relatively low levels of air pollution may have harmful effects on health and this has implication for future standard setting (see also Burnett *et al.* 2018; and section 3.8.1).

There are various joint city initiatives to develop greener and healthier cities by reducing transport emissions: for

[43] The most recent data are published in 'State of Global Air – 2018', www.stateofglobalair.org/report.
[44] European Court of Auditors, Special report no 23/2018: 'Air pollution: our health still insufficiently protected', https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=46723.

example, the C40 Fossil-Fuel-Free-Streets Declaration[45] that includes Paris, London, Copenhagen, Barcelona, Milan and Rome. Collective local government initiatives on sustainability also commit to developing healthy communities[46]. The Global Covenant of Mayors, together with the European Commission, recently announced[47] their initiative to build the city research and innovation agenda to address critical knowledge, data and innovation gaps. This commitment focuses on enabling cities to take more ambitious climate action, to make cities more liveable, prosperous and healthy, and to facilitate implementation of the Paris Agreement. Related issues for city provision of drinking water and sanitation are also subject to collective engagement[48].

Other urban policy actions will bring health benefits. The literature on the origin of urban heat island effects and how to minimise them has been reviewed by Shahmohamadi *et al*. (2010). Urban green space can improve air quality and microclimate (Száraz 2014) and the literature documenting effects of green infrastructure on human health has been reviewed by Coutts and Hahn (2015). However, care must be taken to avoid inadvertent consequences of green infrastructure for human health, for example if increased biodiversity leads to increase in disease vectors and pathogens (Lõhmus and Balbus 2015). Recent work confirms that increasing green space in cities can improve climate/urban heat-island effects (see, for example, Geletič *et al.* 2019) and has been observed to have a protective effect on clinical depression. These beneficial health effects were more pronounced among women, those younger than 60 years and those residing in areas with low neighbourhood socio-economic status or high urbanicity (Sankar *et al.* 2018). A study in the UK[49] suggests that the value of parks and green spaces to the economy is more than £34 billion a year, including savings to the UK's National Health Service from improved mental and physical health. The review by WHO Europe[50] documents the effects of green space interventions on obesity and cardiovascular disease as well as on mental health and well-being, particularly again among lower socio-economic groups. Analysis of case studies indicated that effectiveness is promoted when physical improvement to green space is coupled with social engagement/participatory programmes.

4.5 Case study in mitigation: health co-benefits from action on agriculture and food systems

It was described in section 3.7 how climate change may have considerable effects on European agriculture and food systems. It is also important to appreciate that agriculture itself contributes very substantially to climate change and to other pressures on environmental resources, such as water (Vanham *et al.* 2018; Willett *et al.* 2019). The pressures from EU activities are experienced worldwide (Sandstrom *et al.* 2018): of the total area of land used by EU citizens to produce the food they consume, about 20% is located outside the EU (see also section 2.2 and EEA (2017d)). Currently, agri-food systems worldwide account for about 30% of GHG emissions (CO_2, methane and N_2O); about half of this sum can be attributed to food production and half to land conversion (EASAC 2017b)[41,51]. Animal-based food production accounts for about 70% of the total land used for agriculture, most land being required for dairy farming and beef production (EEA 2017d). Nearly half of EU cropland is used for animal feed production (other detailed statistics on land use related to consumption patterns are given by Giljum *et al.* (2013)). Consequently, livestock are a major source of agricultural GHG emissions and, if current trends continue, food production alone will reach, if not exceed, global targets for total GHGs (EASAC 2017b).

Recent meta-analyses (Poore and Nemecek 2018; Vang Rasmussen *et al.* 2018) have begun to explore the great heterogeneity in environmental costs when comparing various types of food production system. Although it has been inferred that agricultural intensification is rarely found to lead to simultaneous positive ecosystem service and well-being outcomes (Vang Rasmussen *et al.* 2018), little of this evidence comes from Europe. In the period up to 2050, as a result of expected changes in population and income levels, the environmental effects of the global food system could increase by 50–90% in the absence of technological changes and dedicated mitigation measures (Springmann *et al.* 2018a). A combination of measures (dietary change towards healthier, more plant-based diets, improvements in technologies and management, reduction in food loss and waste) is needed to mitigate the projected increase in environmental pressures[52].

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[45] www.c40.org/other/fossil-fuel-free-streets-declaration.
[46] www.iclei.org.
[47] Global Covenant press release 22 March 2018 on www.globalcovenantofmayors.org/.
[48] www.iwa-network.org/programs/cities-of-the-future.
[49] Fields in Trust 2018, 'Revaluing parks and green spaces', on www.fieldsintrust.org.
[50] 'Urban green space interventions and health' 2017, on http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/publications/2017/urban-green-space-interventions-and-health-a-review-of-impacts-and-effectiveness.-full-report-2017.
[51] Progress in reducing this contribution has been disappointing. In the UK, for example, there has been no progress over the past 6 years in reducing GHG emissions by agriculture (Committee on Climate Change, UK to Secretary of State on 6 November 2017 'Role of agriculture, land use and the natural environment in tackling climate change').
[52] However, measuring the efficiency of land-use change from the perspective of GHG emissions is challenging and more work is needed to compare different methodological approaches to quantifying impacts (Searchinger *et al.* 2018).

According to previous EASAC work (EASAC 2017b), there is significant scientific opportunity to reduce food waste, to tackle overconsumption and to change dietary habits in a way that will reduce GHG emissions. As well as contributing to climate change mitigation and helping to reconcile current priorities with the interests of future generations, adjusting consumption patterns would also bring public health co-benefits in those populations that already consume large amounts of food from animal sources. If the average UK dietary intake were optimised to comply with the WHO recommendations, there could be an incidental reduction of 17% in GHG emissions. Adherence to such a diet could save almost 7 million years of life lost prematurely in the UK over the next 30 years and increase average life expectancy by over 8 months (Milner *et al.* 2015). Diets that result in additional GHG emission reductions could achieve further net health benefits but diets resulting in emission reductions greater than 40% could begin to reduce the improvements in some health outcomes and acceptability will diminish.

A systematic review (Aleksandrowicz *et al.* 2016) of the evidence on GHG emissions and land and water use achievable by shifting current Western dietary intakes to environmentally sustainable dietary patterns demonstrated that reductions in environmental footprints were generally proportional to the magnitude of animal-based food restriction. These dietary shifts yielded modest benefits in all-cause mortality risk. Recent monitoring of food intakes in Germany, Greece, Ireland, the Netherlands, Spain, Poland and the UK (Walker *et al.* 2018) shows that individuals abstaining from red meat have lower environmental impacts while maintaining adequate nutrient intakes but that there is a large spread of eating patterns which may complicate recommendations for sustainable diets. It is also noteworthy that detailed analysis in Germany (Treu *et al.* 2017) found that the average organic diet requires about 40% more land than the average conventional diet: animal-based foods were responsible for about 75% of land use in both diets.

Although there is an accumulating evidence base on the impacts of food systems on GHG emissions (see also Reisinger and Clark 2018), the debate on practical ways to adjust diets so as to capture the health benefits has been more contentious (EASAC 2017b; Godfray *et al.* 2018; Willett *et al.* 2019). It is a complicated task to elucidate the consequences of different actions aiming to reduce meat consumption, although recent modelling work using worldwide data on mortality and health-related costs associated with red and processed meat consumption provides increasingly robust insight on how consumption could be influenced by tax (Springmann *et al.* 2018b). A systematic review of ways to affect the 'physical microenvironment' to reduce meat demand, for example by portion control and retail positioning as well as by price (Bianchi *et al.* 2018), identifies important options for management choices. However, concern has been expressed that if there were to be a tax on red meat consumption in European countries, the impact is likely to be greatest on those with lowest income, potentially exacerbating the costs of consuming a healthy diet unless specific measures were implemented to prevent widening inequities such as reduced income taxes for low-income families or subsidies for healthier food items particularly fruit, vegetables, nuts and seeds and whole grains. One obstacle to dietary change may be consumers' underestimation of the environmental consequences of different types of food: to correct this lack of awareness, a well-designed carbon label on food products would help to give information about total GHG emissions within the supply chain (Camilleri *et al.* 2019).

From analysis of household data in Africa, Asia and the Americas, there is an association between child stunting and low intake of animal-sourced foods (Headey *et al.* 2018), although more needs to be done to assess causality. While this concern may not have the same priority within the EU, more work is required on the status of vulnerable groups, and there is need for continuing discussion on what is a sustainable healthy diet and how to educate purchasing and consumption behaviours (Godfray *et al.* 2018; Willett *et al.* 2019). The implications of reducing overconsumption and, in particular, ruminant meat consumption, on human health and on land use continue to be an important topic for the science agenda (discussed in further detail in EASAC (2017b)): for example, in determining the impact of diets of differing composition on children's development and learning, and in clarifying the impact of different feed conversion efficiencies in animal species on land use.

Ruminant meat for human consumption has declined in Europe over the period 1990–2000 but since then (2000–2013) has not declined further (Watts *et al.* 2018a)[53]. Is there a disconnect between achieving climate change objectives in terms of reducing livestock production and the advice for consuming a healthy diet commensurate with targets embedded in the SDGs (see also section 4.7)? A recent US modelling study demonstrates the importance of incorporating sustainability criteria for food systems in developing dietary guidelines (Blackstone *et al.* 2018). Similar work

[53] Animal-based product consumption *per capita* is expected to continue to increase over the 2014–2020 period for the vast majority of animal product categories (EEA, 'Food consumption – animal based protein', briefing published 29 November 2018, on https://www.eea.europa.eu/airs/2018/resource-efficiency-and-low-carbon-economy/food-consumption-animal-based).

is needed in the EU: incorporating transdisciplinary processes, dialogue and collaboration to develop sustainable dietary guidelines.

At the same time, research and development opportunities for meat substitutes[54] as innovative foods and other 'future' foods (e.g. from insects, algae and seaweed (Parodi *et al.* 2018)) are worth pursuing, alongside clarification of the associated socio-political and regulatory challenges (Stephens *et al.* 2018). A recent summary from the European Parliamentary Research Service (Kurrer and Lawrie 2018) discusses how laboratory/bioreactor-grown meat, using stem cell technology, is biologically similar to conventional meat but with greatly reduced environmental impact (a claim that is also made for other alternatives to current animal-source foods (Parodi *et al.* 2018)), potentially helping to meet EU targets for cutting GHG emissions. However a recent paper suggests that the energy requirements for cultured meat are high and if the energy is provided by fossil fuels the GHG emissions from cultured meat can exceed those from cattle over time because of the long atmospheric residence time of CO_2 compared with methane (Lynch and Pierrehumbert 2019). Thus if cultured meat becomes a scaleable option energy will need to be provided from renewable sources which may be become challenging if consumption increases dramatically. The cost of production has been falling and it may become a viable commercial product. As the European Parliamentary Research Service observed, the food value of laboratory-grown meat could be controlled to optimise nutritional content for consumer health, it would not require the use of antibiotics (another potential health benefit) and it might reduce the spread of food-borne pathogens such as *E. coli* and *Salmonella*. However, major changes in food production and consumption would have a significant effect on agricultural communities and have implications for EU policy to promote rural diversity. There is more for the EU to do in evaluating technologies now coming within range, and the implications for health and the environment.

4.6 Case study in adaptation: actions to tackle the increasing threat of infectious diseases

What Europe cannot change, we must adapt to. Opportunities for adjustment to health systems as part of the broader adaptation responses to climate change have been exemplified during the discussion in sections 4.1 and 4.2; here we return to the previous work of EASAC on infectious diseases and the opportunities for improving preparedness and responsiveness.

Table 4.1 Update on previous EASAC work on climate change and infectious disease

EASAC recommendation (2010)	Progress since 2010
Increased surveillance for vectors and hosts as well as pathogens, accompanied by interagency partnership for monitoring and investigation of outbreaks.	Significant progress has been made in the work of ECDC, including guidance to EU Member States. See discussion below.
Identifying research funding priorities and promoting integration of EU and Member State funding strategies and alignment with the global agenda. Among key general issues raised were the following. (1) Commitment to supporting fundamental research in advance of a crisis. (2) Skill development – preparing the next generation of researchers, for example in epidemiology, microbiology and entomology. (3) Modelling and simulation.	EU Horizon 2020 has been helpful (and plans for the latter part of Horizon 2020 provide increasing focus on issues for climate change and health)[55]. However, there is less evidence for integration between EU-national-global strategies. Particular scientific priorities identified by EASAC (e.g. basic research on the scientific characteristics of that probably small proportion of vectors with a high infectious load) still need more work.
Connecting research with innovation, particularly new drug development.	There is still a weak pipeline of anti-infective agents in the EU because of difficult business models and insufficient incentives for private sector research and development in this therapeutic area. There are opportunities for public–private partnership (e.g. building on significant progress in the Innovative Medicines Initiative).

Continued

[54] The work of the World Economic Forum has discussed commercial initiatives worldwide relating to cultured meat, plant-based meat surrogates and insect-based food and feed (P. Laudiana 'How a new approach to meat can help hunger', November 2018, on https://www.weforum.org/agenda/2018/11/how-a-new-approach-to-meat-can-help-end-hunger).

[55] Likely scope includes vector-borne diseases, water-borne diseases and implications of 'high-end' climate change scenarios. The need to do more to bring together the climate change and the health scientific communities is also being recognised. In addition to supporting particular priorities, there is general need for Horizon 2020 and Horizon Europe to pursue the aim for the 'internal market for knowledge' where data and knowledge circulate freely.

Table 4.1 Update on previous EASAC work on climate change and infectious disease (*continued*)

EASAC recommendation (2010)	Progress since 2010
Collaboration between veterinary and public health sectors.	'One Health' is much discussed but there is room to do more in developing coherent strategies for education[56], for preparedness and responsiveness at EU level and in many Member States.
Preparing for the future: for example, impacts of climate change on infectious disease should be part of policy considerations for interaction of the EU with other Mediterranean and neighbouring countries and for support for capacity building in other low- and middle-income countries.	Some progress but more to be done. For cross-sectoral opportunities, see discussion below.

Some progress has been made in addressing the issues raised in the EASAC work (2010) on infectious diseases. A summary of our previous recommendations is provided in Table 4.1.

With regard to the continuing objectives for disease surveillance and planning, there are opportunities coming within range to develop the public health resource to anticipate and prepare for the spread of threats: the interaction between the European Commission and Member States must draw on the evidence and best practice worldwide (Ebi *et al.* 2013). Prototype case studies for early warning systems (malaria transmission in Greece, West Nile fever in southern/eastern Europe, and dengue importation into Europe) indicate that monitoring of the relevant climatic and other factors can help to predict vector-borne disease threats (Semenza 2015). Work by the JRC on the climate impact of water-borne infections is similarly helping to generate predictive models for crisis mitigation and management[57].

In addition to the proximal impacts of infectious disease on health, there may be disruptive effects on health care systems and on other sectors including trade, tourism, civil protection, transport and agriculture (Suk *et al.* 2014). Therefore, in projecting impacts and in planning for the future, it is prudent to move beyond narrow models of risk to take into account interdependencies between health and other sectors so as to better develop systematic resilience and adaptation responses to the risks.

Similar adaptation principles may also apply to other invasive species outside the area of human infections. For example, the control of the spread of allergenic plant species may be an important health adaptation strategy in response to climate change: this is discussed in detail elsewhere (see, for example, Beggs and Ziska 2016).

4.7 Systems thinking for developing coherent strategy: identifying and clarifying synergies, disconnects and inadvertent consequences

As noted above, when considering the development of a coherent strategy across Europe and across sectors for policy objectives on climate change and health, there will be interactions between individual decisions made. It is important for policy-makers to consider how to balance trade-offs and for the science community to advise on the key issues for doing so (see recommendations in Chapter 5).

4.7.1 Capitalising on synergies

Synergies, in terms of co-benefits to health from mitigation actions, have been described extensively in previous sections. In addition, there are also opportunities for inter-regional synergy, exemplified by the issues for the Arctic (section 3.12.2). Partnership between the Arctic region and the rest of Europe is important for all, in terms of improving the knowledge base for adaptation and mitigation for continued ecosystem integrity (Parkinson *et al.* 2014; EEA 2017b)[58]. Collective action between the Arctic and the rest of Europe is needed in particular to

- provide regular integrated assessment of the interplay between local and global trends;
- clarify status of ecosystem services and biodiversity;
- minimise risks of infectious disease (re-)emergence;
- reduce impact of long-range pollutants;
- build local capacity to facilitate initiatives aimed at improving Arctic health and living standards, for example by better housing, diets, eHealth, and reducing exposure to harmful substances accumulating in the Arctic food chain.

[56] For example, as discussed in IAMP/FEAM Workshop on Integrated Education in One Health 2013, on http://www.interacademies.org/33897/IAMPFEAM-International-Workshop-Integrated-Education-in-One-Health.
[57] Biocli4crisma, an exploratory project combining experimental molecular biological data with climate modelling for crisis mitigation and management, started in 2015 and coordinated by several Directorates of the JRC.
[58] See also the Arctic strategy and work plan from the European Climate Research Alliance, www.ecra.climate.eu/images/documents/Arctic%20ECRA%20SW_Plan.pdf.

The specific focus on health should also be considered within the context of the proposals for wider Arctic–international cooperation on interdisciplinary research, training, accessible, usable and timely databases and remote sensing linked with *in situ* monitoring (G7 2018).

4.7.2 Avoiding disconnects and unintended consequences

Disconnects may need to be resolved, for example between EU Common Agricultural Policy priorities that have encouraged increased production of dairy products and meat and the environmental and health considerations noted previously, and between increasing allocation of land for bioenergy crops and other land uses.

The potential for unintended consequences of climate change initiatives can also be exemplified by the following.

- Action to increase wetlands as a defence against flooding, which might provide new habitat for disease vectors. According to EEA analysis, restoring flood plains and wetlands offers value-for-money solutions to river flooding in terms of socio-economic and environmental benefits (EEA 2017c), on the basis of case studies in Germany, France, Belgium and Poland, and wetlands can also act as significant carbon sinks. However, there has been less attention paid to health benefits or disadvantages of wetland restoration.
- Action to increase insulation in housing without also increasing appropriate ventilation might promote growth of mould, a risk factor for respiratory disorders and increased household air pollution including radon exposure in some regions (Wilkinson *et al.* 2009).
- Action to increase use of air conditioning if power is generated by use of fossil fuels with associated rise in GHGs, PM and O_3. A US modelling study concludes that without intervention, by mid-century, 5–9% of air-pollution-related mortality will be due to increases in the power sector emissions arising from heat-driven building demand for electricity for cooling (Abel *et al.* 2018).
- Action to reduce transport sector GHGs may adversely affect health because the increased use of diesel and biodiesel to replace petrol can result in increased emissions of fine PM (Williams *et al.* 2018).
- Action to promote wood burning for domestic heating, causing more PM than other options: it may be justified in some regions but is a concern in densely populated areas (Swiss Academies of Arts and Sciences 2015).
- Actions to mitigate climate change through economy-wide GHG emission reductions may negatively affect food security, for example because reducing the agricultural contribution to GHG emissions may affect prices and supplies of key agricultural commodities. One recent modelling study (Hasegawa *et al.* 2018) for the period up to 2050 indicates that stringent climate mitigation policy, if implemented evenly, would have greater negative impact on global hunger and food consumption than the direct effects of climate change, especially in low-income regions. These issues require further examination.
- Actions to increase green space and tree planting in towns for the reduction of urban heat stress may increase pollen allergens in the air. Such actions should avoid planting trees which significantly augment pollen exposure or introduce new allergens from non-native trees, for example the hybrid alder *Alnus × spoethii* tree (Gassner *et al.* 2013).

Several of the examples listed above illustrate that policies for climate change adaptation and mitigation may have unintended adverse consequences for health if these are not addressed systematically through health impact assessments. The Working Group discussed the generic problem – that adaptation and mitigation communities do not always work in concert – and highlighted the need to build better strategic links. There is also the concomitant need to convince policy-makers to incorporate health impact assessment into all proposed adaptation and mitigation initiatives, to incorporate mechanisms that identify and assess unintended consequences, and to ensure coherence in objectives for different policy domains (for example appertaining to agriculture and the environment, see Chapter 5).

4.8 Wider economic and development consequences

Tackling the effects of climate change on health will bring significant benefits for individuals and populations, and it also makes economic sense. The economic case for intervening now rather than later (Stern 2007) reinforces the urgency for action.

Until recently the data on health damage or adaptation costs in European countries have been relatively limited and fragmented (Hutton and Menne 2014) and it has been considered essential to collect more robust and standardised data on economic benefits and costs to support projections and inform policy options[59]. This is beginning to happen. For example, a recent modelling study (Markandya *et al.* 2018) demonstrated that health co-benefits from mitigating air pollution (as assessed by the value of a statistical life) substantially outweigh the policy cost of achieving the target in all scenarios examined. That is, the mitigation efforts can be justified economically by considering the value of multiple benefits including health co-benefits: although this was a global study, the findings were expected to be substantial for the EU.

The following paragraphs describe some of the economic interpretation associated with major health impacts in Europe reviewed in Chapter 3. However, the Working Group emphasised the complexity of calculations, compounded by the problem that the traditional methodological approach used for valuing a life in much of the literature, value of a statistical life, has limitations and is regarded by many as likely to overestimate economic loss (see, for example, Bosworth *et al.* 2017). In future research, more attention should be given to alternative, human capital approaches, to valuing economic impacts, but also to take account of the roles and importance of people who are not economically active or who have lower labour productivity.

The EU JRC's Peseta II project (Ciscar *et al.* 2014) provides a multi-sectoral assessment of heat-related health and economic impacts for the 2071–2100 time horizon. Overall, under the reference simulation, if no further action were to be taken and global temperature increases by 3.5°C ('business-as-usual' scenario), the climate damage to the EU could amount to a loss of 1.8% of current GDP. The greatest negative economic impacts (two-thirds of the total) would be associated with damage to human health, mostly through premature mortality, although this has limited effects on GDP because those who are more likely to die are older and beyond employment age. Moreover, this simulation does not incorporate other, related impacts on health, for example from changes in air quality. This computed GDP reduction also ignores likely huge disruptive impacts of high-end climate change.

Heat-related labour productivity costs to city economies may be substantial, as indicated by a study comparing Belgium, Spain and the UK (Costa *et al.* 2016). These effects depend on the relative size of different business sectors in a city economy as well, of course, as on projected temperature increases. It was estimated that in a warm year by the end of the century, total losses to the urban economy could range between 0.4% of gross value added for London and 9.5% for Bilbao, in the absence of adaptation. A national case study of Austrian cities (EEA 2017a) also provided detailed estimates of climate change and labour productivity, up to 2065, according to different climate scenarios. The negative effects are complex and may be magnified by macro-economic feedback effects. It should also be noted that in this and other studies, the EU will additionally be affected by the effects of heat and humidity on labour productivity in the rest of the world – in particular on subsistence farmers – thus raising food costs for imported food.

Economic impacts of heat-related effects from modelling studies vary widely according to whether current adaptation and future acclimatisation are included or not. Generally, the highest impacts are to be found in the Mediterranean (Cyprus, Greece, Spain, Portugal, southern France and Italy) and some eastern EU Member States (Bulgaria, Hungary and Romania). Economic costs rise strongly in later years but analysis does not often take into account a potential reduction in cold-related mortality (EEA 2017a).

Recent EU-wide projections[60] suggest that, without increased investment in coastal adaptation, the annual damage caused by coastal floods in Europe could increase dramatically, from €1.25 billion now to between €93 billion and €961 billion by the end of the century because of the increase in sea levels. That would affect up to 3.7 million people each year compared with about 100,000 affected now, but given the large range in projections there is need for more evaluation of scenarios and country-level impacts. As noted previously, flood projections are subject to considerable uncertainty and the implications for risk reduction and water resource management should be interpreted with caution (Kundzewicz *et al.* 2017, 2018).

Part of the challenge to derive cost–benefit comparisons is because of the wide range of health outcomes involved (including labour market effects). Although this may seem to be a generic problem in health economics, there are additional complexities in elucidating climate change effects on health. For example, if interventions on climate improve health and thereby increase economic activity, will this in turn drive further GHG emissions? How will abatement strategies and carbon pricing incorporate safeguards to avoid effects on the poor? Does taking an economic perspective help inform climate change health priorities? For example, if older people exert a higher cost on health systems and are particularly vulnerable to some of the health effects of climate change, should interventions concentrate

[59] The costs of climate change on health are also of increasing importance to the financial sector, for example to actuaries (Pryor 2017).
[60] JRC news item, 13 August 2018, on https://ec.europa.eu/jrc/en/news/europe-needs-coastal-adaptation-measures-avoid-catastrophic-flooding-end-century.

on the elderly? Alternatively, should it be a priority to focus attention on those who are economically active?

The Working Group further advised that it is also difficult to generalise about likely implications of climate change intervention on GDP, because the determinants of GDP vary so much between countries. Moreover, there is considerable scepticism that GDP is the best metric for monitoring societal well-being. It has been proposed (Stiglitz *et al.* 2009) that there should be a shift in emphasis from measuring economic production to measuring people's well-being, distinguishing also between assessment of current well-being and of the sustainability of well-being. However, the over-reliance on GDP as a global benchmark of societal success persists and, as it does not function as a reliable metric for health and well-being, alternative indicators are continuing to be discussed (Whitmee *et al.* 2015; Graham *et al.* 2018; Managi and Kumar 2018).

Climate change exacerbates health inequality and economic inequality, and will reduce countries' abilities to achieve SDGs (WHO Europe 2017b). The SDGs provide a great opportunity to integrate health and sustainability objectives into societal priorities (Whitmee *et al.* 2015, and see Table 3.4), including the potential impacts of strategies to reduce emissions of short-lived climate pollutants (Haines *et al.* 2017). The achievement of a range of SDGs can be progressed in concert, for example through improved crop yield- and nutrition leading to reduced poverty, the provision of clean energy and sustainable urban development. It is vital to capitalise on this opportunity to monitor indicators relevant to planetary health as part of the work on SDGs, and to report on progress nationally, regionally and worldwide (see Chapter 5).

4.9 Conveying the urgency of the challenges: tackling barriers to implementation

There are barriers to implementation of adaptation and mitigation at the individual level, in government and the private sector. According to the most recent Eurobarometer data[61], EU citizens are very concerned about climate change: 92% regard it as a serious problem and support action across the EU. In exploring the various socio-political and personal factors involved in forming public attitudes and behaviour about climate change, Happer and Philo (2016) observe, '*Climate change is a collective action problem and will not be solved without the consent of the public to facilitate policy change and/or to potentially make the collective behavioural changes required.*'.

What are the challenges for public engagement? Public perceptions of climate change vary considerably according to location, social circumstances and other factors. Learning about climate change can occur formally through education pathways and informally through the media, personal experience and social interaction (Hopkins 2015; Happer and Philo 2016; a case study on Norway is provided by Ryghaug *et al.* 2011). Various research studies have identified predictors of attitudes to climate change, for example in Europe, understanding of the anthropogenic cause of climate change is the strongest predictor of climate change risk perceptions (Lee *et al.* 2015). However, meta-analysis of literature on the correlates of belief in climate change (Hornsey *et al.* 2016) reveals two broad findings: (1) many 'intuitively appealing' variables such as education, subjective knowledge, and experience of extreme weather events, were overshadowed in predictive power by values, ideologies and political orientation[62]; and (2) climate change beliefs have only a small-moderate effect on the extent to which people are willing to act in climate-friendly ways. From this perspective, a better understanding of what influences beliefs (among the publics and politicians) may help to mobilise and target efforts to intervene on climate change. In this context, as noted previously, carbon labelling of food products with information about total supply chain GHG emissions may help to support behavioural change (Camilleri *et al.* 2019).

Misperception and misunderstanding, particularly relating to public belief that there is a lack of scientific agreement on whether anthropogenic climate change is happening, may be more detrimental than not being aware of climate change (Hopkins 2015). Manufacturing uncertainty by contesting science has been used by corporate and political interests in earlier public health controversies (e.g. tobacco control (Michaels and Monforton 2005; Nilsson *et al.* 2009)) and similar tactics of deliberate misinformation have now been applied to create doubt about global warming by deliberate undermining of science through personal attacks on researchers and concerted attempts to mislead the public (Oreskes and Conway 2010). Computational analysis of climate change politics in the USA has demonstrated that polarisation leads to uncertainty and, in some cases, policy stalemate, and that corporate funding influences the production and thematic content

[61] Eurobarometer 2017 on https://ec.europa.eu/clima/citizens/support_en.

[62] Recent comparisons of the USA, Western Europe and post-communist states (Smith and Mayer 2019) suggest that the political polarisation on whether climate change is harmful is emphasised in Anglophone countries, but this evidence predates the rise in right-wing populism elsewhere. Other recent meta-analysis (van Valkengoed and Steg 2019) indicates that factors motivating climate change behaviour may vary according to the nature of the climate change impact. However, most of this literature has examined motivating factors in response to flooding, storms and wildfires; heatwaves and drought are understudied and no literature was found on motivating factors for climate change adaptive behaviour with regard to vector-borne diseases (van Valkengoed and Steg 2019).

Box 4.2 The role of health practitioners

A study in Germany (Herrmann and Sauerborn 2018) finds that health effects of heat are perceived to be increasing by most general practitioners (although, as noted previously, heat-related deaths may be declining in many high income country settings) but this was mostly attributed by them to population ageing and the impacts of climate change were judged as uncertain by many. The knowledge and awareness of general practitioners and other health service professionals about heat health effects and other health effects of climate change need to be augmented. Primary care services have important functions in addition to treating illness with, for example, roles to provide appropriate advice and guidance in changing behaviour to bring environmental co-benefits, in surveillance, health system strengthening, and education and advocacy for planetary health (Xie *et al.* 2018).

of contrarian, polarisation efforts (Farrell 2016a,b). The science community has to be more proactive in countering such activities, including through better public engagement, working with political scientists to uncover evidence and, where necessary, confronting powerful interests that are financially supporting activities to misinform the public.

When people lack the expertise and skills to evaluate the science behind a claim, they will substitute judgement about something complex – climate science – with judgement about something simpler – the character of those who speak about climate science. Misinformation and misperceptions can be countered in various ways (Cook *et al.* 2017, 2018). Exposing and explaining fallacious reasoning within misleading denialist claims can be applied to engage with those who lack expertise in climate science. Such engagement must include tackling any misperception about lack of scientific consensus on global warming (Ding *et al.* 2011) and being aware, for example in social media, that user comments on a news story can influence the way a climate story is perceived as credible and can disrupt the intended message (Hinnant *et al.* 2016).

Analysis from US survey work shows that framing of climate change in terms of public health issues makes impacts more personally relevant with those segments of the public who are currently disengaged or dismissive (Myers *et al.* 2012). Recent work in France, Germany, Norway and Sweden (Bothner *et al.* 2019) confirms that health information is particularly important for the willingness of households to mitigate climate change through alterations in consumption behaviour. The focus on climate and health in hopeful terms is particularly helpful with a younger audience, in supporting pro-environmental behaviour, whereas efforts to emphasise risk can backfire by breeding despair, denial and inaction (Stevenson and Peterson 2016).

Apart from the young and those with political and commercial interests, who else is resistant or hesitant about climate change messages? Analysis of German data from more than 12,000 households (Andor *et al.* 2018) shows that elderly people are less concerned about climate change (but more concerned about other global changes). It may be, therefore, that ageing populations are less likely to support climate-friendly policies and allocation of public resources. However, attitudes in the elderly may be related to their underestimation of the health effects of climate change (see section 3.12), emphasising a key role for health practitioners, who also need to be well-informed (Box 4.2).

5 Conclusions and recommendations

5.1 What do we know and why are we concerned?

It is vital to ensure the well-being of current populations without compromising that of future generations. On the basis of the analysis of the Working Group in the preceding chapters, EASAC makes the following conclusions.

1. *Climate change is happening and is attributable to human activity.*
   Because of these changes, to protect current and future populations we need to safeguard the health of the vulnerable by adapting to climate change that cannot be prevented and rapidly stabilise the climate to reduce risks to health in the future.

2. *Climate change poses serious threats to human health.*
   A wide range of health outcomes is affected and the effects are both direct and indirect. Effects are mediated by various pathways including extreme events, air quality, food quantity and quality, water availability, change in infectious disease risks, with the potential for increased migration. It is recognised that many other factors are involved in determining the magnitude of the effect of climate change on health.

3. *Rapid and decisive climate action could greatly reduce the risks to health from climate change and bring near term co-benefits for health including through reduced air pollution.*
   There is a big opportunity to improve public health by moving to a more sustainable economy including through the use of zero-carbon energy, increasing the consumption of healthy low-environmental-impact diets and through urban policies in sectors such as transportation and the built environment.

4. *Actions to tackle climate change and health impacts are urgent.*
   If we do not act soon, we take increasing risks with our and future generations' health. The costs of acting now are much lower than if action is delayed.

5. *Health in the EU is affected by climate change within the EU and by changes outside the EU.*
   Effective response cannot be achieved only by acting at the national level. It is vital for the EU to act with solidarity and to take a global lead in addressing priorities, working with other nations to strengthen adaptation and mitigation policies.

6. *Solutions are within reach and much can be done by acting on present knowledge, but this requires political will.*
   Health issues are not just a matter for health departments: there must be 'Health in all Policies'. Human health is strongly influenced by environmental factors. Policy-makers must take a lead across a broad front, including promoting education and communication initiatives about impacts of climate change on health and ensuring effective individual, institutional and political responses.

7. *The scientific community has important roles in generating new knowledge and countering misinformation.*
   There is need for increased collaboration across disciplines, to reduce uncertainties in the evidence base, enable better informed decisions and to monitor the consequences of action. Research funders need increasingly to support transdisciplinary research that aims to build knowledge on impacts of climate change and the effectiveness of adaptation and mitigation strategies. The scientific community must also actively participate in public engagement.

What are the next steps? In Chapter 2, key questions are listed (Boxes 2.1 and 2.2) about the nature of the health effects of climate change and how to prepare and respond. The evidence reviewed in Chapters 3 and 4 helps to clarify major health impacts in Europe and to identify who is most vulnerable. There is recognition that tipping points leading to sudden irreversible changes in health and the environment may be a particular concern but the timing is uncertain and, of course, subject to actions taken now and development pathways chosen. As discussed previously, the potential benefits of intervention range from the health effects of reducing air pollution concomitantly with reducing GHG emissions, to helping to reduce obesity and non-communicable diseases by transforming fossil fuel-dependent urban transport to more physically active modes, and by reforming agricultural systems to reduce their GHG emissions alongside changes in dietary consumption (Haines *et al.* 2009; Chang *et al.* 2017).

The modelling of future health effects, direct and indirect, short- and long-term, has an important role to play in adaptation and mitigation decisions, putting in place systems and expertise to manage climate change risks (Nissan and Conway 2018). In imputing and projecting health effects, it is important to recognise the uncertainties and difficulties in utilising the current evidence base for practical purposes; nonetheless, actions taken to tackle climate change on the basis of the present evidence represent major opportunities to advance public health, as described in the previous chapters.

Further, with regard to the points in Boxes 2.1 and 2.2, it is becoming clearer that future climate change will interact with other socio-economic developments, for example population ageing, increasing urbanisation and health inequalities. The EU has the resources and systems that can be improved to manage the impacts of climate change on health. However, resilience is lower in lower-income countries and the EU has both a responsibility and the self-interest to help lead efforts globally. For all countries and regions, there is much more to be done to understand the determinants of resilience, the best adaptation strategies (and their combination) and the consequences of mitigation decisions.

In terms of wider economic and development issues (Box 2.2), in many cases, it is probable that action would be found highly cost-effective when all costs and benefits are taken into account but, to maximise effectiveness and efficiency, it is critically important to be aware of, and resolve, policy disconnects, trade-offs and unintended consequences. EASAC acknowledges that certain aspects of public health and health delivery are Member State responsibilities, where the EU Institutions traditionally had little competence to act. Nonetheless, there are many actions that the EU Institutions can take now in the health sector, for example improving surveillance and modelling, promoting research and innovation (technical, regulatory and societal innovation), enabling communication and flexible management frameworks to anticipate future developments. There are also shared priorities for the EU and Member States to deliver with regard to 'Health in all Policies'. In this respect, governance of energy generation, transport, the built environment, and agriculture and food systems should be regarded as public health policies.

In order to continue addressing the questions posed in Boxes 2.1 and 2.2, to reiterate, better use must be made of present knowledge to inform policy and practice. A considerable body of information is already available, as discussed in previous chapters and the sources cited, and other analysis and interpretation of the evidence already available is increasing rapidly, worldwide[63]. In the recent evaluation of its adaptation strategy (see Appendix 3), the European Commission suggests, '*It may be time now to switch focus from generating knowledge to applying it for decision-making under uncertainty, particularly in economic sectors that are potentially more vulnerable, such as agriculture in the Mediterranean region or the European outermost regions.*' EASAC supports the intentions to use knowledge more effectively but we also note the importance of continuing to fill knowledge gaps, perhaps particularly for health which has not, hitherto, been a significant part of the European Commission's adaptation strategy.

5.2 What should we do about the challenges?

The details underpinning and exemplifying the EASAC recommendations drawing on Working Group analysis and conclusions are presented in previous chapters. Some messages demand repetition: as an overarching recommendation, we reaffirm the top priority to stabilise climate and accelerate efforts to limit GHG emissions, with the aim of achieving a zero-carbon economy before 2050. Collectively, we must also build better strategic links between the adaptation and mitigation communities and those working on climate change and on pollution, and between other sectors. There must be continuing debate on what is EU-level and what is Member State responsibility and how there can be effective integration of roles. The effects of EU decisions on climate change impacts elsewhere and the prospects for adaptation and mitigation, particularly in low and middle income countries should be systematically considered.

With regard to both the better use of present knowledge and the generation of new knowledge, the priorities for linking research outputs and policy development continue to be the following:

- elucidating and quantifying climate change effects on health;
- understanding the (co-) benefits for health of policies to mitigate climate change;
- clarifying challenges and effective policies for adaptation;
- evaluating unintended consequences of policy action and proposing effective approaches to minimise them including supporting implementation research to promote the uptake of evidence-informed interventions, technologies and policies.

5.3 Generating and using the evidence base

5.3.1 Filling knowledge gaps by research

This requires sustained commitment to basic research, the fundamental resource for all discovery and innovation, and support for the transdisciplinary research agenda, based on a systems approach. Although it is not the present purpose to be comprehensive in identifying individual research priorities, and all available research tools should be used[64], among the critical needs are the following.

[63] For example, the US Fourth National Climate Assessment, on https://www.globalchange.gov/nca4.
[64] For example, there may be increasing opportunity to mine data obtained from social media to study climate effects at large-scale and track in real-time (Cecinati *et al.* 2019). More generally there is need for many countries to make progress in using unique patient identifiers to link healthcare and other data, while protecting patient confidentiality.

- Long-term observational studies, collecting durable, rigorous data under research quality conditions, e.g. using national cohorts, and assessing exposure–response (climate/aeroallergens/air pollution-health) functions. Such studies also need to collect disaggregated data to focus on compiling information on vulnerable population groups and vulnerable territories, accompanied by other research to ascertain the basis for vulnerability and for promoting health equity.

- Research and modelling to understand the implications of 'high-end' climate change scenarios and nonlinearities (dangerous and irreversible tipping points), what might be the warning signals and time frames, and the various limits to adaptation. Even if there is only limited understanding of thresholds currently, the risks of exceeding them is likely to increase with continued emissions.

- Improved understanding of attributing extreme weather events and health outcomes to climate change: European meteorological[65] and public health services should consider making an annual, assessment.

- Clarifying, improving and validating indicators of vulnerability and exposure to climate-related hazards (EEA 2017a, 2018), of current health impacts and projected risks, and of adaptation processes, outcomes and health system resilience (Ebi *et al.* 2018b). Assessments need to include socio-economic impact; economic analysis of the costs of climate-sensitive health impacts and the costs of responding to hazards.

- Increasing effort to evaluate and attribute mental health impacts and other indirect effects of climate change.

- Evaluating the cost-effectiveness of adaptation and mitigation strategies, taking into account multiple benefits and, where relevant, adverse consequences and trade-offs.

- Undertaking behaviour change and implementation research to understand better the levers and barriers to change at the level of individuals, communities and governments.

- Encouraging the global collective assessment of research priorities, and agreement on internationally coordinated research funding streams, for example through the work of the Belmont Forum initiative on Environment, Climate Change and Health.

5.3.2 Improving monitoring and integration of data sets

There is need to strengthen understanding of the links between hazard, exposure, susceptibility and outcomes. Opportunities are coming within range to link environmental, socio-economic and health data sets to develop new insights into possible associations and understand current and future trends. There is a core need to improve surveillance (partly by sharing good practice, for example in vector surveillance) with systematic monitoring, data integration and updating, assessment of risks, and provision of alerts for policy-makers, health services and other stakeholders. The option to set up a European Observatory (for the EU and neighbouring regions), linked with a Planetary Health Watch System (Haines *et al.* 2018) or other global observatory (Kulmala 2018) initiatives, to perform these functions, and interact with other relevant interests, for example for air quality, One Health, should now be considered[66]. When integrating data sets (particularly between human data and biophysical, chemical and biological data), it is important to be aware of differing standards for generating data, and that data sets may not be comprehensive.

5.3.3 Health in all policies

Adaptation, mitigation and promotion of resilient and innovative systems requires coherent policy framework and leadership to implement within the intergenerational context. There is a current policy disconnect in that there is significant EU collaboration in tackling some aspects of climate change but health policy is mainly prioritised at the national level. There is need for more EU coordination on health, and policy-makers need to go beyond their usual short-term timeframe. Among key priorities for the EU are the following.

- Ensuring that health is a major focus in the impending reform of the EU Adaptation Strategy (Appendix 3).

- Reinforcing commitment to current health protection objectives, for example consistent implementation of EU air pollution standards, while informing progress on new standard setting (on PM and O_3) according to the accumulating research evidence base, which suggests adverse effects well below current air quality standards.

[65] For example, the European Centre for Medium-Range Weather Forecasts, www.ecmwf.int.
[66] Efforts in linking data sets and EU policies might also take advantage of the new risk data hub constituted by DG Echo (Civil protection and humanitarian aid operations) that will map loss from extreme weather events as part of extended disaster risk reduction actions in Europe.

- Including health impact assessment in all sectoral climate change adaptation and mitigation initiatives, for example for housing, urban design, transport, energy, biodiversity[67]. This requires partnerships across governments, agencies and the private sector and integrated EU Member State objectives for tackling the greatest challenges, such as protecting human health in cities (e.g. via Covenant of Mayors for Climate and Energy). This also requires continuing effort to understand potential policy trade-offs and disconnects for example between health policy and environmental policy.

- Addressing the challenges for understanding and addressing food security–diet–environment interactions and improve EU policy coherence and governance for domestic and global food and nutrition security. A priority is to incorporate sustainability considerations into dietary guidelines and food policies. Action must include elaboration and implementation of climate-smart food systems and exploration of the implications for other EU policy, in particular the Common Agricultural Policy[68]. Current policy actions by the EU and Member States on food systems tend to concentrate on how to protect health from contaminated food, but there is less agreement on the degree to which the State should use health or environmental considerations to regulate the supply of ruminant (or other foodstuffs with high environmental impacts) through interventions that affect production, sale, processing and distribution of food products (Godfray *et al.* 2018). There are potential options for labelling schemes (health or environmental criteria), certification programmes (environmental criteria) or fiscal interventions (taxes). Sustainable agriculture for human and planetary health must also tackle issues such as pesticide use with the interconnected implications for agricultural, environmental and health policies and the innovation agenda (for new approaches to crop protection).

- Linking objectives and strategy on climate change and health with other key EU policy plans, for example for the Circular Economy and Bioeconomy[69], and for air quality.

- Emphasising potential health effects relevant to the EU initiatives to provide financial support for local and regional climate adaptation, and including priorities for climate adaptation-health benefits in EU Cohesion Policy for post-2020.

- Building better links for health in Europe between the European Commission and WHO. At a meeting[70] in June 2018 the WHO and European Commission agreed to strengthen collaboration in public health, especially in the areas for health systems, health emergencies and healthier populations. Climate change was not mentioned explicitly in the outcome of this meeting but should be an important focal point for future collaboration.

- Aligning all the above recommendations with EU and global activity in tackling the SDGs (see Box 5.1 and Appendix 4). Ensure that EU effort is used to inform other international activity for example by the G7 and G20.

- Considering issues for climate change and health in EU policy for neighbouring and other countries. In particular: (1) take into account the potential consequences for other countries of EU decisions in key sectors (e.g. agriculture), to reduce any resultant pressures for societal instability and migration; (2) ensure issues for climate change and health are covered in European Neighbourhood Policy[71]; and (3) put in place coherent policies to support the health of migrants arriving in the EU.

The health community can help with this policy development for all of the actions itemised above by framing the issues and identifying their health burden; setting priorities for prevention and responsiveness; mapping linkages between hazards and impact; clarifying the potential for synergies, unintended consequences and trade-offs; and showing the

[67] An initiative 'All Policies for a Healthy Europe' (https://healthyeurope.eu/) was launched recently at an event in the European Parliament (November 2018), proposing a European Commission office to assess and implement cross-sectoral policies in health policy-making, including across security, migration, economic growth and environment protection.
[68] Recent criticism of the Common Agricultural Policy post-2020 objectives by the European Court of Auditors notes that objectives are vaguely defined and not translated into quantified targets including how climate change will be taken into account in the EU's vision for agriculture such that it '*does not reflect a clear increase in environmental and climate ambition.*' (European Court of Auditors, Opinion No 7/2018: concerning Commission proposals for regulations relating to the Common Agricultural Policy for the post-2020 period, https://www.eca.europa.eu/en/Pages/Docitem.aspx?did=47751).
[69] For example, the 2018 update of the EU bioeconomy strategy includes reducing GHG production occurring in the building sector, https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy.
[70] http://www.euro.who.int/en/about-us/partners/news/news/2018/7/european-commission-and-who-strengthen-collaboration-on-public-health.
[71] European Neighbourhood Policy as part of the EU External Action responsibilities (https://eeas.europa.eu) provides relevant practical help, for example in supporting local development in 2018 in flood-affected areas of Bosnia and Herzegovina. However, more research is needed to understand multiple impacts of climate change in neighbouring countries—in the Mediterranean region as well as in the Balkans.

Box 5.1 Relevance to the SDGs

Many of the issues discussed in this report are relevant for multiple SDGs (Appendix 4). Climate change threatens progress towards the SDGs and will have an even greater impact on the achievement of sustainable development in decades beyond 2030. Well-designed adaptation and mitigation strategies can support progress towards multiple SDGs whereas poorly designed policies could have adverse effects. There may be opportunities to develop composite indicators (ASviS 2018) that monitor integrative assessment of disparate targets; there is need to collect and utilise evidence in designing these indicators.

However, some SDG targets are poorly defined and there is a role for the academies in leading the academic community, together with other stakeholders, in supporting greater rigour in clarifying, refining, analysing and monitoring targets and their indicators. Assessment of global progress on indicators is provided by the UN Department of Economic and Social Affairs[72].

The SDGs are relevant throughout EU policy objectives, not only to those policies that pertain to lower-income countries. Consequently, there will be continuing need to document and emphasise climate change and health issues in the follow-up to the imminent EU report on embedding SDGs in the EU policy framework.

There is also need to develop the knowledge base to support informed consideration of what strategy will be put in place to come after the SDGs in 2030.

In 2019, the UN High Level Political Forum is focusing on SDG 13, climate action, as one of its priorities; this is an opportunity to highlight health issues for Europe and worldwide.

evidence for effective interventions and tracking outcomes for risk and impact as part of increasing accountability.

5.3.4 Health risk communication

There is urgent need to raise awareness of the current and potential effects of climate change on health and of the opportunities for adaptation and mitigation:

- It is imperative to counter misinformation and denial of scientific knowledge by vested interests and so reduce polarisation in public and policy debates. There are opportunities to begin this process in schools as well as promoting activities to engage with the general public.
- There are research needs to understand individual and institutional behaviour, support stakeholder empowerment, and influence change.
- The lay community has to be involved in co-design of research projects, early warning systems, and sustainable dietary recommendations.
- There is also need to improve knowledge of climate change effects, adaptation and mitigation in the health services including policies to reduce the environmental impact of health services.
- There are opportunities to build better links in assessing and communicating the need for integrated action on climate change adaptation and mitigation – for example by considering an augmented role for the EU Consumers, Health, Agriculture and Food Executive Agency[73].

5.3.5 What is the continuing role of the academies?

The work of academies is independent of commercial or political vested interests, and is based on verifiable science and transdisciplinary engagement. There is a considerable role for academies in demonstrating 'responsibility under uncertainty' to include the following.

- Convening function to gather information across disciplines and share perspectives between sectors and countries, to foster cooperation.
- Influencing research funders and universities to support transdisciplinary research, education and capacity strengthening.
- Horizon scanning and supporting modelling for emerging challenges, opportunities and trade-offs.
- Engaging on the relevant issues for the SDGs (Box 5.1), including monitoring of progress.
- Raising awareness with policy-makers, other stakeholders, the media and the public-at-large at the national, regional and global levels: including informing robust responses to tackle 'fake news' and other attempts to mislead.

EASAC and its member academies are committed to supporting further analysis, engagement and action in Europe on the matters raised in this report. We also aim to catalyse further discussion with academies more widely through the work of the InterAcademy Partnership, the global network of science, medicine and engineering academies.

[72] https://unstats.un.org/sdgs/indicators/database. See also the 2018 SDG Index and Dashboards Report on http://sdgindex.org.
[73] www.ec.europa.eu/chafea, whose interests currently span health, consumer protection and food safety.

Appendix 1 Working Group composition and timetable

The report was prepared by consultation with a Working Group of experts acting in an individual capacity, nominated by member academies of EASAC:
Volker ter Meulen (co-chair, Germany)
Andrew Haines (co-chair, UK, nominated by FEAM)
George Christophides (Cyprus)
Regula Gehrig (Switzerland)
Patrick Goodman (Ireland)
Roy Harrison (UK)
Markku Kulmala (Finland)
Zbigniew Kundzewicz (Poland)
Blahoslav Marsalek (Czech Republic)
Maria Nilsson (Sweden)
Martin Röösli (Switzerland)
Filipe Duarte Santos (Portugal)
Sebastian Vollmer (Germany)
Jaap van Dissel (The Netherlands)
Christos Zerefos (Greece)
Nina Hobbhahn and Robin Fears (EASAC project scientific secretariat)

The initial scope of the project was reviewed by the EASAC Biosciences Steering Panel in November 2016 (Brussels) and the initial range-finding discussions were held with DG Sante and DG Research and Innovation in March 2017 (Brussels). Project scope, objectives and design were discussed and approved by Council at EASAC meetings in May 2017 (Tallinn) and November 2017 (Sofia).

The Working Group met in London in April 2018, with Lukasz Aleksandrowicz (Wellcome Trust) as observer and in November 2018 with Howard Frumkin (Wellcome Trust) as observer. We thank our observers for their active inputs to discussion, in particular the contribution of Howard Frumkin to highlighting issues for communication about climate change.

The project was announced on www.easac.eu, with a call for evidence in May 2018.

Peer review and EASAC member academy endorsement was completed during February–March 2019.

We thank Michael Norton, Director of EASAC Environment Programme, for his helpful review of the text, and the EASAC Biosciences Steering Panel for their support of the project proposal and its elaboration.

Appendix 2 Scope of climate change impacts for human health: some previous reviews of evidence

The *IPCC* assessment (Smith *et al.* 2014) lists heat- and cold-related impacts; floods and storms; ultraviolet radiation; vector-borne and other infectious diseases; food- and water-borne infections; air pollution; allergens; nutrition; occupational health concerns; mental health; violence and conflict. More recent IPCC work on comparing likely effects of 1.5°C and 2°C is discussed in Chapter 2.

The *European Commission's Climate Adaptation Platform for Health*[74] identifies the main indicators for health in terms of extreme temperature; floods; air pollution; vector-borne diseases; and the urban environment.

The *EEA's* (2017) detailed analysis summarises the main effects of climate change on health as related to extreme weather events; changes in the distribution of climate-sensitive diseases; and changes in environmental and social conditions. Some of the indicators have recently been updated (EEA 2018). The EEA observes that quantitative projections of future climate-sensitive health risks are difficult owing to the complex relationship between climactic and non-climactic factors and future adaptation measures.

WHO Europe (2017a,b) addresses direct impacts of high temperatures; extreme events; forest fires; floods and drought; and indirect effects via agriculture and food systems; conflict and migration. The WHO (2018) summarised key statistics and messages to contribute to the COP24 discussions.

The *US Global Change Research Program*[75] focuses on temperature-related deaths and illness; air quality impacts; extreme events; vector-borne diseases; water-related diseases; food safety, nutrition and distribution; and mental health and well-being.

The *World Economic Forum*[76] outputs agree that the main climate change impacts on global health will be attributed to high-temperature effects, particularly in urban heat-islands, and in exacerbating chronic conditions in those who are already vulnerable; air pollutants and respiratory disorders; vector-borne and zoonotic disorders; and effects mediated by food systems (malnutrition, food-borne and water-borne diseases).

The *Lancet Countdown* initiative (Watts *et al.* 2018a,b) is tracking a set of indicators of progress on health and climate change, chosen for their relevance to public health and to the main anthropogenic drivers of climate change, their geographical coverage, data availability, resource and timing constraints. These indicators are divided into five broad sections: (1) climate change impacts, exposures and vulnerabilities; (2) adaptation planning and resilience for health; (3) mitigation actions and health co-benefits; (4) economics and finance; (5) public and political engagement.

The 2017 Countdown assessment (Watts *et al.* 2018a) notes, '*The delayed response to climate change over the past 25 years has jeopardised human health and livelihoods.*' Although the past 5 years have seen a growing response solidified in the Paris Agreement, the Lancet Countdown indicators demonstrate a world that is only just beginning to respond to climate change and hence only just unlocking the opportunities available for better health. The 2018 Countdown assessment (Watts *et al.* 2018b) again emphasises the global challenges, with stark and unequivocal messages, as follows.

(1) Present changes in heatwaves, labour capacity, vector-borne disease and food security provide early warning of the compounded and overwhelming impacts on public health that are expected if temperature continues to rise. Trends show an unacceptably high level of risk for current and future health.
(2) Lack of progress in reducing emissions and building adaptive capacity threatens both human lives and the viability of health systems.
(3) Despite delays, some sectors (including power generation and transportation) have seen the beginning of low-carbon transitions, and the nature and scale of the response will be the determining factor in shaping health for centuries to come.
(4) Ensuring widespread understanding of climate change as the central public health issue will be crucial in delivering an accelerated response. This latest Countdown assessment concludes that there is '*great cause for concern, with the pace of climate change outweighing the urgency of the response.*'

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[74] https://climate-adapt.eea.europa.eu/eu-adaptation-policy/sector-policies/health.
[75] https://www.globalchange.gov/browse/reports/our-changing-planet-fy-2017. See also the US Fourth National Climate Assessment on https://www.globalchange.gov/nca4.
[76] https://www.weforum.org/agenda/2016/01/what-is-climate-change-doing-to-our-health/.

Appendix 3 The need to connect science, health and policy in the wider EU climate change strategy development context

Strategy for long-term EU greenhouse gas emissions reductions[77]

The public consultation on future options closed in October 2018 and the European Commission strategy is expected during 2019. The EU is currently putting in place policies to reduce GHG emissions by at least 40% by 2030. The EU also currently shares in the objective by higher-income countries as a group to reduce emissions by 80–95% by 2050 (compared with 1990 levels). It is recognised that GHG emissions from all parts of the economy are key parameters of the problem—and this includes agriculture. Among the objectives of the EU Climate Knowledge Innovation Centre[78] are developing a low-carbon economy to include low-carbon agriculture and advancing the bioeconomy in the food value chain.

Adaptation strategy

The EU Adaptation Strategy[79] was intended to promote greater coordination and information sharing by Member States, to ensure that adaptation considerations are addressed in all relevant EU sector policies ('mainstreaming'). The recent report from the European Commission evaluating the strategy[80] concluded that, overall, the strategy had delivered on its objectives, for example to bridge knowledge gaps, enable climate proofing of CAP, and introduce adaptation in the Covenant of Mayors. These rather optimistic conclusions are controversial in some respects. For example the European Court of Auditors was more sceptical about success of efforts for the Common Agricultural Policy, and the European Commission has admitted also that '… *none of the priority knowledge gaps have been closed and new gaps have emerged.*' Looking ahead, the evaluation recognises that there is scope for reframing the adaptation strategy to better align with international policy developments as well as better assess implications for the EU of cross-border effects of climate impacts in non-EU countries, for example migratory flows. It is noteworthy that public health is only mentioned in the evaluation strategy in the context of future intentions—there is no mention of 'health' in the evaluation sections covering what had already been done (apart from an isolated mention in the opening paragraph). In the view of EASAC it is vitally important that health issues are accorded greater prominence in the continuing strategy development and are linked to priorities in other sectors such as agriculture and landscape use.

Multiannual financial framework 2021–2027

The European Commission request[81] is welcome in proposing increased support for actions to mitigate climate change, to provide impetus for protecting health and to tackle inequalities. Further EU added value may come from prioritising research on health care systems in the new Horizon Europe research funding programme that may help to improve health outcomes.

Circular economy

The EU Action Plan for the Circular Economy[82] acknowledges that proposed options must 'preserve the high level of protection of human health and the environment' but it does not elaborate on the health-related aspects of the actions. The concept of the circular economy is widely seen as a route to sustainable growth, good health and employment, while sparing natural resources, and is expected to support attainment of SDGs, especially SDG 12 on

[77] Ares (2018) 3742094-13/07/2018.
[78] www.climate-kic.org.
[79] The Adaptation Strategy was adopted in 2013 as COM (2013) 2016 (final). The DG Clima discussion of the present Consultation strategy and Evaluation Roadmap is on https://ec.europa.eu/clima/events/articles/0119_en and evaluation of the Adaptation strategy was completed in late 2018. The DG Clima discussion also provides links to draft versions of country assessments outlining climate change adaptation. A public consultation on the evaluation of the Adaptation strategy was completed in March 2018 and analysis is provided on https://ec.europa.eu/clima/sites/clima/files/consultations/docs/0035/summary_report_en.docx.
[80] Report from the European Commission to the European Parliament and Council on the on implementation of the EU strategy on adaptation to climate change, 12 November 2018 COM (2018) 738 final.
[81] Proposal made on 2 May 2018, with agreement on budget proposals with European Parliament and Council expected by May 2019.
[82] The EU Action Plan for the Circular Economy was published by the European Commission in 2015, with targets for achievement up to 2030. The European Parliament adopted the Circular Economy Package in 2018; currently it is awaiting approval by the European Council before it can enter into force.

responsible consumption and production. Yet the understanding of the health implications of transition to a circular economy is relatively limited (WHO Europe 2018). As a large proportion of GHG emissions are related to patterns of consumption and production (Alfredsson *et al.* 2018), the agendas for the circular economy and climate change adaptation/mitigation need to be brought together. The WHO Europe report (2018) outlines the opportunities for direct benefit to health care systems and indirect benefit to health from reducing negative environmental impacts together with the risk of adverse and unintended health effects from actions undertaken in pursuit of a circular economy.

SDGs

The European Commission's intentions relevant to SDGs, covering issues for governance, financing, measurement of progress and involvement of stakeholders in shared responsibility, is set out in the corresponding Communication (European Commission 2016). Their subsequent report, with options and recommendations for how SDGs can be embedded in the EU policy framework, is expected soon; it will be important to ascertain the focus on health issues. Details of current EU SDG-relevant policy and actions are on https://ec.europa.eu/sustainable-development/about_en and a report from Eurostat on EU progress on SDGs up to 2018 is on https://ec.europa.eu/eurostat/web/sdi/overview.

Climate change adaptation and mitigation actions can support progress towards the SDGs through a range of pathways. For example, well-designed mitigation strategies can support progress toward SDG 1 (poverty reduction), SDG 2 (sustainable agriculture), SDG 3 (health), SDG 7 (clean energy), SDG 11 (sustainable cities) as well as climate change (SDG 13) (Haines *et al.* 2017; see also Appendix 4).

Appendix 4 Examples of the relevance of SDG targets to climate change and health issues

SDG 1: No poverty

1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

SDG 2: Zero hunger

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality.

SDG 3: Good health and well-being

3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
3.d Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

SDG 4: Quality education

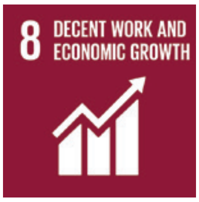
4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development.

SDG 6: Clean water and sanitation

6.4 By 2030, substantially increase water-use efficiency across all sectors … .
6.5 … implement integrated water resources management at all levels … .
6.6 … protect and restore water-related ecosystems … .

SDG 7: Affordable and clean energy

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix.



SDG 8: Decent work and economic growth

8.3 Promote development-oriented policies that support productive activities … .
8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation… with developed countries taking the lead.

SDG 9: Industries, innovation and infrastructure

9.2 Promote inclusive and sustainable industrialisation … .
9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries … .

SDG 11: Sustainable cities and communities

11.B By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change … .

SDG 12: Responsible consumption and production

12.2 By 2030, achieve the sustainable management and efficient use of natural resources.
12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature.

SDG 13: Climate action

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
13.2 Integrate climate change measures into national policies, strategies and planning.
13.3 Improve education, awareness raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

SDG 15: Life on land

15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

SDG 16: Peace, justice and strong institutions

16.6 Develop effective, accountable and transparent institutions at all levels.
16.7 Ensure responsive, inclusive, participatory and representative decision-making at all levels.

SDG 17: Partnerships for the goals

17.6 Enhance north–south, south–south and triangular regional and international cooperation on and access to science, technology and innovation … .
17.9 Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the sustainable development goals … .
17.14 Enhance policy coherence for sustainable development.
17.16 Enhance the global partnership for sustainable development … .
17.17 Encourage and promote effective public, public–private and civil society partnerships … .
17.19 By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement gross domestic product … .

Further details on SDG targets are on https://www.un.org/sustainabledevelopment. Other discussions on interactions between individual SDGs and their targets were published by the International Council for Science (2017).

Abbreviations

CAP	Common Agricultural Policy
CO_2	Carbon dioxide
DALY	Disability adjusted life years
EASAC	European Academies' Science Advisory Council
ECDC	European Centre for Disease Prevention and Control
EEA	European Environment Agency
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
NET	Negative emission technology
NO_x	Nitrogen oxides
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SSP	Shared Socio-economic Pathway
WHO	World Health Organization

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