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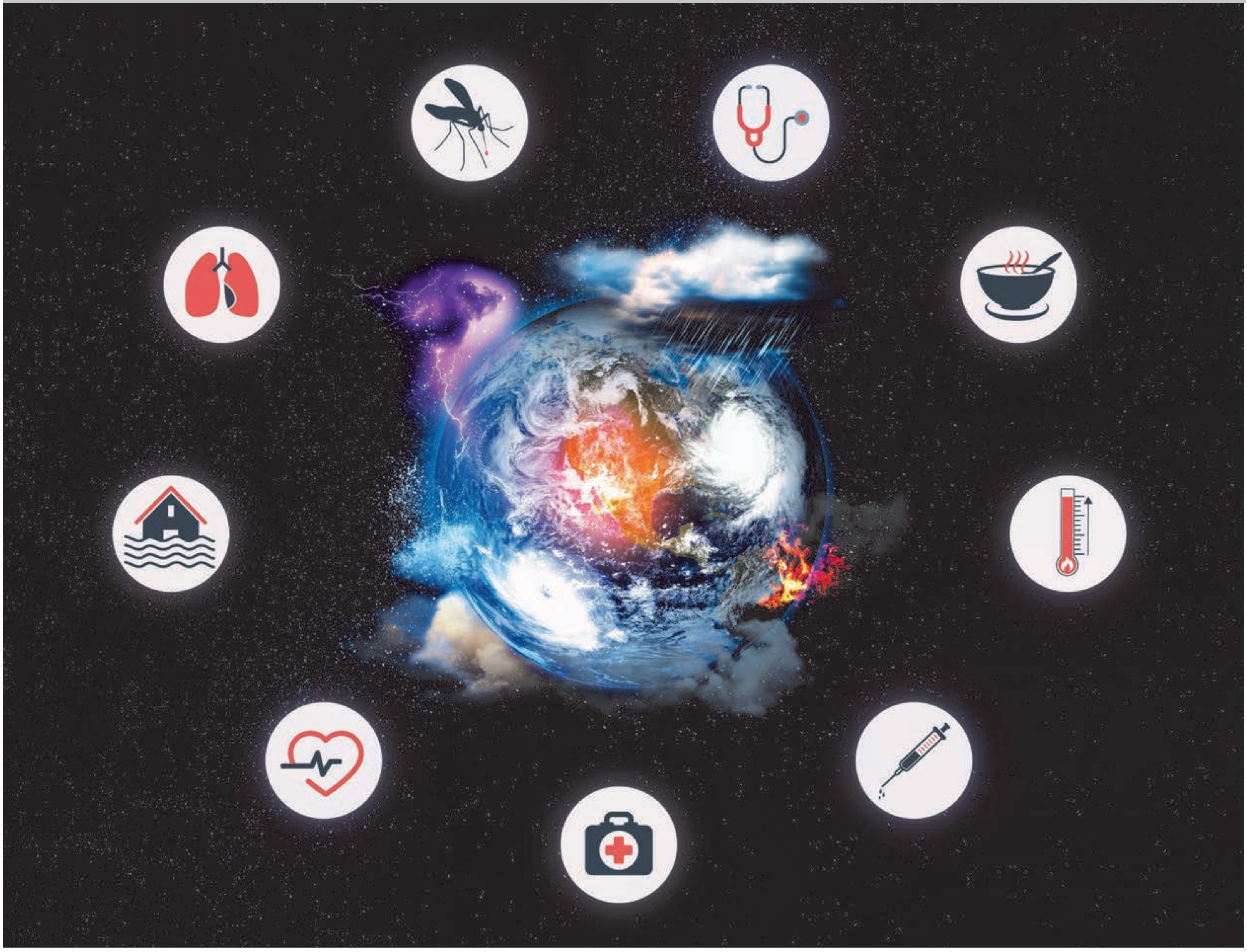
Health in the climate emergency: a global perspective



Network of African Science Academies NASAC

aassa The Association of Academies and Societies of Sciences in Asia

IANAS Interamerican Network of Academies of Sciences

European Academies easac Science Advisory Council

Health in the climate emergency: a global perspective

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In Memoriam

Academician Professor Emeritus Dato' Dr Khairul Anuar bin Abdullah

Medical doctor

President of the Association of Academies and Societies of Sciences in Asia (AASSA)

An outstanding expert and committed colleague of the global 'Climate Change and Health' project and a highly esteemed friend

Contents

Foreword

The World Health Organization recently emphasised that the climate crisis is the single biggest health threat facing humanity[1]. Until recently the adverse health effects of the climate crisis had been relatively neglected by policy-makers but that is beginning to change and must now change quickly.

Although the scale, nature and timing of adverse effects of climate change on physical and mental health, via both direct and indirect pathways, vary within and between regions of the world, there are common challenges. To achieve health equity and climate justice, these challenges must be tackled by better integration of mitigation and adaptation solutions and an increased focus on the most vulnerable groups in marginalised and disadvantaged communities. There are unprecedented threats but also unprecedented opportunities to use scientific knowledge to inform policy and practice. Much can be done now to use the evidence already available to effect rapid and decisive action to reduce long-term risks to health and bring near-term benefits, for example through the reduced air pollution that will accompany decarbonisation of energy systems.

This report is the outcome of a project by the InterAcademy Partnership (IAP), the global network of more than 140 academies of science, engineering and medicine, enabling the voice of science to be heard in addressing societal priorities. Previous work by IAP has addressed a wide range of issues for action on climate change. For example, in 2021 IAP publications included "A net zero climate-resilient future: science, technology and the solutions for change" and "Climate change and biodiversity: interlinkages and policy options". IAP has also provided advice on the necessary scientific infrastructure and procedures to put in place worldwide, for example in 2022 with the "Call for a global health data sharing framework for global health emergencies". In the present report, we concentrate on issues for identifying and implementing policy solutions countering the detrimental effects of climate change on human health.

Our inter-regional, inclusive, project based on an innovative design previously developed for the IAP project on Food and Nutrition Security and Agriculture (published in 2018), encourages academies to capture diversity in evaluating evidence from their own countries, using a transdisciplinary, systems-based approach to planetary health to inform policy options for collective and customised action. Working groups from four regional academy networks were constituted: in Africa (the Network of African Science Academies, NASAC), Asia (the Association of Academies and Societies of Sciences in Asia, AASSA), the Americas (the InterAmerican Network of Academies of Science, IANAS) and Europe (the European Academies' Science Advisory Council, EASAC). The networks agreed on the overall scientific scope and project design and on priority questions to address as the common starting point. Publication of the regional reports was accompanied by engagement with the science and policy communities in the regions and at national level. The four regional reports and the feedback on them were then also used as a resource to prepare this fifth, global report under the auspices of an expert editorial group. The global report was independently peer reviewed and endorsed by IAP.

Our assessments are integrated across sectors, to emphasise the need for health-in-all-policies, and levels of governance – national, regional and global. The particular purpose of this global report, in supporting the regional outputs, is to advise on inter-regional matters, local-global connectivities and those issues at the science-policy interfaces that should be considered by intergovernmental organisations

[1] https://www.who.int/campaigns/world-health-day/2022.

and other bodies with international roles and responsibilities. We are aware, of course, that there are other reports available on the range of issues that IAP covers and, indeed, our report coincides with the emerging outputs from the IPCC 6th Assessment Cycle that represents a major science-based endeavour of great significance. However, the knowledge base is fragmented and unequally distributed, and the climate change policy imperative to act for health as yet insufficiently recognised. Therefore, the distinctive and inclusive nature of the IAP project can add value to other international initiatives. IAP represents the combined scientific resources of the world's academies, drawing on excellent science across all disciplines and with access to other sources of knowledge such as from Indigenous Peoples, to proffer evidence to inform policy now, independent of political or commercial bias, to show where there is scientific consensus and where controversial issues require further consideration.

The IAP regional and global reports form a basis for the academies' commitment to continuing long-term engagement in broadening discussion with policy-makers, other stakeholder groups and civil society, with particular regard to the following:

(1) Acting on the available scientific knowledge to facilitate robust and coherent policy development, support responsible innovation, and shape public understanding of the challenges, including challenges for implementation.

(2) Continuing to build global scientific capacity and partnerships, including reform of geographical imbalances in generation and use of research.

Our report takes a strategic view of the priorities rather than attempting to be overly policy prescriptive. What do we cover? We describe and exemplify the requirements for better specification and integration of adaptation and mitigation solutions, the issues for aligning follow-up to the Paris Agreement and Agenda 2030 and other global and regional strategic initiatives. We emphasise the urgency in resolving the global climate finance gap in pursuit of health and equity objectives. Also, the value of learning lessons from responses to the COVID-19 pandemic to apply to other global health challenges through scientific cooperation and mobilisation of resources at scale. We recognise that tackling climate change together with biodiversity loss and food and nutrition insecurity demands better use of the shared evidence and rethinking of international science advisory capacities in pursuit of coherence in policy-making. We affirm that academies with their strong convening powers are keen to expand their collective roles in evaluation and delivery of evidence at science-policy interfaces. Academies can advocate for the increasing health focus, support greater national and regional ambitions to tackle climate change, and amplify the voices of those who have not always been heard in policy debates.

We take this opportunity to thank Volker ter Meulen and Andy Haines for their outstanding leadership of the project and Robin Fears for preparing the global report. We thank the many scientific experts who have generously contributed their time, expertise and enthusiasm to our regional working groups and our global editorial group. We are also grateful to all our peer reviewers and our academies and their regional networks, our IAP Steering Committee colleagues and our core project team for their sustained efforts. All of us in IAP also express our thanks for the very significant financial support provided by the German Federal Ministry of Education and Research (BMBF).

We welcome discussion of any of the points raised in our report or on other related issues that merit attention. The forthcoming UN FCCC COP27 provides a critically important opportunity for health and equity to come to the foreground in international climate change deliberations.

Richard Catlow and Depei Liu
IAP Co-Presidents
April 2022

Summary

There is increasing evidence for the adverse effects of climate change on human health, both physical and mental, posing serious challenges to the health gains made over recent decades. The scale, nature and timing of these problems differ across countries and within their populations, influenced by geography and socio-economic status; however, there are commonalities. Shared challenges to health from climate change necessitate that all actions taken to identify and quantify mitigation and adaptation solutions to combat the challenges of climate change focus on the most vulnerable groups, to ensure that we develop resilient, sustainable and equitable health systems, as well as correct fragmentation and imbalances in research systems and knowledge use. Climate change is a health crisis as well as an environmental crisis: the effects are experienced here and now, and the search for solutions is urgent.

InterAcademy Partnership project design and purpose

Many academies of science have a long history of interest in climate change and health topics. In this report, the InterAcademy Partnership (IAP), the global network of more than 140 academies of science, engineering and medicine, brings together established regional networks of academies to examine issues for understanding, responding to, and preparing for, adverse effects of climate change on human health. We aim to show how science can support and impel innovation, public policy and practice in developing and applying solutions. With its wide geographical representation, IAP can express the voice of those who have not always been heard in designing contextually appropriate research, or during the processes whereby evidence informs policy and practice.

The first phase of the IAP project was designed to comprise regional academy network working groups in Africa, Asia, the Americas and Europe. Each consisted of experts from across the region, each drawing on excellent science with a mandate to analyse current circumstances and future prospects, and proceeding from a common agreed starting point to delineate the scope of inquiry. The four regional reports have now all been published and are being used as a basis to engage with national and regional policy-makers and other stakeholders. The regional reports also serve as a resource for the global analysis presented in this, fifth, project report. Here, our emphasis is on the policy environment in which to inform, develop and implement solutions, and we summarise evidence from all the regions to provide a clear basis for action. Both mitigation and adaptation approaches are essential and increasingly must be integrated to achieve resilient net-zero emission societies. It is also essential for policy-makers to consider the potential benefits for health, and other outcomes, when designing mitigation actions.

Our objective with the global remit is to help maximise the value of the regional recommendations, addressing regional imbalances and climate injustice, while also emphasising additional global roles to undertake collective action. These include tackling risk and its transmission in a rapidly connected and uncertain world and focusing on the global provision of public goods: those that have to be provided on a scale that is beyond the capacities of individual countries or regions. Science-based policy actions must be integrated, both vertically between different levels of governance and horizontally, between different sectors within the overall context of promoting local–regional–global interconnectedness. The IAP project has been designed to add value by taking a systems-based approach with inclusive perspectives, robustly evaluating the evidence for mitigation and adaptation solutions, sharing examples and lessons of good practice within and between regions, and assessing knowledge-based policy options even if challenging and controversial.

IAP's main messages

In summary, our aggregate messages are the following:

- Climate change poses serious threats now to human physical and mental health. Climate change health risks will increase over time. The need for action is urgent.
- Rapid and decisive action could greatly reduce the long-term risks to health from climate change and bring near-term benefits for health, including through reduced air pollution and other co-benefits of climate change mitigation.
- As health within a region is also affected by activities that contribute to climate change and the impacts outside that region, it is important to integrate inter-regional responses to climate change together with regional and national actions.
- Solutions for adaptation and mitigation are within reach using present knowledge, but action requires political will.
- The scientific community has important roles in generating new knowledge, for example about cost-effective technologies, policies and implementation strategies, and in countering misinformation and addressing equity in climate–health responses.
- There is need for better monitoring and surveillance of potential health impacts due to climate change. There is also need for better evaluation of implemented actions, to assess and quantify benefits, trade-offs and costs and document facilitators and barriers to action.
- Climate change intersects with and exacerbates other global challenges, including COVID-19, pollution, and loss of biodiversity. The pandemic is providing important lessons about responding to threats worldwide through cooperation and rapid mobilisation of resources at large scale.

The pathways of climate change exposure are complex and health impacts are modified by social determinants. While there are uncertainties in attribution and extrapolation, it is clear that climate change affects health and health systems in multiple ways. These include both direct pathways (e.g. heat, drought, wildfires, flooding) and indirect via disruption of ecological and socio-economic systems (e.g. food insecurity, changes in infectious disease vectors, pathogens and habitat, migration, declining labour productivity). The adverse effects of climate change on agriculture were highlighted by the United Nations Food Systems Summit and in COP26, and must be addressed for climate-resilient and sustainable food systems alongside reducing the contribution made by food systems to greenhouse gas (GHG) emissions. In addition, global drivers of environmental change have health effects that should be distinguished from the direct and indirect effects of climate change itself. In particular, air pollutants that are co-emitted with GHGs from fossil fuel combustion, a principal driver of climate change, also have negative effects on human health.

Among the major health effects of climate change and its drivers overall are cardiovascular, cerebrovascular and respiratory diseases, mental health outcomes, communicable diseases, malnutrition, and hazard-related injury and death.

Conclusions and recommendations

Recommendations for change require transdisciplinary assessments, based on collaboration between scientific disciplines and intersectoral coordination (e.g. between health, agriculture, energy, transport and urban planning sectors). Filling knowledge gaps requires coordinating between countries in research and data collection, sharing infrastructure, skills and methodologies, and building trust in responsible science.

Climate change is a global health emergency and IAP reaffirms the top priority must be to stabilise climate and accelerate efforts to limit GHG emissions as soon as possible, with the aim of attaining the agreed target of a zero-carbon economy before 2050 by implementing concerted and radical actions promised at COP26.

Our recommendations pertaining to health can be summarised as follows:

1. Using the evidence base already available to inform policy with greater urgency and ambition

Although there are many research gaps still to fill, this should not be used as an excuse to delay acting on the best evidence currently available for health-in-all-policies. The following chapters of our report show where and how there is enough evidence available now to act.

National level. Increased ambition and action require integrating health issues effectively into nationally determined contributions and national adaptation plans, which must contain sufficient detail on health objectives aligned with emission reduction and other targets, and on the resources required to make and implement decisions. There must also be better integration of individual mitigation and adaptation measures, hitherto often applied in a fragmented way, including mitigation in the health sector itself.

Regional level. Health policy objectives have regional (continental) connotations. For example, when there are cross-border threats, and to ensure key decisions taken in one place do not lead to negative consequences, inadvertent or not, elsewhere. Collaboration is enhanced by the critical mass afforded by multiple countries acting within a region. There are already several models available for regional coordination, for instance as developed by African Union, European Union and in the extended Arctic and Mediterranean regions. There are some priorities that must also be addressed in a coordinated way at both national and regional levels, including support for climate finance, climate justice and research.

Global level. Practical challenges for embedding adaptation and mitigation solutions worldwide include the following:

- **Coherence in intergovernmental policy** and linkage to collective action on Sustainable Development Goals.
- **Financing agreed actions**, for example to align with the priorities for social justice and 'Loss & Damage' objectives, taking account of benefits for health. Reallocating budgets in pursuit of integrated policy objectives requires rethinking of subsidies, incentives and other financial instruments. For example, there must be cessation of subsidies and other public financing of fossil fuels, other polluting activities, and harmful agricultural impacts.
- **Identifying and financing transformative options**, for example that may require further effort to find alternatives to gross domestic product to monitor societal well-being, and re-examination of other proposals for change, such as personal carbon allowances, in order to deliver health and other societal benefits.
- **Facilitating convergence of policy action** on climate change, biodiversity and sustainable food systems that will require better coordination and further development of science-based intergovernmental advisory panels. A focus on human health helps to strengthen and catalyse linkage of global agendas, including those of the G20 and G7.
- **Responding to concurrent crises such as climate change and COVID-19** particularly to protect those most vulnerable to the health consequences.

There is also potential for delivery of sustainable recovery after the pandemic where a low-carbon trajectory combines benefits for health, equity and the environment, as well as for the economy.

2. Filling knowledge gaps by research

This requires sustained commitment to basic research, including assessment of the relationships between exposure to hazard, biological effect and health impact;al so to applied research, for example the evaluation of effectiveness and cost-effectiveness of interventions, including health risk assessment of technology development and implementation. It is important to develop transdisciplinary understanding and quantification of health effects and their attribution to climate change. One essential component is correction of the currently skewed geographic distribution of research worldwide. Low-to-middle-income countries and highly exposed regions (e.g. Arctic and the Small Island States) must be better represented in research design and its conduct. For research involving highly vulnerable groups, key stakeholders, including Indigenous Peoples, patients, farmers, people of colour, women and youth, must be engaged in research co-design. Qualitative as well as quantitative research is important—to understand the lived experience of climate change impacts on health outcomes as well as the contexts within which mitigation and adaptation efforts unfold.

3. Strengthening monitoring and surveillance activities that link health and climate

The traditions of using evidence to inform policy differ in the health and environmental change communities. It is now necessary to build on the best of both, for example moving away from narrow, discipline-focused approaches (that had characterised health data gathering) and recognising the value of systematic review methods (hitherto, little used in environmental assessments). Bringing together data streams also requires resolution of multiple problems for data collection, organisation, curation and sharing and increased commitment to surveillance and monitoring. Recent regional activity to develop a Climate and Health Observatory provides a useful platform model which could be replicated in other regions and extended globally, but this requires political will and sustained investment.

4. Improving evaluation of impacts of climate mitigation and adaptation actions

Although there is a rapidly accumulating literature on climate change effects on health, there is more to be done to clarify the extent to which adverse effects are attributable to climate change, and are location-, population group- or disease-specific. Moreover, there is only limited information to assess the comparative success of alternative mitigation and adaptation solutions, for example for sustainable cities, and to understand which responses are most effective at protecting human health, most cost effective and scalable.

Until recently, the impact of the health sector itself had rarely been included in decarbonisation policy discussions. This omission is beginning to be addressed, stimulated by momentum for mitigation action within individual health facilities and health systems. There are new opportunities to share good practice worldwide on how to combine impacts on decarbonisation with improved resilience in health services. These sectoral initiatives merit support by public policy initiatives.

5. Effective health risk communication and countering misinformation

It continues to be a priority to counter misinformation and denial of scientific knowledge by vested political or commercial interests in order to reduce polarisation in public and policy debates. Health professionals have a responsibility to be champions of change in the wider community: by advising on how climate change risks health;how equitably to support adoption of sustainable, healthy lifestyles;and how to el icit change in their own and other sectors.

6. Identifying and implementing academy roles in support of science as a public good to inform policy and practice

Academies worldwide are acquiring considerable expertise in bringing together policy-makers and the scientific community. The IAP global framework facilitates integration of academy action at multiple scales. For example, at the country level, policy-makers are sometimes hesitant to act if evidence about climate effects is not available for their own territory: academies can help by communicating how the evidence available from elsewhere is relevant to the local setting. In addition, academies can help to advocate and support an increased focus on health in nationally determined contributions, coupled with advising on greater representation of science and health expertise in national negotiating teams. Academies could also play a greater role in advocating for, and engaging in, better monitoring, surveillance and assessment of health impacts and their attribution to climate change and in the evaluation of policies and interventions. Academies can also help by taking account of local health profiles, local ecosystems and cultures and by linking local action with the national regional and global pathways of change as these emerge. At a regional level, variation in societal attitudes and values brings additional challenges to policy-making: academies are well placed to help policy-makers understand diversity, such that policy can be made that is science-based and economically and socially feasible. At global level, the geographical extent of IAP and its reach-out enables inclusion of voices from low-to-middle-income countries and vulnerable populations to emphasise issues for health equity and climate justice and hold policy-makers to account.

In closing our assessment, we observe that some have suggested that COP26 was the last and best opportunity to set the path for net-zero in 2050. No-one knows the longer-term consequences of COP26. But we do know that there are great opportunities, and great urgency, to use the knowledge that is already available. We must use scientific advances worldwide to develop adaptation and mitigation solutions with cooperative intent, customised according to context. However, to be successful, greater political attention to the health effects of climate change and the health benefits of mitigation and adaptation actions must occur.

1 Introduction to the challenges for the shared global agenda

1.1 Sustainable development, climate change and health

The pace and extent of recent environmental change pose serious challenges to global health gains made over recent decades. Many natural systems are degrading at unprecedented rates (Whitmee *et al.* 2015) and there is considerable concern that the health of future generations is being put at risk to realise economic and development gains in the present. Moreover, improvements in higher-income countries have been made at the expense of the rest of the world.

It will not be possible to continue to exploit nature according to the same development paradigm. Instead, efforts must define the environmental limits within which humanity can safely operate (Steffen *et al.* 2015). As highlighted in Conference of the Parties (COP) negotiations and elsewhere, equity and justice are critical to this transition and it is vital not to marginalise low-to-middle-income countries (LMICs) further.

Planetary boundaries have been proposed for nine processes identified as underlying a stable and resilient Earth (Figure 1). Crossing these boundaries increases the risk of generating large-scale abrupt or irreversible environmental change with consequent threats to the integrity of human civilisation (see also the most recent assessment of the global environmental outlook in UNEP (2019)). Health must be part of the global environmental agenda (Willetts *et al*. 2022).

'*Most of these risks are not clearly recognised or monitored, and are invisible to the policy, economic and social systems that can help mitigate them*' (Belesova *et al*. 2020a).

The Anthropocene Epoch – the age of humans – which is now characterised by these environmental risks, confronts humanity with unprecedented challenges. Meeting these challenges demands fundamentally different modes of thought, institutions, technologies, policies, values and governance systems than those of the Holocene Epoch (Haines and Frumkin 2021). Climate change is the greatest health threat that defines the Anthropocene Epoch and it is already adversely affecting human health and health systems (Haines and Ebi 2019). During 2021 and 2022, there has been increasing awareness of climate change, for example in terms of extreme heat, wildfires, storms and flooding, and of the acute effects on deaths and a range of health outcomes. These immediate impacts, terrible as they may be, are yet only a small part of the longer-term public health burden.

There is accumulating evidence of both direct and indirect adverse effects of climate change on human health – physical and mental – worldwide, with indirect effects mediated by disruption in ecological systems (e.g. agriculture, pathogens and vectors) and socio-economic systems (e.g. population displacement, declining labour productivity). Moreover, air pollutants that are co-emitted with greenhouse gases (GHGs) from fossil fuel combustion, a principal driver of climate change, also have negative effects on human health: the health effects of these drivers as well as climate change itself will be addressed subsequently. Climate change has already produced considerable shifts in the underlying social and environmental determinants of health at the global level. Indicators of climate change impacts, exposures and vulnerabilities are changing for the worse, '… *with the 2020 indicators presenting the most worrying outlook report since the Lancet Countdown was first established*' (Watts *et al*. 2021). The latest *Lancet* Countdown report (Romanello *et al*. 2021) confirms alarming trends in all indicators affecting people everywhere: including heatwave exposure, reduction in work capacity, increasing exposure to wildfires, transmission of infectious diseases, sea level rise, declining crop yield and quality and areas affected by drought. This is happening here

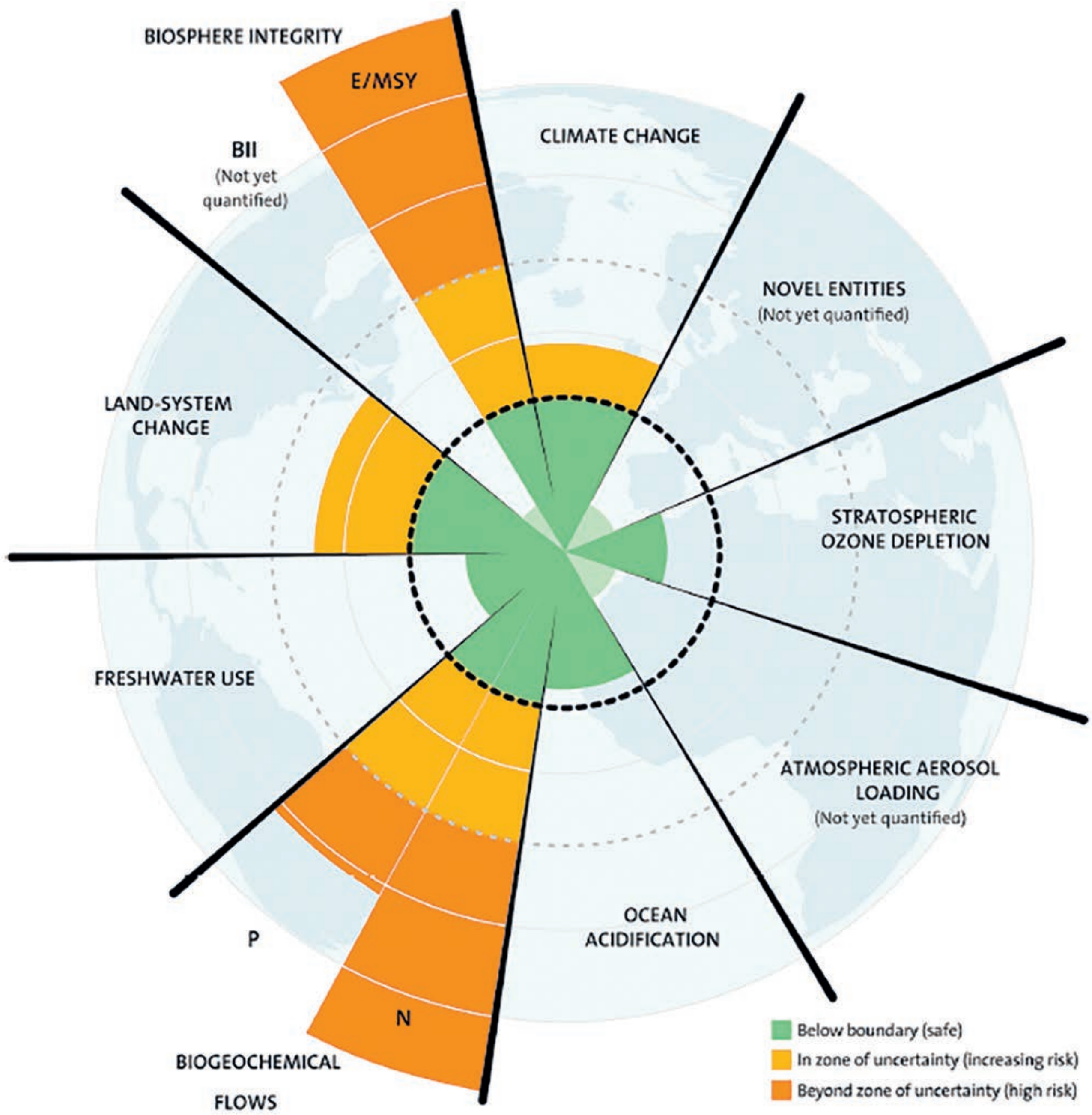


Figure 1 Planetary boundaries and estimates of the control variables that indicate how close they are to being breached. Climate change is in the zone of uncertainty for exceeding its planetary boundary. Further discussion of the two core boundaries of climate change and biodiversity is presented in EASAC (2020). BII, sum of genetic diversity and functional diversity; e/MSY, extinctions per million species-years. Source: Stockholm Resilience Centre: J. Lokrantz/Azote based on Steffen et al. (2015).

and now and it is a global health emergency. Pathways of exposure are summarised in Figure 2 and will be discussed in detail together with impacts in following chapters.

If no additional actions are taken, then over the coming decades, substantial increases in mortality and morbidity can be expected (Haines and Ebi 2019). Despite the accumulating evidence, protecting human health has only recently become a major consideration in global policy discussions about climate change. The increased recognition of health issues brings new demands from decision-makers for robust scientific data for knowledge synthesis and its use to inform policy for health and health care, including evidence on the attribution of effects (Vicedo-Cabrera *et al*. 2021) and for quantification of adaptation and

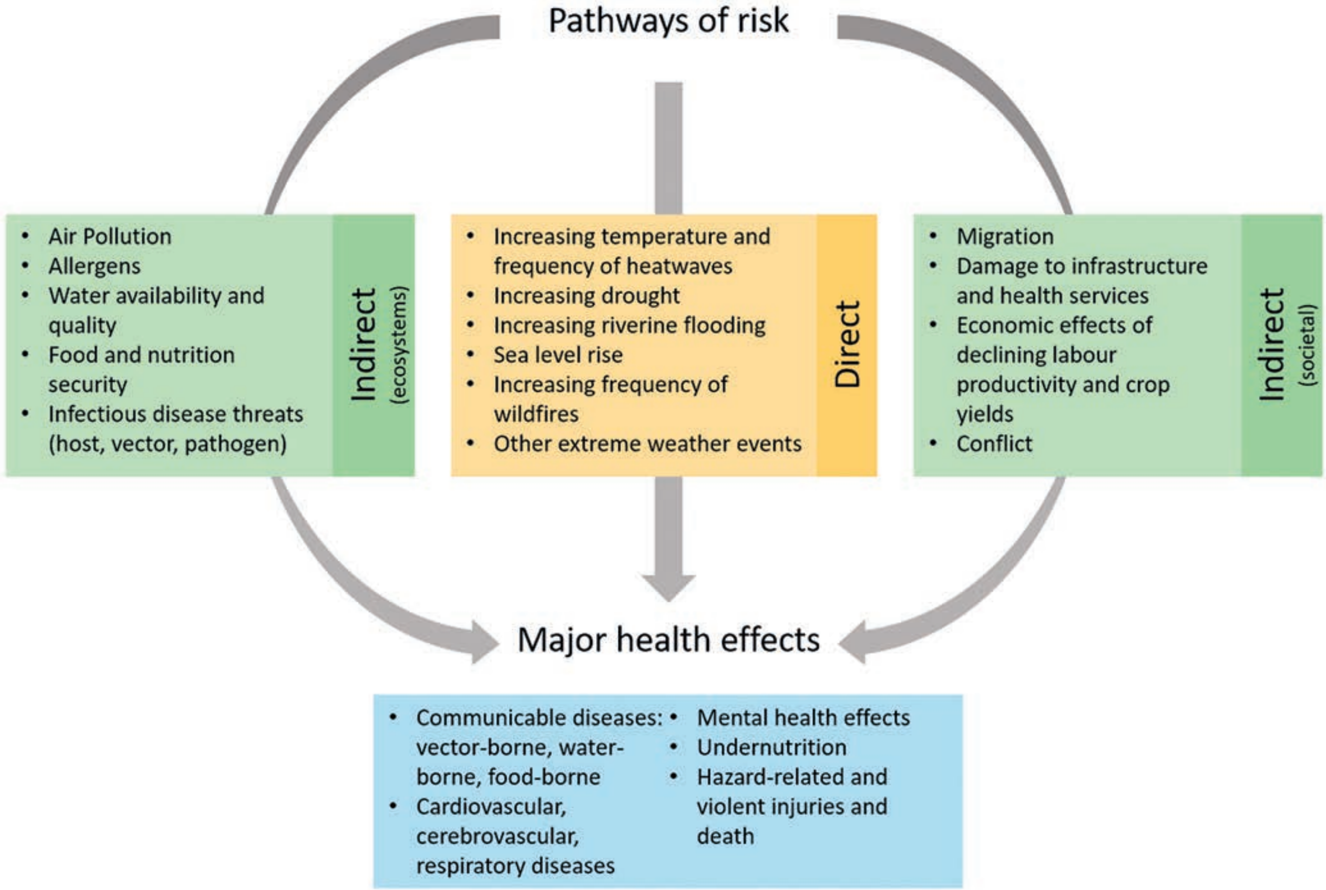


Figure 2 Direct and indirect pathways of exposure to climate change and their health consequences.

mitigation solutions (Hobbhahn *et al.* 2019). The challenge is to bring evidence-based interventions to scale (Patz and Thomson 2018). This requires robust evaluation of the scientific opportunities arising from advances in research across multiple disciplines, and for the scientific community to engage with wider communities and policy-makers.

Academies of science and medicine have a substantial history of interest in climate change and health topics. The InterAcademy Partnership (IAP), the global network of more than 140 academies of science, engineering and medicine, brings together established regional networks of academies to ensure that the voice of science is heard in addressing societal priorities. In the present report we draw on regional assessments of climate change effects on health to focus on solutions: mitigation, adaptation and cooperation. In this collective academy work our objective is to convey strong consensus, evidence-based messages about the global opportunities and challenges, while also facilitating learning among the regions, sharing lessons of good practice and building capacity for action worldwide. The academies, independent and free of vested political and commercial interests, are well placed to make an objective and open evaluation of the evidence and, in so doing, counter vested interests generating misinformation.

1.2 Recent and projected changes in climate

The climate is changing, primarily because of the emission of long-lived greenhouse gases (GHGs) such as carbon dioxide (CO_2) and shorter-lived climate pollutants such as methane and black carbon, from human activities. We face unprecedented risks but there are also unprecedented opportunities

Box 1 The current state of the climate and future projections

1. It is unequivocal that human influence has warmed the atmosphere, ocean and land. Human-induced climate change is already affecting many climate systems and increasing the incidence of extreme weather events in every region across the globe.
2. Global surface temperature was 1.1 °C higher in the decade 2011–2020 than between 1850–1900.
3. The past 5 years have been the hottest on record (since 1850).
4. The recent rate of sea level rise per year has nearly tripled compared with 1901–1971.
5. It is '*virtually certain*' that hot extremes including heatwaves have become more frequent and more intense since the 1950s, while cold events have become less frequent and less severe.
6. Many of the changes due to past and future GHG emissions are irreversible for centuries to millennia.
7. Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5 °C and 2 °C will be exceeded during the 21st century unless deep reductions in CO_2 and other GHGs occur in the coming decades.
8. Among the regional assessments of extreme heat, drought and precipitation: there is a consensus that increase in drought, aridity and wildfires will particularly challenge agriculture, forestry, water systems, health, and ecosystems in Southern Africa, the Mediterranean, much of the Americas and Australia;i ncreasing precipitation will affect the high latitudes of the Northern Hemisphere. There will also be continuing increases in coupled events, for example heat and drought.

Source: IPCC, Climate Change 2021: the Physical Science Basis, https://www.ipcc.ch/report/ar6/wg1/ - Full Report.

See also World Meteorological Organization 2021, Climate change indicators and impacts worsened in 2020, https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate.

for action. The Paris Agreement was viewed as an initial political triumph with signatories committed to reduce GHG emissions and limit climate change to well below a global temperature rise of 2 °C above pre-industrial levels, and preferably limiting increases to 1.5 °C. However, much more commitment and action are needed, as starkly illustrated by the Intergovernmental Panel on Climate Change report (IPCC 2021) (Box 1).

Promises are not enough and '*insufficient action means that temperature increases are likely to be well in excess of 2 °C, a catastrophic outcome for health and environmental stability*' (Atwoli *et al*. 2021). The recent nationally determined contribution (NDC) synthesis report projects a sizable increase in global GHGs in 2030 compared with 2020 (Figure 3). According to the latest IPCC findings, such an increase, unless actions are taken immediately, may lead to a temperature rise of about 2.7 °C by the end of the century.

The latest UN Environment Programme gap report (UNEP 2021a) confirms that countries are not delivering on mitigation promises and that the emissions gap (between target and achievement) is projected to continue.

Projected, updated temperature increases were published by Climate Action Tracker after COP26 (Figure 4) and illustrate the continuing challenges.

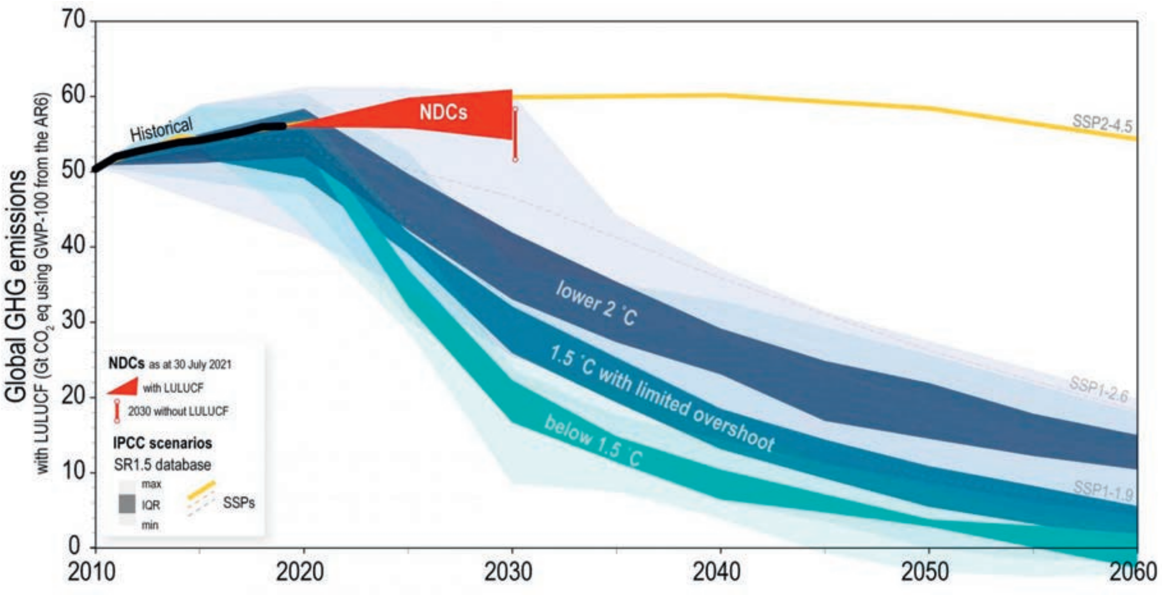


Figure 3 GHG projections from the United Nations Framework Convention on Climate Change (UNFCCC) report 'Nationally determined contributions under the Paris Agreement' 17 September 2021 FCCC/PA/CMA/2021/8. This report includes information from all 191 Parties to the Paris Agreement, based on their latest NDCs available. Further explanation of the trends and additional discussion of forecasting over this period, including mitigation and adaptation plans is at https://unfccc.int/sites/default/files/resource/cma2021_08_adv_1.pdf .

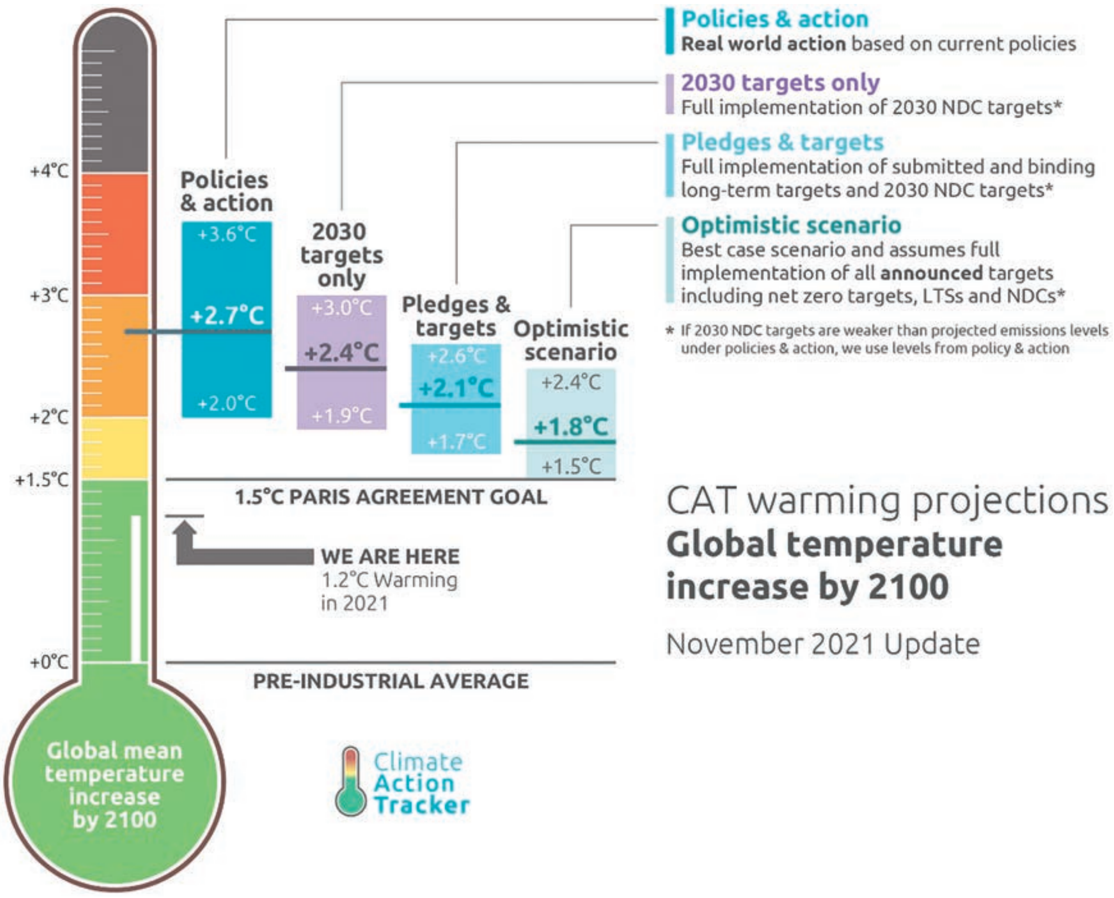


Figure 4 Post-COP26 warming projections. Note, the world is now at 1.2 °C warming, compared with 1.1 °C described by the IPCC report in Box 1. The projections are the median warming estimate in 2100: this means that there is a 50% chance that the calculated temperature would be exceeded if the given emissions pathway is followed; see https://climateactiontracker.org/global/cat-thermometer.

1.3 Solutions to reduce climate change health risks are within reach

Adverse health effects of climate change are already happening, and we cannot prevent all future effects, although much can be done to protect and promote human health. There is sufficient evidence available to act now. This is a global crisis and there must be global solutions, encompassing localised action. Effective policy responses to the multiple effects of climate change on health require integrating diverse mitigation and adaptation measures across sectors for more resilient systems. Mitigation actions to reduce emissions of GHGs can benefit population health locally and in the near-term. These are additional to the more generally distributed environmental and global health benefits that will follow from mitigation as a result of reduced exposure to climate hazards. The health co-benefits of mitigation could help to offset the costs of tackling climate change, for example, by reducing costs of ill health (including impacts on labour productivity) and of health services provision. Adaptation actions to support individuals, communities and governments in coping with the unavoidable consequences of climate change that cannot be mitigated can also reduce the effects of climate change on health.

Finding and implementing solutions must be based on the synthesis of available research findings from across multiple scientific disciplines and knowledge systems accompanied by new research to fill knowledge gaps. One of the problems hitherto in using scientific evidence has been the limited research conducted in LMICs (Berrang-Ford *et al*. 2021a) as well as those areas experiencing disproportionate levels of warming (e.g. the Arctic, Small Island Developing States (SIDS)). This has resulted in a lack of inclusivity in designing contextually appropriate research and in using research outputs. The IAP project aims to contribute to highlighting this gap by summarising perspectives, clarifying and evaluating evidence worldwide, prioritising the challenges faced by vulnerable groups and the need to respect cultural and other diversity. Science can help generate solutions to protect and improve health and health equity by providing the resource for innovation, by guiding practice and by informing public policy. However, effective responses to climate change require a systems-based approach (Pongsiri *et al*. 2017; Pongsiri and Bassi 2021) to understand how human health outcomes emerge from complex interactions between natural and social systems and then to act on that understanding. Both understanding and action necessitate transdisciplinary collaboration supporting coherent and coordinated policy across all sectors (horizontal integration) and between local, national, regional and global levels of governance (vertical integration), ensuring 'health-in-all-policies'.

The IPPC report on impacts, adaptation and vulnerability (Box 2) was published at a late stage during the finalisation of this IAP report. Some of the IPCC strategic points relevant to health are summarised in Box 2 and are in close agreement with conclusions in the present report.

1.4 Objectives of the IAP project

Why are we publishing a new report? We acknowledge that many of the issues are already being evaluated by international bodies and it is not our purpose to duplicate analysis of the rapidly accumulating evidence base that is well covered in other work. We provide links to those detailed assessments in the following chapters and aim to provide complementary insights to these other sources. We concur with the view (Anon. 2022a) that '*the research community's work stretches far beyond IPCC*' and that there is continuing great need to progress research for supporting, monitoring and evaluating innovation, public policy and practice in addressing climate change everywhere. The recent Glasgow Climate Pact[1]

[1] Glasgow Climate Pact, November 2021, https://unfccc.int/documents/310475.

Box 2 IPCC: climate change 2022 impacts, adaptation and vulnerability

This latest report recognises the interdependence of climate, ecosystems, biodiversity and human societies and integrates knowledge more strongly across the natural, ecological, social and economic sciences than earlier IPCC assessments. There is a particular focus on transformation and system transitions.

Many of the impacts are now irreversible. Over 40% of the world's population are highly vulnerable.

Extreme weather events linked to climate change are hitting humans and other species much harder than previous assessments indicated. These impacts are already going beyond the ability of many people to cope. Between 2010 and 2020, 15-fold more people died from floods, droughts and storms in very vulnerable regions, including parts of Africa, South Asia and Central and South America, than in other parts of the world.

As well as the physical health impacts, climate change is exacerbating mental health issues, including stress and trauma related to extreme weather events and the loss of livelihoods and cultures.

Near-term actions that limit global warming to close to 1.5 °C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared with higher warming levels, but cannot eliminate them all.

Climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Some responses to climate change result in new impacts and risks, including risks from maladaptation and adverse side effects of some emission reduction and CO_2 removal measures.

Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits. However, adaptation progress is unevenly distributed. The effectiveness of adaptation will decrease with increasing warming.

Comprehensive, effective and innovative responses can harness synergies and reduce trade-offs between adaptation and mitigation to advance sustainable development

Adapted from Report of Working Group II contribution to the 6th Assessment Report of the IPCC, 27 February, 2022. https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf.

See also Box 1 for evidence of the physical basis for the impacts.

issued after COP26 recognised the broad importance '*of the best available science for effective climate action and policymaking.*' IAP engages with science academies in many countries in summarising the evidence for effects and solutions for their own countries and regions and to contribute to developing the critical mass of knowledge for global action.

We acknowledge that much of the relevant action happens at the national and regional levels as described in the IAP project's regional reports that form the underpinning for this global report (see chapter 2 and EASAC 2019a; AASSA 2021; IANAS 2022; NASAC 2022). The regional reports have great value for helping academies and others in the scientific community to engage in regional decision-making and they furnish an important evidence source for sharing lessons of good practice worldwide. Our present report takes on an additional global role to explore collective action in (1) tackling risk and its transmission in a rapidly connected and uncertain world;and (2) for the pr ovision of global public goods—those that have to be provided on a scale that is beyond the capacities of individual countries or regions. This includes the commitment to develop the required critical mass for the generation and use of research evidence for risk assessment, adaptation and mitigation of climate change. A global perspective on governance is further warranted because national competition acts to drive externalisation of costs of climate change on human health and the environment. There is a major underlying problem of regional imbalances and climate injustice whereby oftentimes countries that are high GHG emitters are not affected by the negative consequences of climate change as severely or immediately as countries with low GHG emissions. In the medium to long term, climate change has concerning and potentially catastrophic consequences for all populations.

In addition to external objectives to advise on how science can inform policy and practice, our project and its reports have an internal objective, to help newer and smaller academies to strengthen their capacity for work at the science–policy interface. At the time of starting the project, the World Health Organization Global Strategy on Health, Environment and Climate Change (WHO 2020) observed that '*only a limited number of countries currently have advisory bodies with the mandate or capacity to set national agendas, track national progress on health and environment, and provide this evidence directly to policy makers*'. The IAP project helps to provide insight to enable member academies to support those required country-level activities and to aggregate the learning to support regional-level activities.

1.5 Audiences for the IAP global report

IAP directs messages and recommendations to a wide range of audiences, which include the following:

- All those in the UN system concerned with tackling the climate change and health issues that we raise and their interconnections with other issues, for example for addressing the SDGs.
- Those involved in preparing for COP27, in the United Nations and at regional and national levels.
- Other intergovernmental groups, for example LMIC groups such as G77; and G20, G7 and international membership bodies such as the Organisation for Economic Co-operation and Development (OECD).
- International research initiatives at global and inter-regional levels.
- Audiences at national, regional and local levels, for example policy-makers, public health authorities, city administrations (including urban networks) and other stakeholders. IAP reaches these and the general public with the help of follow-up activities by national academies and regional academy networks.

It is one of the design strengths of IAP inter-regional projects that follow-up can be pursued at local, national, regional and global levels. The extensive reach of academy networks facilitates articulation of critically important issues for promoting inclusivity, equity and multilateralism in global governance mechanisms. IAP is a founder member of the Sustainable Health Equity Movement, whose aim is to promote sustainable health equity as an ethical principle that guides all national and international economic, social and environmental policies[2].

The issues addressed in this report are urgent. Climate change is already affecting human health and projected climate changes will increase the burden of climate-sensitive health outcomes. There is, of course, considerable variation within and between regions that has to be taken into account in composite evaluations and recommendations. This variation reflects diversities in geography, socio-economic status and health systems, as well as in scientific infrastructure, research capabilities, research usefulness (the extent to which the research questions posed can guide decision-making and health practice) and the degree to which research outputs are used by policy-makers and others. Those areas with weaker health infrastructure will be least able to cope. Nonetheless, despite the heterogeneities, there are also commonalities in the challenges posed to health and a shared need for all countries to develop resilient, low environmental impact and equitable health systems. There are also significant commonalities worldwide in the need to address fragmentation of research activities and bias in knowledge systems from inequitable resource distribution and lack of engagement of the most affected communities.

The climate crisis affects everybody and while there are unprecedented threats, there are also unprecedented opportunities to build on scientific advances worldwide to develop solutions, adapted to local contexts. In chapter 2 we describe the IAP inter-regional project procedures and the potential for added value of this innovative project design. Chapter 3 summarises evidence from the regional reports and other literature on the effects of climate change on health. Chapters 4 and 5 discuss mitigation and adaptation measures, and chapter 6 reviews related issues, particularly for climate justice, biodiversity and the concurrent COVID-19 crisis, that should be embraced within the systems-based approach. Conclusions and recommendations are presented in chapter 7.

[2] https://www.interacademies.org/news/sustainable-worldwide-collaboration-respond-ongoing-inequities-and-health-emergencies. See Castro *et al*. 2022.

2 Design and conduct of the IAP climate change and health project

Summary of emerging points in chapter 2

The scope and design of the IAP Climate Change and Health project are described.

Four policy areas are the focus of the project: (1) the impacts of climate change on health; (2) the benefits of a 'low-carbon' economy; (3) adaptation to climate change and its limits; and (4) the potential effects on health of interacting policies coupled with the challenges of implementation of climate actions. The IAP project aimed to be policy relevant without being prescriptive, and to focus on scientific opportunities and science-based solutions.

The project builds on a European project on Climate Change and Health completed in 2019 (EASAC 2019a). In late 2019, each of the remaining three IAP regional academy networks (NASAC for Africa; AASSA for Asia and the Pacific; and IANAS for the Americas) nominated a multidisciplinary working group of experts. Collective discussion of the European project's outputs at the start of the project led to the development of an agreed common template of scoping questions.

The IAP project sought to capture regional diversity and heterogeneity, and to maintain a focus on vulnerable population groups. It also aimed to build on and add value to relevant initiatives by the academies, their regional networks, and by other organisations, and to avoid the duplication of efforts.

The Working Groups were independent from each other, in consultation with additional experts including young scientists, to develop a set of recommendations and options for policy and practice at the national and regional levels.

The wider health and science communities were engaged through a series on online discussion events, including participation at the virtual meetings of the World Health Summit (2020), the Consortium of Universities for Global Health (2021), the WHO European consultation on climate and health (2021) and Africa Climate Week (2021) as well as online and physical participation in COP26

The three regional reports, published in 2021–22, the 2019 European report and a review of key scientific literature were used to inform this global synthesis report. It aims to compare and reflect on regional similarities and differences for informing global conclusions and consensus recommendations, for the generation of knowledge to advise on issues at the science–policy interface.

2.1 Framing the scope and scale

Much of the thinking in this broad area for climate change effects on health derives from the work of McMichael and colleagues (1996, 2006, 2008) whose publications directed attention to the damaging effects of climate change and other human pressures on health and health equity as well as on the biophysical and ecological systems. Based on these insights, strategies were set out (McMichael *et al*. 2008; see also initial development of concepts by Haines *et al*. (2006)) to prevent or lessen the harm encompassing four policy foci:

- Impact of climate change on health, livelihoods and social stability.

- Benefits of moving rapidly to a low-carbon economy (see further elaboration of the ideas in Haines *et al*. (2007) and Haines *et al*. (2009)).
- Effectiveness of adaptation—and its limits.
- Unintended health effects of policy actions including what trade-offs may have to be made.

This policy framework, together with the impetus generated by the *Lancet* Countdown initiative (latest assessment; Romanello *et al.* 2021) and other international initiatives, particularly by the World Health Organization (WHO) and Intergovernmental Panel on Climate Change (IPCC), provides the baseline for our project.

2.2 Designing IAP project procedures

The project comprised the four IAP regional academy network partners who constituted working groups in Africa (Network of African Science Academies, NASAC), the Americas (InterAmerican Network of Academies of Science, IANAS), Asia (the Association of Academies and Societies of Sciences in Asia, AASSA) and Europe (European Academies' Science Advisory Council, EASAC). Each working group had an ambitious mandate to analyse current circumstances and future prospects, share evidence, clarify controversial points and identify knowledge gaps. Each continental (regional) working group was invited to proffer advice on options for policy and practice at the national and regional levels, customised according to local contexts and strategic needs so as to make the best use of resources available. Each working group consisted of experts convened from across the region, nominated by IAP member academies and selected to provide an appropriate balance of experience and scientific expertise from the health, biological, physical and social sciences. Working groups also engaged with younger researchers through the Global Young Academy and national Young Academies.

Reflecting a legacy of interests in climate change and health by the member academies of EASAC, the European working group was initiated in 2018 and its report was published in 2019 (EASAC 2019a; Hobbhahn *et al.* 2019). This initial European activity was followed by work focusing on neighbouring vulnerable regions, the Arctic (NASEM *et al.* 2020) and the Mediterranean (EASAC *et al.* 2021) and by an examination of issues for decarbonisation of the health sector itself (EASAC and FEAM 2021). Working groups were initiated by IAP in Africa, Asia and the Americas in parallel in 2019 (Box 3) and their reports published in 2021-22.

Outputs from the European work were used as one input to inform initial IAP collective discussion so that all regions started by

Box 3 National academy involvement in regional academy network Working Groups/ steering committee

Africa: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cote D'Ivoire, Ethiopia, The Gambia, Kenya, Mauritius, Nigeria, Senegal, South Africa
Asia-Pacific: Armenia, Australia, Azerbaijan, Bangladesh, China, India, Indonesia, Japan, Malaysia, Nepal, New Zealand, Pacific Islands, Pakistan, Republic of Korea, Russian Federation (Far East), Turkey
Americas: Argentina, Brazil, Canada, Costa Rica, Granada, Guatemala, Mexico, Peru, United States, Uruguay
Europe: Cyprus, Czech Republic, Finland, Germany, Greece, Ireland, The Netherlands, Poland, Portugal, Sweden, Switzerland, UK

Scientists from additional countries were involved in peer review.

Box 4 Common starting points, agreed by all regional working groups

1. What are the main effects now of climate change on health?
2. What are projected impacts[3], subject to various climate change scenarios?
3. What are main adaptation options and implications for policy?
4. What are mitigation options that bring co-benefits for health, and are there trade-offs that should be addressed?
5. Are these adaptation and mitigation options already sufficiently covered in national adaptation plans and nationally determined contributions, and how should the level of ambition be increased?
6. What work has already been done by academies, for example within IAP Health?
7. What needs to be done to improve the evidence base and monitoring?
8. How to link recommendations with other policy initiatives, especially for SDGs?
9. How to ensure focus on vulnerable groups with the aim of reducing inequities?
10. How to be distinctive and add value to what is already being done elsewhere?

See EASAC (2019a) for additional detail on starting points.

addressing an agreed and common, template of scoping questions (Box 4). Our discussions used the term 'net-zero carbon' to mean GHGs more generally, while recognising that the concept has been criticised as allowing focus on carbon sequestration rather than emissions reduction.

During the project, progress in each of the regions was regularly discussed within the core project team including regional academy network leads and working group chairs.

2.3 Building on regional diversity for collecting evidence

The project was designed to engage the four regional (continental) networks in analysis and synthesis of diverse issues, according to their own experience, expertise and expectations while, at the same time, conforming to shared academy standards of excellence, transparency and clear linkage of conclusions to the evidence available. As noted by NASAC (2022) for African countries, but equally relevant for the other regions, '*countries differ in topology, geography, political governance, health infrastructure and socio-demographic profiles*'. The EASAC, NASAC, AASSA and IANAS regional reports all extensively discussed variation within the region. For example, NASAC reviewed particular vulnerabilities for northern, southern, eastern, western and central Africa, building on earlier intraregional evaluation in the IPCC 5th Assessment Report. NASAC also reviewed issues for the African Small Island Developing States, SIDS (Cabo Verde, the Comoros, Guinea-Bissau, Mauritius, *São Tomé and Príncipe*, and the Seychelles), which may be particularly threatened by rising sea levels, extreme weather events, rising air and sea surface temperatures and changing rainfall patterns. As NASAC commented, '*While considerable attention has been given to the biophysical impact of climate change on SIDS, there has not been sufficient focus on how climate change could exacerbate social vulnerability.*'

In consequence of the multiple diversities involved in the project assessments, it was anticipated that the regional work would accrue diverse evidence and might identify varying solutions. The richness of this heterogeneity is regarded as a strength of the distinctive project design and is an important project resource for comparing

[3] In our report we use the terms 'impacts' and 'effects' interchangeably.

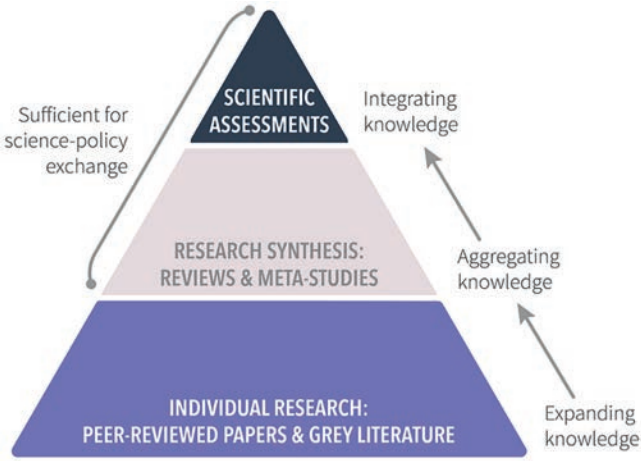


Figure 5 Knowledge production for science–policy interaction related to climate change (from IANAS 2022, adapted from Minx et al. 2017). See IANAS (2022) for further discussion.

and investigating regional similarities and differences and for generating global conclusions and consensus recommendations.

The regional working groups did not attempt to duplicate evidence gathering that has already been done for example by IPCC and in the WHO Climate and Health Country Profiles (https://www.who.int/activities/monitoring-health-impacts-of-climate-change-and-national-progress) and all of the regional reports cite other relevant work extensively. Furthermore, throughout the conduct of the project, efforts were also made to engage with the wider health and science communities worldwide to seek feedback on emerging points, ensure inclusivity and capture diversity. Notably, discussion events were organised as part of the virtual meetings of the World Health Summit (2020) and Consortium of Universities for Global Health (2021), the WHO European consultation on climate and health (2021) and Africa Climate Week (2021) and virtual and physical meetings at COP26. In addition, initial characterisation of the scope of the project was published (Fears *et al*. 2021) to elicit further engagement with the wider scientific community.

The regional reports and this global report prioritise citing systematic review or meta-analysis to summarise the climate change and health literature, representing a late step in the pyramid of knowledge production aimed at the science–policy interface (Figure 3). Other literature is cited, guided by working group discussion, to illustrate particular topics. This approach is not intended to provide an exhaustive bibliographic listing (see further discussion of bibliographic limitations in chapter 3) but rather, as emphasised by IANAS (2022), '*enables an assessment of bigger-picture science-policy questions while adding depth and nuance via case study examples*'.

Because of the COVID-19 pandemic, all activities since March 2020 were held online but it had already been a principle of the project design to minimise the carbon footprint by replacing international travel with online contributions when possible. The published summaries of the regional reports are presented in Appendix 1.

These four regional reports are being used at national and regional levels as a resource for engaging in sustained follow-up with policy-makers and other stakeholders (see Appendix 2 for examples of how the EASAC report has been used since its publication in 2019). In addition, the regional reports have been used as a major resource in preparation of this global report and will be discussed in detail in the subsequent chapters (see Appendix 3 for global report preparation procedures).

As noted in chapter 1, the purpose of this global report, in supporting and building on the regional reports, is to examine inter-regional matters, local-global connectivity, to share examples of good practice, and advise on those issues at the science–policy interface that should be considered by intergovernmental bodies and other institutions with international roles and responsibilities.

2.4 Potential added value of this project

It is an IAP priority to seek to add value to the work that has already been done by others: the topics addressed are of such considerable importance and urgency that IAP recognises the responsibility to use its resources to help effect change, agreeing that '*Scientists have a moral obligation to clearly warn humanity of any catastrophic threat .pl anet Earth is facing a climate emergency*' (Ripple *et al*. 2019).

Our aim is to be policy relevant without being overtly policy-prescriptive, to be distinctive in focusing on scientific opportunities and science-based solutions, recognising that there is considerable diversity in health and political systems. A significant strength of the IAP project approach is the opportunity to capture – at local, national and regional levels – knowledge and perspectives about variation in health effects and in socio-political systems and their receptivity to scientific inputs. Policy discussions depend, of course, on more than evidence from the natural sciences, taking into account, for example, variability in societal attitudes towards risk, and other social values. A difficulty in engaging with, and fully using, evidence from the social sciences and humanities may limit the policy relevance of previous assessments (e.g. IPCC; Minx *et al*. 2017; although this may be changing (Box 2)). While we do not claim that we have solved this problem in our transdisciplinary project design, national academies are well placed to help policy-makers understand diversity in attitudes and values so that science-based policy options can be pursued that are economically and socially feasible.

The innovative project design and its research methodologies were developed for a previous IAP project on Food and Nutrition Security and Agriculture (IAP (2018) and see links to the underpinning regional network reports). Particular attributes of the distinctive design that may enable IAP to add value to the excellent work of many other researchers and institutional initiatives are discussed in further detail elsewhere (Canales Holzeis *et al*. 2019; Fears *et al*. 2020a).

2.5 Previous relevant IAP outputs

Specific previous work by IAP and its member academies will be cited when appropriate. In addition, IAP has published a range of material that is relevant in the broader context of climate or other environmental change. These include the following:

- IAMP (2010) Health co-benefits.
- IAC Co-chairs report on IPCC's 5th Assessment Report (2013).
- IAP Statement Climate change and education (2007).
- IAP project report Food and Nutrition Security and Agriculture (2018).
- IAP initial Statement on tropical forests and climate change 2009, and further work in Communiqué on tropical forests (2019a).
- IAP project report on SDGs (2019b).
- Communiqué on Green recovery after COVID-19 (2020).
- IAP Statement on linkages between policies for climate change and biodiversity (2021).

3 What are the major physical and mental health risks of climate change and the drivers of climate change?

Summary of emerging points in chapter 3

Climate change has impacts on human health through numerous interacting direct and indirect pathways. Although low-income countries account for a very small proportion of the global carbon dioxide (CO_2) emissions, their inhabitants have a much higher probability of being adversely affected by climate disasters. The elderly, children, women, people with pre-existing medical conditions, outdoor workers, Indigenous Peoples, migrants and other marginalised populations are the most vulnerable to the health impacts of climate change. Rapid and decisive action is needed to minimise risks and reduce the burden of inequity.

Despite increased interest on climate change and health, the geographic distribution of studies is uneven, most studies address a single health discipline, and some topics are underrepresented. Increased focus on integrated assessments and projection of impacts across all health domains is urgently needed.

The major exposure pathways and health effects are reviewed, along with relevant examples discussed in the regional reports. These include the following:

1. *Heat-related health effects. Additional heat exposure attributed to climate change has already led to increased numbers of premature deaths globally, particularly in urban environments, where heat and air pollution act synergistically to contribute to mortality. The length, frequency, and intensity of heatwaves will increase unless urgent action is taken but many deaths occur at temperatures above the optimal for a specific location but below the threshold required to fulfil the definition of a heatwave. Heat exposure is linked to several health impacts (e.g. cardiovascular, respiratory and kidney diseases, injuries, reproductive and mental health) and to socio-economic impacts such as labour productivity (especially for outdoor workers), disruptions to the tourism sector. Heat will also impact habitability, as environmental conditions in parts of the world begin to exceed the human thermoregulatory capacity. The elderly, pregnant women and the new-born, people with pre-existing health conditions and in low-resource settings are most affected, highlighting the importance of socio-economic factors and the burden of inequity. Heat also mediates health impacts indirectly, for example through ecosystems disruptions and reduced agricultural production.*

2. *Wildfires. Although fires can play a role in the natural cycle of some ecosystems, there is evidence that hotter atmospheric temperatures and changing precipitation patterns are factors increasing the incidence and severity of accidental wildfires, representing both a global health and environmental problem. Deliberate wildfires include the burning of crop residues (e.g. in Asia) and fires to clear land for cultivation. Health impacts linked to wildfires comprise respiratory and cardiovascular illnesses (due to air pollution), problems resulting from the contamination of food and waterways, and mental health challenges. Furthermore, the release of greenhouse gases (GHGs), the damage to natural resources, and the loss of biodiversity caused by wildfires further contribute to global warming.*

3 *Droughts. Linked to increasing atmospheric temperatures and changes in precipitation patterns, droughts are important drivers of other pathways (such as wildfires) and*

particularly impact food security, water availability and quality, sanitation, air pollution and heat-related health effects. Drought is a worsening problem in some parts in the world, such as the Eastern Sahel in Africa and the Eastern Mediterranean and Middle East (EMME), areas where water scarcity has been a long-standing problem. Under the worst-case scenarios, a further reduction of up to 45% in precipitation can be expected by the end of the century in the most affected regions. The health consequences of inadequate access of water for drinking and sanitation include diarrhoeal disease (especially in children); parasitic diseases such as schistosomiasis; toxicity from the contamination of water supplies; and an increasing incidence of vector-borne diseases. Children and vulnerable individuals are most affected by these health impacts, as well as low-income populations who cannot afford to buy safe water. Drought also affects health indirectly, through reduced agricultural productivity.*

4. *Flooding events. Multiple, climate change-related pathways lead to an increase in the frequency and intensity of floods: sea level rise, the melting of glaciers and thawing permafrost, changes in monsoon systems, and extreme weather events. Changes in land use practices, especially urbanisation, can exacerbate the problem. The health impacts of flooding include waterborne, foodborne and vector-borne diseases, injury and death, and mental health challenges. These impacts are compounded by damage to infrastructure, agricultural land and by the disruption to the provision of essential services, which frequently occur during severe floods. The effects are experienced worldwide but while the impacts from flooding are often disproportionately borne by low-income households, existing policies to respond to flood events often omit the most vulnerable groups.*

5 *Increased mortality and morbidity from infectious diseases. Climate change is leading to a change and expansion of environmental range of disease vectors, which is also affected by human driven change of ecosystems. Health impacts described comprise (i) vector-borne diseases, including rising incidence rates and changing geographical distribution of diseases transmitted by insects (e.g. malaria, dengue and Zika virus), and by ticks (e.g. Lyme disease, tick-borne encephalitis); ii) increased threat of infectious disease transmission resulting from change of climatic conditions, particularly in the Arctic, including the (re)-emergence of zoonotic diseases; iii) waterborne infections associated with temperature and rainfall factors which are impacted by climate change, in particular diarrhoeal diseases; and iv) rising foodborne infections as climate change affects the incidence of pathogens in many steps of food systems.*

6 *Food and nutrition security. Diets, health and climate change are inextricably linked: food systems contribute about one-third of the human GHG emissions, and in turn are highly impacted by the effects of climate change. Malnutrition in all its forms (which encompasses undernutrition, malnutrition and overconsumption of calories leading to obesity) is a global problem, with increasing numbers of people undernourished and overweight/obese, unable to afford a healthy diet. Unhealthy diets are the largest global contributor to morbidity and premature mortality. An estimated 2 billion people lack access to safe, nutritious and sufficient food worldwide. The situation is compounded by conflict, extreme weather events, and other factors such as the COVID-19 pandemic, all important drivers of food insecurity. Climate change impacts all components of food systems. In terms of agricultural production, changing weather conditions, in particular rising atmospheric temperatures and precipitation patterns and the increased incidence of extreme weather events, impact both crop productivity and nutritional quality. Rain-fed systems are most affected. Increases in ambient temperature will also result in dangerous conditions for outdoors workers for part of the year in many regions. Vulnerable populations whose livelihood relies on the*

use of natural resources are most affected. Climate change also impacts the incidence and distribution of crop and animal pathogens and pests, and of beneficial insects. Changing climatic conditions is already impacting fisheries, with the warming and acidification of the oceans damaging aquatic ecosystems, changing the distribution of marine species.

7 Migration. Climate change and environmental degradation, compounded by civil unrest and socio-economic factors, are increasingly important drivers of regional migration and the relocation of populations within national borders. The loss of livelihoods by climatic factors and the ensuing increase in food insecurity, can in turn lead to conflicts and social unrest. Low-income, marginalised groups are particularly affected. Migrant populations typically lack access to adequate social support and health systems, although the health impacts of migration are complex and not easy to quantify.

3.1 Introduction to scope and scale: climate change and drivers of climate change

In the past, climate change has often been framed primarily as an environmental challenge, but recent research has helped to conceptualise it also as a human health issue (see chapter 2 for framing). There are multiple interacting pathways for the effects of climate change on health and, as with other health risks, the frequency, magnitude and distribution of the risk depend on the nature of the hazard, the level of exposure to the hazard, and on individual/community vulnerability.

Broadly, pathways of exposure can be characterised (Figure 2; and Smith *et al*. 2014; Ebi *et al*. 2015; Haines and Ebi 2019; Watts *et al*. 2021) as the following:

- Direct, for example temperature, increasing intensity, scale and frequency of heat; flooding; wildfires; changing cryosphere; and other extreme weather events.
- Indirect via ecosystem disruption, for example effects on food and nutrition security; changes in infectious disease incidence and distribution of pathogens and vectors; air pollution; and allergens.
- Indirect via socio-economic pathways, for example conflict and migration; increased poverty including from declining labour productivity; damage to health systems and other infrastructure.

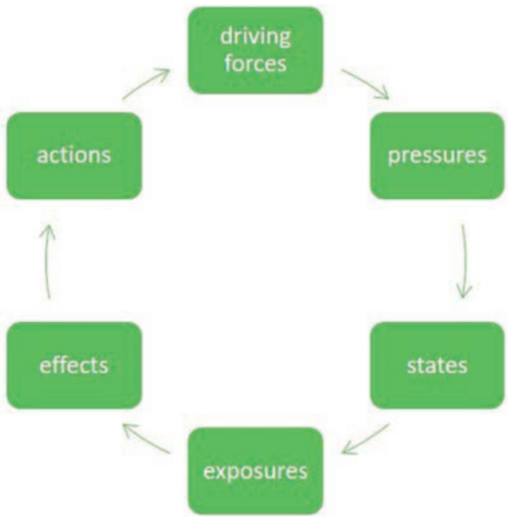


Figure 6 DPSEEA framework (driving forces, pressures, states, exposures, effects, actions), adapted from Frumkin and Haines 2019.

In this chapter, we also discuss the well-documented concern that some drivers of climate change, in particular fossil fuel combustion, have additional, negative consequences on human health, mediated by air pollution. The Driving Force, Pressure, State, Exposure, Effect, and Action (DPSEEA) framework (Figure 6) provides a useful approach to analysing global environmental change.

Taking the example of air pollution: the driving force is primarily the demand for energy from fossil fuels; the pressure is the emission of GHGs and other short-lived climate pollutants; the state is climate change; the exposure includes air pollution as well as changes in temperature, rainfall, extreme events, dietary shifts and other impacts (Figure 2); the health effects will include physical and mental health disorders, undernutrition and obesity (Figure 2); and desired actions include decarbonising the economy, providing clean energy, promoting low environmental impact and healthy diets, implementing sustainable cities, increasing resilience and promoting effective adaptation. The DPSEEA relationships are cyclical such that action can in turn reduce the driving forces. The relationships will be discussed in further detail in this and subsequent chapters.

Figure 7 from the US Centers for Disease Control also portrays some of the complexity in linking climate change effects with environmental changes and health impacts. However, it is difficult to encapsulate the interactions between multiple pathways, to incorporate the life course perspective of cumulative risk, or to show the role of inequities and socio-economic determinants in modifying the effects. Examples of these complexities will be discussed subsequently.

Alternative representations of pathways and their interactions and health impacts were discussed in the regional reports: EASAC (see their Fig. 3.1 and Mora *et al*. 2018); AASSA (see their Fig. 3.1 and Hashim and Hashim 2016); IANAS (see their Fig. 2.2); and NASAC (see their Figs 3.1 and 3.2 according to the DPSEEA model and Kjellstrom and McMichael 2013 and Frumkin and Haines 2019).

Extreme weather event-related disasters represent only one of the pathways whereby climate change affects society. Nonetheless, a recent World Meteorological Organization (World Meteorological Organization and UN DRR 2021) assessment of the period 1970–2019 found a fivefold increase in natural

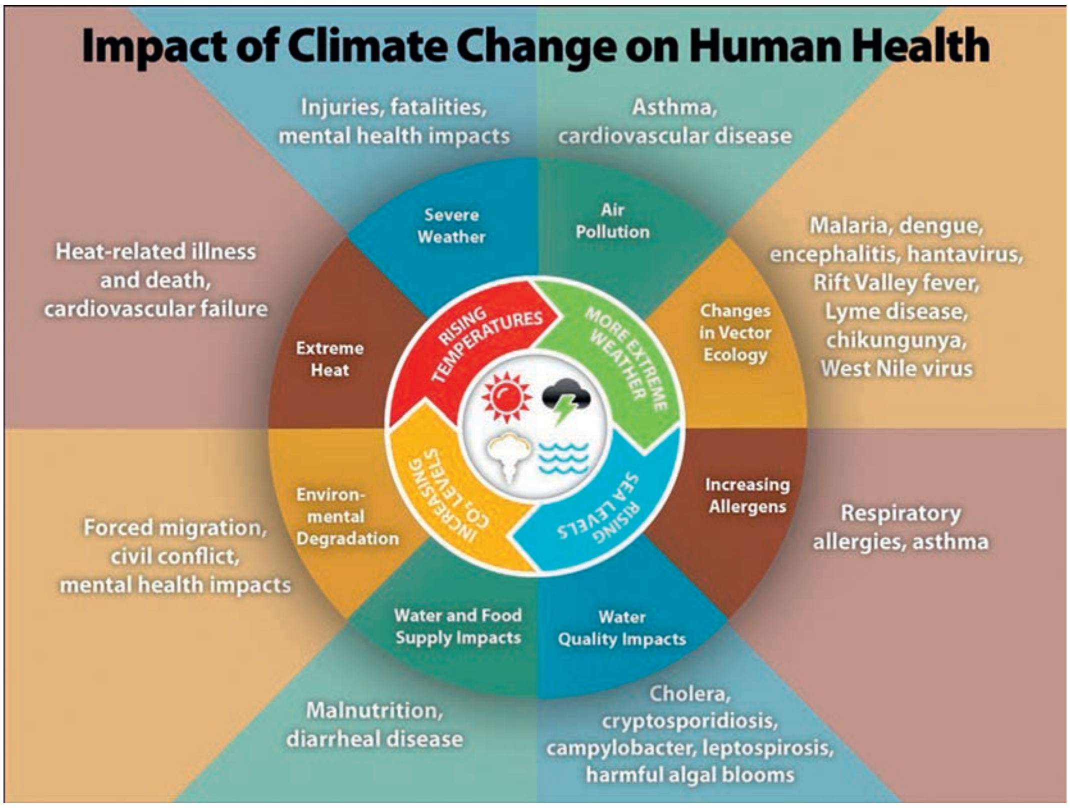


Figure 7 Multiple direct and indirect pathways of exposure, drivers and outcomes. Source: US Centers for Disease Control and Prevention https://www.cdc.gov/climateandhealth/effects/default.htm.

hazards, inducing dramatic economic losses and in many cases attributable to climate change and disproportionately impacting poorer countries (e.g. 91% of deaths were in developing countries). However, over the same period, the number of deaths (according to the EM-DAT database[4]) decreased almost threefold, explained by improved early-warning systems and disaster management. This finding reflects complex interactions and cannot be relied on to continue in the face of increasing climate hazards (see also section 3.4.3 for the discussion of evidence on declining vulnerability to high temperatures), but it warrants more research, particularly as there also appears to be a convergence in vulnerability between higher- and lower-income countries (Formetta and Feyen 2019), although there is still a considerable climate hazard vulnerability gap between them.

There is another issue that must also be taken into account when appraising these statistics. The mortalities quoted in the WMO report (World Meteorological Organization and UN DRR 2021) represent an early effect of the disaster whereas the time between exposure of a person to a hazard and attributable deaths can vary widely. The WMO report uses the WHO assessment of El Niño (2015–2016) to exemplify the issues for setting this into context. Thus, the direct injuries and fatalities were followed by indirect and longer-term effects mediated by vector-borne diseases, waterborne diseases, disruption of health services, mental health challenges, respiratory and other non-communicable diseases and malnutrition. The WMO also uses the case study of Hurricane Maria in Puerto Rico in 2017: the initial estimate of the number of deaths was 16, with subsequent official government estimates revising the number to 64 at the end of 2017. Subsequent studies arrived at much higher numbers, for example a conservative estimate of 1,139 deaths up to the end of 2017 (Santos-Lozada and Howard 2018) and other estimates were up to fivefold greater. Furthermore, most longer-term effects may not have been manifested by this time. Future work to quantify meaningful, attributable, health impacts must take a longer-term as well as short-term perspective.

Among the most vulnerable groups at highest risk of climate change impacts on health are the elderly, children, women, those with pre-existing medical conditions, outdoor workers, Indigenous Peoples, migrants and other marginalised populations. Low-to-middle-income countries (LMICs) are particularly affected by extreme weather events and other effects of climate change because they are more exposed to the damaging effects of a hazard and have lower coping and adaptive capacity (Ecological Threat Register 2020; Eckstein *et al*. 2021). For example, as discussed by IANAS (2022), the 31 countries classified as low income accounted for less than 0.5% of global CO_2 emissions combined (in 2016), but in low-income countries, people exposed to climate disasters are sixfold more likely to be affected (injured, displaced, required medical attention) and sevenfold more likely to die than those in high-income countries (see also Box 2). In part, this is due to the greater economic impact of climate disasters, limited health sector resources and capacity to invest in climate-resilient health structures as well as to existing challenges in the underlying social determinants of health for these populations.

Specific climate–health effects will be discussed in the following sections in this chapter, but it is important to emphasise the increased risk of vulnerable groups to many or all of the different hazards. For example, a recent scoping review of the literature on climate change and child health (Hellden *et al.* 2021) found that major effects in children were mediated by multiple exposure pathways involving temperature change (including *in utero* consequences of maternal exposure),

[4] https://www.emdat.be/

wildfires, floods, pathogens, air pollution, food insecurity, and migration, with pervasive mental health impacts.

3.2 Recognising limitations in the published evidence base

An overview of systematic reviews up to mid-2019 on the health impacts of climate change found most to suggest that climate change is associated with worse human health, especially infectious disease, all-cause mortality, and respiratory, cardiovascular and neurological outcomes (Rocque *et al*. 2021). There is scientific consensus from the recent literature discussed in our report that climate change is affecting human health now and, that without sufficient action the effects will worsen, but that rapid and decisive action could greatly reduce the risks.

There is a concern that focusing only on peer-reviewed literature may miss evidence from the 'grey literature' (such as government reports, outputs from health organisations and non-governmental organisations) that may cover important issues, for example for documenting and analysing climate change adaptation responses (Bierbaum *et al*. 2013; Berrang-Ford *et al*. 2015; Scheelbeek *et al*. 2021). In this report we cite grey literature sources where appropriate (see the hierarchy of evidence portrayed in Figure 5).

Rising temperatures worldwide threaten ecosystems and, because relationships are not linear, may exceed tipping points with little warning. Projections of future health effects depend, of course, on expectations of future GHG emissions and much of the published literature relies on the various scenarios for climate change defined in the Representative Concentration Pathways (RCPs) of the Fifth Assessment Report of the IPCC, and recently focusing also on comparisons of 1.5 and 2 °C of warming. Relevant literature will be discussed with respect to specific health effects. Perhaps because of a traditional research and care focus narrowly on individual medical disciplines, the integrated assessment and projection of impacts across all health domains is rarer. Recent assessment of multi-model impact studies (e.g. Rocklov *et al*. 2021) attempts to develop a more coordinated and consistent approach to enable understanding of future, aggregated, health impacts: what they are and where they will be. Although there are current limitations in the evidence base, coordinated impact modelling on climate–health risks is an advancing field of study (Anon. 2021c).

3.2.1 Geographic biases

The publication of primary research on health and climate change has increased eightfold from 2007 to 2019 (Watts *et al*. 2021). Nonetheless, while research on climate change and health is a rapidly growing field, much of the literature has taken a retrospective view and addressed qualitative, short-term effects rather than quantifying impacts, longitudinal future effects, and action-oriented adaptation and mitigation solutions. Moreover, there is unequal distribution of research efforts with much less occurring in the LMICs (WHO 2021a) and regions experiencing disproportionately higher levels of warming (e.g. the Arctic), and this imbalance must be addressed to achieve the aim of improving the evidence base for policies to protect health from climate change. Further detailed assessment of the literature comes from semi-automated mapping of research worldwide on climate and health (Berrang-Ford *et al*. 2021a). This finds that the literature is dominated by impact studies (84% of the total), with air quality and heat stress being the most frequently studied exposures, and all-cause mortality and infectious disease incidence being the most frequently studied health outcomes. This systematic mapping reveals significant geographical gaps in the evidence, for example from Central Asia, Central and North Africa, South America and the Mediterranean region (Figure 8), and that high-income countries with China dominate the numbers (79% of the total).

Certain topics are particularly underrepresented in the current literature for certain regions. For example in Africa

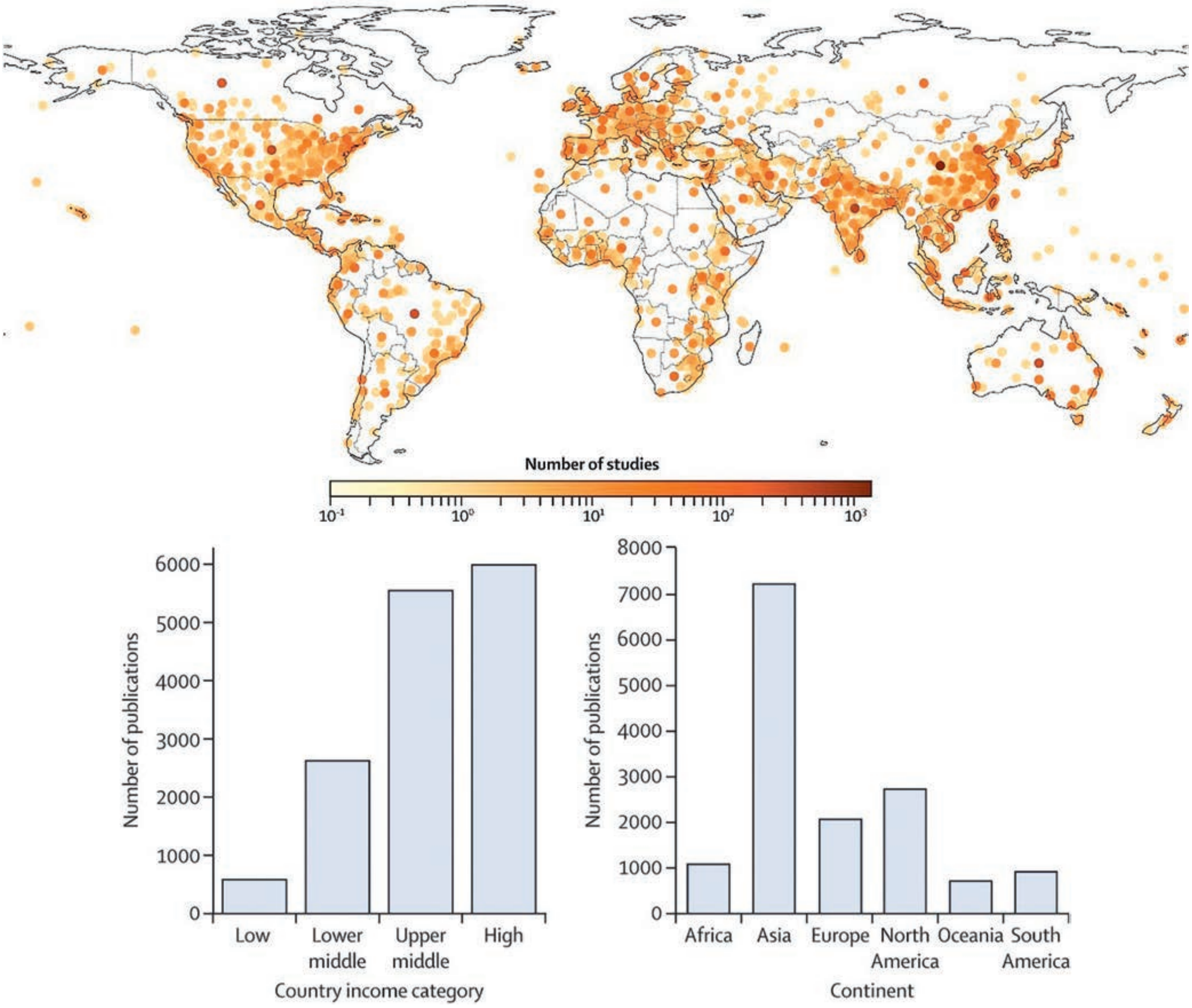


Figure 8 Systematic mapping of the research worldwide on climate and health (Berrang-Ford et al. 2021a). This analysis is of literature published in English in the period 2013–2020.

there appears to be lack of research on climate change effects on mental health, child health, respiratory infections and nutritional deficiencies despite the potential for substantial impacts on these indications (maternal and child health accounts for highest disability-adjusted life years lost in Africa and respiratory infections are the second highest). The IAP inclusion of some LMICs in the regional working groups (Box 2), and the follow-up with many more as part of endorsement and longer-term engagement procedures, are intended to help redress the global imbalance in researcher representation.

In the following sections of this chapter, we discuss some of the major exposure pathways and health effects, drawing on the outputs of the regional working groups and other peer-reviewed literature. This overview is intended to provide a summary basis for our subsequent focus on mitigation and adaptation responses: to identify issues that are common and critical to all regions to inform the selection of generalisable solutions (and adaptable to local contexts), but also to highlight points that may have only been made in one regional report but that deserve to be shared more widely. More detailed assessment of health effects, their variation and methodological uncertainties in their determination are provided in the regional reports.

3.2.2 Attribution

One continuing need to strengthen the aggregate evidence base relates to the development and use of formal methodologies for detection and attribution: that is, whether a particular event can be detected and/or assigned to climate change or to natural variability. The following sections include literature where attribution has been possible, for example on heat effects on health. There is further presentation of evidence in the regional reports (particularly IANAS 2022) and methodologies are discussed by Ebi and co-workers (2017, 2020) to take forward analysis of the causal chain from GHG to observed human health outcomes, to quantify risks and to determine policy and communication priorities.

As noted above (Figure 6), it is also essential to appreciate that some drivers of climate change affect health in other ways. In particular, fossil fuel combustion in the energy, transport and industrial sectors is responsible for both GHGs, resulting in climate change, and pollutants such as particulates that damage health. Before proceeding to the review of climate hazards and pathways the major related health risk of ambient pollution is discussed.

3.3 Health effects of climate drivers: ambient air pollution

A comprehensive survey on global exposure to air pollution and its health impacts (HEI and IHME 2020) observes that air quality has improved in some high-income countries over the past decades whereas higher levels of air pollution persist in LMICs. At the same time, it is become increasingly apparent that exposure to particulate matter has effects on health even at very low levels. Pollution is intimately linked to global climate change particularly as a consequence of the burning of fossil fuels or the role of methane as a precursor of tropospheric ozone.

3.3.1 Air pollution from fossil fuels and biomass

Fossil fuel combustion in high- and middle-income countries and burning of biomass in low-income countries accounts for a high proportion of anthropogenic particulate pollution and almost all pollution by oxides of sulfur and nitrogen in addition to considerable GHG emissions. The main causes of death arising from air pollution are cardiovascular, cerebrovascular, respiratory, lung cancer and other non-communicable diseases. The loss of life expectancy from air pollution rivals that of tobacco smoking (Lelieveld *et al.* 2020). In addition, there is evidence that *in utero* and early childhood exposure will influence later-life outcomes, for example via neurological and cognitive ability development (EASAC 2019a; Shi *et al.* 2020). For example, in a Danish population cohort study (Antonsen *et al.* 2020), levels of nitrogen oxides (NO_x) levels are associated with subsequent risk of schizophrenia. Exposure to nitrogen dioxide (NO_2) in ambient air is also associated with the incidence of paediatric asthma, with the greatest contributions from land transportation emissions, domestic burning of solid fuels and power generation from fossil fuels (Chowdhury *et al.* 2021). However, there are large regional differences in the source of some contributions, for example the domestic burning of solid fuels is a major contributor to NO_2-related asthma incidence in India and Nepal while emissions from shipping are the leading source in Scandinavian countries. The literature documenting the negative health effects of air pollution is growing rapidly, for example to identify the risk of premature, birth, diabetes as well as nervous system dysfunction and changes to the developing brain (Landrigan and Grandjean 2021).

There is no doubt that fossil fuel burning causes very large numbers of premature deaths annually from air pollution. Coal combustion is a major cause, accounting for perhaps half of these premature deaths. Recent re-evaluation of concentration–response functions for global mortality from

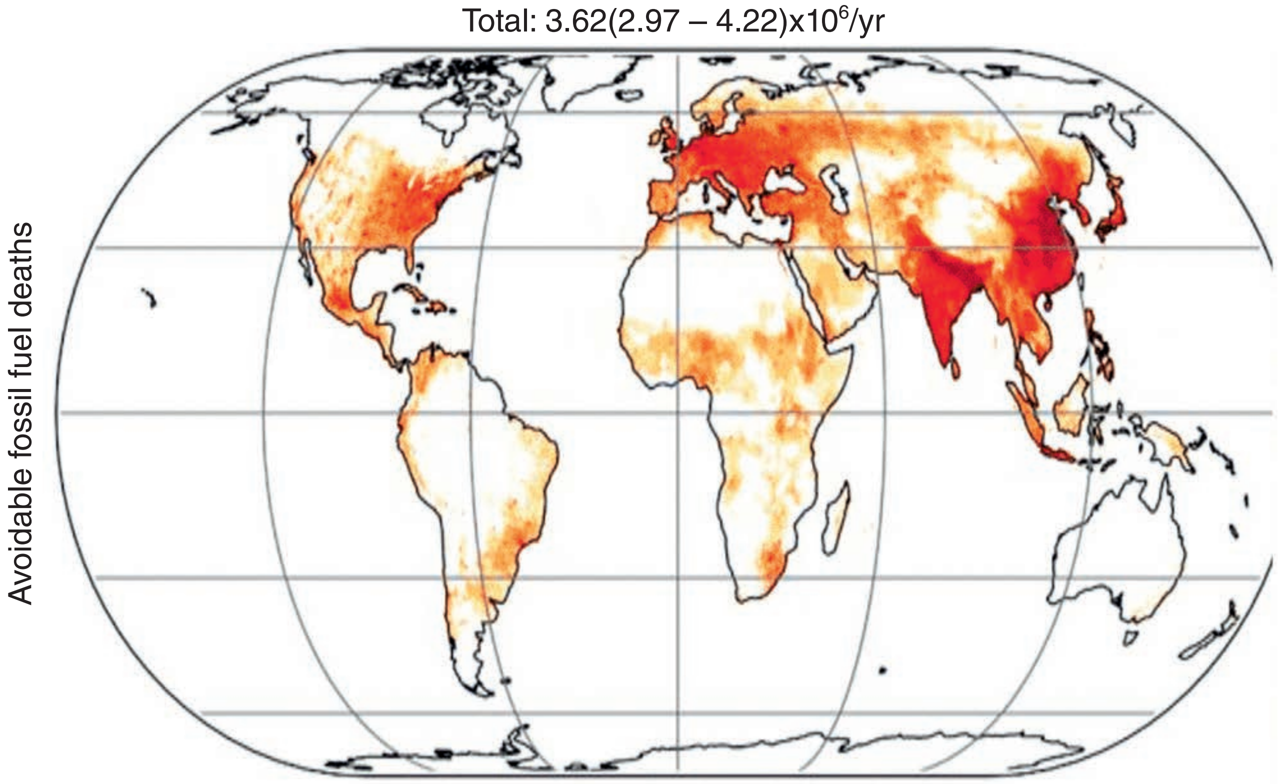


Figure 9 Phasing out fossil fuel burning could prevent approximately 3 6 million premature deaths annually from ambient air pollution: global mapping from Lelieveld et al. (2019), who also list modelling data for individual countries.

$PM_{2.5}$[5] particulate pollution suggests even higher mortality than previously assumed. While there is uncertainty about estimated magnitudes according to the assumptions and differing methods of calculation used (see assessments by Lelieveld *et al*. 2019; McDuffie *et al*. 2021; Vohra *et al*. 2021), all agree that it is a major health burden. Further research is also required on the different oxidative potential of different PM_{10} samples to help connect data on PM oxidative stress metrics to human health data (Weber 2020).

The importance of urgently phasing out fossil fuel combustion to mitigate GHG emissions, tackle climate change and bring health co-benefits is discussed in chapter 4. Comprehensive modelling studies provide compelling evidence for the importance of taking an integrated approach to accomplishing the mutual goals of clean air and a stable climate (Lelieveld *et al*. 2019, discussed in detail in EASAC 2019a). Although action on fossil fuel combustion in pursuit of decarbonisation removes cooling aerosols as well as warming pollutants, this additional, rapid-onset radiative transfer consequence is soon outweighed by subsequent cooling (see Shindell and Smith (2019) for further discussion). Modelling (Lelieveld *et al*. 2019) showed that a phase-out of fossil fuels could avoid an excess global annual mortality of 3.6 million (range 3.0–4.2 million) deaths per year from ambient air pollution at today's population (Figure 9). Fossil-fuel-related emissions account for about 65% of the excess mortality rate attributable to air pollution. The global annual benefit could be up to 5.6 million (range 4.5–6.5 million) fewer deaths per year from ambient air pollution if, additionally, emissions of non-fossil-fuel anthropogenic sources of ambient air pollution, in particular from agriculture and household air pollution, were controlled (see also section 3.5 for discussion of effects of wildfire smoke). Evaluations, for example

[5] Particulate matter of sub-2.5 µm size.

for India (Dandona *et al*. 2021) and Europe (Khomenko *et al*. 2021), further document the health and economic gains from tackling air pollution and emphasise where policy actions to reduce air pollution are needed most urgently.

Country and regional assessments are provided by Lelieveld and co-workers (2019), and the available literature is discussed further in the regional reports[6]. For example, in the European Union (EU)[7], fossil-fuel-related emissions account for more than half of the excess mortality attributed to air pollution, with the highest proportions in Austria, Croatia, Germany, Hungary, Poland and Romania. In the AASSA region, the health effects of air pollution and links to climate change are discussed, for example for Australia, Azerbaijan, China, Japan, Malaysia, Nepal and New Zealand, with an additional emphasis on the transboundary risks (see also Jalaludin and Morgan 2019, and David and Ravishankara 2019). The IANAS (2022) report notes the extensive literature for North America (although there are research gaps such as the potential combined or synergistic effects of different pollutants) but also observes that there is less information on Central and South America, where there is also often a relative lack of reliable and extensive air quality monitoring. In some cases, pollutant levels from wildfires are higher than air pollution customarily observed in the large urban centres and more likely to confer high levels of oxidative stress. Wildfire smoke can travel great distances and have adverse effects on health far from the source (see Ye *et al*. (2021) for a discussion of evidence in Brazil). Household biomass combustion together with the transport sector are major sources of black carbon (a potent short-lived climate pollutant) in South Asia, parts of Africa and Latin America, and research is needed to evaluate integrated action to address all of the impacts of fossil fuel and biomass combustion.

3.3.2 Other sources of air pollution

One other contributor to air pollution is Aeolian dust. THE EMME-CCI[8] Health Task Force identified the Sahara and Arabian Peninsula as two major sources of airborne dust, strongly affecting the concentration and deposition of dust particles over a very large area. Increases in temperature and reduction in humidity associated with climate change in the region in the past decade may have increased dust emissions. Water shortage, poor water management, land erosion and deforestation are creating new drylands and thus new sources of dust. Many microorganisms, including human pathogens, have been transported in dust plumes over long distances. Airborne dust originating from agricultural areas could potentially facilitate the spread of antibiotic resistance genes (Gat *et al*. 2017). Although the viability and pathogenicity of the dust-borne microorganisms is still unclear, chronic and episodic exposure to high dust levels have been associated with numerous health problems (Schweitzer *et al*. 2018) including allergies, silicosis, other chronic respiratory diseases and infections such as granulomatous disease and sarcoidosis. Groups that are particularly vulnerable to the exposure to high dust concentrations include the very young and elderly (because of underdeveloped or

[6] While the IAP report was being finalised, additional evidence and assessments on the health effects of air pollution were published; some of these are summarised in the editorial of Anon. (2022b). These recent studies include exploration of the interaction between $PM_{2.5}$ concentrations and other risk factors (e.g. ageing), and the association between NO_2 pollution and paediatric asthma. Recent publications also provide increasing evidence for the negative health consequences of very low levels of air pollution and for the need to implement both climate change and air pollution policies together. Another recent publication (Masselot *et al*. 2022) characterises the location-specific relative risk associated with different $PM_{2.5}$ components, indicating that differences in composition may explain a substantial part of the heterogeneity in risk.
[7] In the EU, the main sources of GHGs are electricity and heat production > manufacturing industry and construction > transport > residential/commercial buildings > agriculture.
[8] EMME-CCI is the Cyprus Government initiative for coordinating climate change actions in the Eastern Mediterranean and Middle East, https://www.cyi.ac.cy/images/international_collaborations/cy_climate_change_init/Work_Programme_200929.pdf; see also https://emme-cci.org. Reports from the Task Forces, including Health Task Force, will be published in 2022. In conjunction with the Health Task Force, IAP, EASAC and the Cyprus Institute organised a workshop in 2021 on health issues in the wider region which has been published as EASAC *et al*. (2021).

deteriorating immunity) as well as those with chronic cardiopulmonary diseases.

3.3.3 Effects of climate change on air pollution

In addition to wildfire risks, extreme weather events and high temperatures may exacerbate air pollution, for example by increasing concentration of tropospheric ozone (O_3) and by influencing the rate of release and degradation of synthetic pollutants (see discussion in the AASSA (2021) and IANAS (2022) reports). Furthermore, high temperatures and other climate effects may worsen the health impacts of pollutants (see Analitis *et al*. (2018) and Hong *et al*. (2019) for studies in Europe and China respectively). However, as commented by IANAS (2022), while many studies have examined the wide range of health impacts related to air pollution and exposure to temperature, fewer have investigated the combined or synergistic effects (one is Kinney 2018).

3.4 Heat direct effects

The following sections cover the direct and indirect effects of climate change pathways on human health.

3.4.1 Regional and inter-regional assessments of impact

Extreme heat is perhaps the most obvious sign of climate change and high temperatures can be harmful to human health, particularly in older people and those with pre-existing medical conditions (Capon *et al*. 2019). Systematic assessment of data from sites in 43 countries estimated the mortality burden associated with additional heat exposure that resulted from human-induced warming during the period 1991–2018 (Vicedo-Cabrera *et al*. 2021): crucially, it was concluded that 37% of warm-season heat-related death can be attributed to anthropogenic climate change and that increased mortality was evident on every continent.

Global projections (Gasparrini *et al*. 2017) indicate that all regions will see increasing numbers of deaths associated with extreme heat, with the LMIC regions affected the most, particularly Southeast Asia, Central and Southern America. There is a lack of data on which to base projections for most of Africa. Until recently, evidence was lacking for the Middle East–North Africa region but projections under 'business-as-usual' scenarios now indicate extreme heatwaves, potentially life-threatening and societally disruptive (Zittis *et al*. 2021; see also footnote 8 on page 27).

A recent comprehensive review (Ebi *et al*. 2021b) describes the health risks of hot weather and heat extremes, other impacts on occupational health and productivity and the physiological limits of heat tolerance. Heat-related morbidities include heat exhaustion, heatstroke, cardiovascular challenges, renal failure and respiratory distress (see Frumkin and Haines (2019) for a review of the global literature on climate and other environmental change impacts on non-communicable diseases). Systematic reviews demonstrate also that extreme heat exposure impacts other health outcomes including increased risk of pre-term birth, stillbirth and low birthweight (Chersich *et al*. 2019). These risks may be largest in LMICs.

Discussion in IANAS (2022) exemplifies the range of other health effects. There is growing evidence for adverse mental health effects, including suicide (Burke *et al*. 2018; IANAS 2022), possibly via an effect on serotonin function and impulsivity (Kim *et al*. 2019). The effect of heat makes it a factor comparable to other well-studied determinants of suicide such as the impact of economic recession (Burke *et al*. 2018). Anomalously high temperatures are also associated with increasing injury deaths (including deaths from drowning, transport and violence (Parks *et al*. 2020)) and with sleep disturbances (EASAC 2019a).

Kidney failure in relatively young people, is a major concern in several regions and there has been much debate about the causes, with a focus on heat exposure, dehydration and agrochemical exposure in Central America and agrochemical and heavy metal exposure in

South Asia (Redmon *et al*. 2021). International collaborative research is underway to elucidate the causes (Glaser *et al*. 2016). If heat exposure proves to be a significant cause, as the risk of heat stress increases under climate change, high-risk areas for kidney disease are projected to expand northwards through the USA (IANAS 2022; see also discussion of global climate threats and opportunities (Barraclough *et al*. 2017)).

In summary, even under low emission scenarios and with strong adaptation efforts, excess mortality is projected to increase throughout the Americas (Guo *et al*. (2018) and other literature discussed in IANAS (2022)). However, the impacts of heat exposure are not equitably distributed within and between countries in the Americas, varying greatly based on geography, political landscape, economics as well as biological and social factors. For example, in the June 2021 heatwave in British Columbia, Canada, which led to 300% increase in mortality compared with previous years, 79% of the heat-related deaths were in those aged 65 years or older (IANAS 2022).

Among the African regions, eastern Africa seems to have the highest potential attributable heat-related excess number of deaths projected in a no-adaptation scenario (NASAC 2022). Although there is very limited information on temperature–mortality functions for either rural or urban populations in Africa, there are some estimates for regional projections of extreme temperature days and the related potential risk to human health up to the end of the century (Garland *et al*. 2015). Evidence also shows that warming over Southern Africa is happening at twice the global rate. The NASAC (2022) report emphasises the point that most heat-related deaths occur as the result of sustained temperature rises in summer, and now spring and autumn in some parts of the continent, not during heatwaves[9], which are by definition infrequent events. In detailed review of the literature for South Africa, vulnerability to heat–health risks is high for pregnant women and the elderly. Exposure is high in certain outdoor occupations (e.g. agriculture and outdoor services) but also in indoor environments (e.g. houses, schools and in some public sector health facilities) where air conditioning is often lacking and electricity supply unreliable.

As well as the direct effects, high temperatures (often in concert with changes in rainfall) also have indirect deleterious consequences on health mediated by ecosystem disruption: for example wildfires (section 3.5), food systems (section 3.9), freshwater scarcity (section 3.6) and pathogens and vectors (section 3.8), and allergic effects of changes in airborne pollen seasonal distribution (Ziska *et al.* 2019; Anenberg *et al.* 2020). Further details are discussed in the regional reports and Figure 10 for the integrated assessment by AASSA (2022): summarising direct impacts on human health and indirect effects via ecosystems and socio-economic systems, health sector performance and other sectoral services.

In parts of the AASSA region, for example Malaysia, heat impacts on health during the past decade are judged to have been relatively minimal (Suparta and Yatim 2017, 2019) but future effects, primarily on cardiovascular and respiratory diseases, will be larger. In other parts of the region, heat effects are much greater; for example, '*over the last 100 years, heatwaves have resulted in more loss of life in Australia than any other natural hazard*'. Climate change is likely to exacerbate these effects. There is considerable concern throughout the region and evidence for heat-related mortality, and morbidity is discussed in detail for countries including Armenia, Bangladesh, China, India, Japan, Korea, Nepal, New Zealand and Turkey (AASSA 2021). Projections are also reviewed, for example for China (Wang *et al*. 2019). Increased exposures and vulnerabilities are

[9] Heatwaves are by definition rare events and most heat-related deaths are above the optimum temperature but below the threshold for heatwaves, often defined as the 99th centile of temperature for a given location.

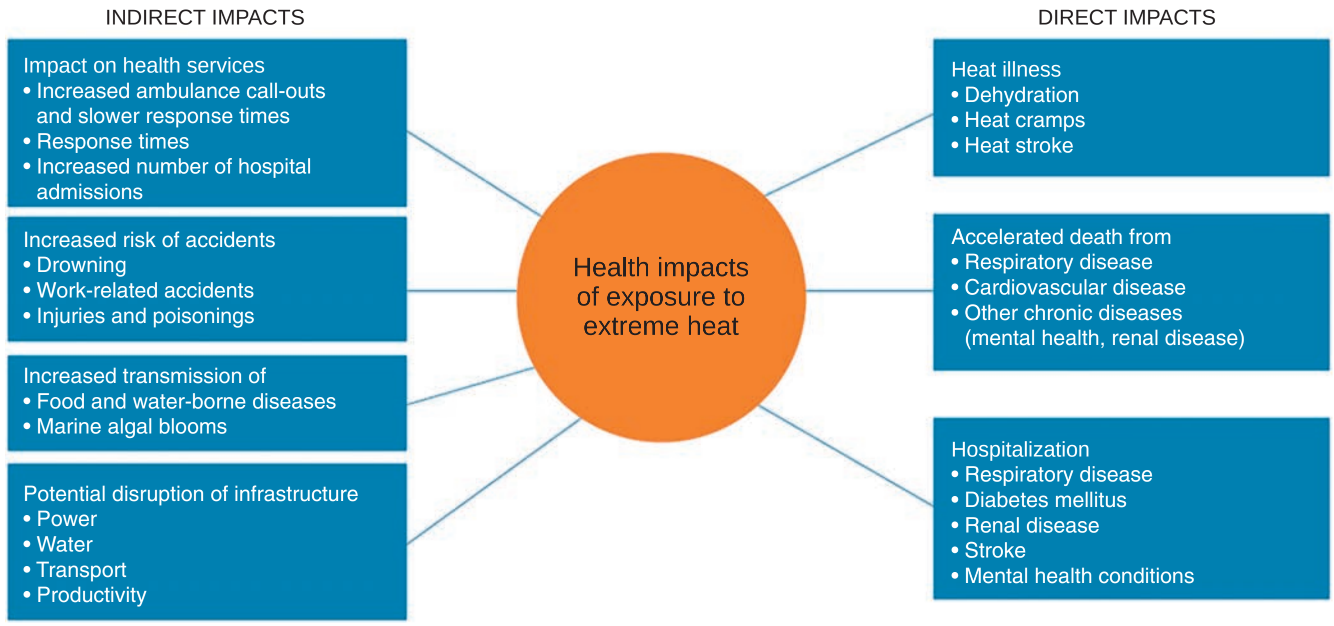


Figure 10 Impacts of exposure to extreme heat: this figure summarises the literature from the Asia-Pacific region but can be regarded as broadly relevant worldwide.

discussed in terms of (mega-)cities, workers outdoors and the elderly (AASSA 2021) and, similar to the EASAC (2019a) and IANAS (2022) reports, heat-related effects are also noted on mental health, loss of labour productivity and employment, as well as on inter-community violence. NASAC (2022) also noted the effects of heat and extreme weather events to increase violence and aggression.

The AASSA (2021) report also discussed the potential for multiple impacts of climate change on human fertility, including the action of higher temperature on reproductive tissue function. This possibility warrants further research on biological mechanisms and their interaction with other potential determinants of fertility, for example via effects of climate change to modify human behaviour (Casey *et al.* 2019).

For the European region, assessments by the European Environment Agency (discussed in EASAC 2019a) demonstrate that there have been tens of thousands of premature deaths associated with high temperatures since 2000. The strongest trend for the number of hot days has been over the Iberian Peninsula and elsewhere in the Mediterranean. However, heat extremes have occurred in many other parts of Europe, for example in Poland where a serious threat has been posed to the elderly and those with cardiovascular disease (Graczyk *et al.* 2019). Other studies, for example in Slovenia and Portugal (EASAC 2019a), confirm that the elderly and women are particularly vulnerable in heatwaves, indicating the importance of social factors as well as the risk from pre-existing circulatory disease. Projections (Gasparrini *et al.* (2017) and other literature discussed in EASAC (2019a)) are confident that the length, frequency and intensity of heatwaves will increase unless action is taken, and that the impacts on hospital admissions and mortality will be highest in Southern Europe. Limiting warming (Vicedo-Cabrera *et al.* 2018) below 2 °C could prevent large increases in mortality but the comparison of differences in impact between 1.5 °C and 2 °C is characterised by higher uncertainty (EASAC 2019a).

The data are becoming increasingly robust but further work is needed on detection and attribution of heat-related deaths (see section 3.2.2) and other health outcomes to climate change rather than natural variation. The effect of heat is consistently underestimated in routine statistics because death certificates commonly list a cause of death, such as heart failure, without noting exposure to high temperatures (Witze 2021). For this reason, changes in total mortality are used to study the effects of extreme heat exposure. This requires accurate and timely vital registration systems to ensure that deaths are recorded in a standardised way, but some LMICs do not have comprehensive civil registration services (World Bank 2021). Potentially, use of social media to study heat impacts at large scale and to track events in real-time (e.g. in India (Cecinati *et al*. 2019)) may help to bring together public health and environmental data.

3.4.2 Urban heat

Worldwide, heat exposure is, and will continue to be, particularly pronounced in cities (Heaviside *et al*. 2017; Milner *et al*. 2017) because urban heat islands amplify exposure during the day and inhibit recovery at night. The greatest urban effects are anticipated in those cities at mid- to high latitudes, with large seasonal variations.

Discussion of urban effects in Europe (EASAC 2019a) confirmed that projected temperature rises for some cities are much higher than the computed global average (e.g. Bucharest, Madrid and Zagreb (Milner *et al*. 2017)). Furthermore, the urban environment may exacerbate the synergistic effect of heat and air pollution on mortality (for PM_{10} and possibly O_3 in a study of Italian cities (Scortichini *et al*. 2018)); additive effects of high temperature and air pollution also result in increases in hospital admissions for cardiovascular and respiratory diseases (Mueller *et al*. 2017; EASAC 2019a).

Urban heat island intensity varies between but also within cities and leads to differential impacts on different demographic groups. In a global study of 25 cities (Chakraborty *et al*. 2019), it was found that, in most cases, poorer neighbourhoods experience greater heat exposure. This disparity is not confined to LMICs (see also Anon. 2021a; Witze 2021). An IANAS (2022) case study on Mexico City showed that the urban heat island effect has most severe impact on high-density neighbourhoods with lower socio-economic conditions, emphasising the point (Vanos *et al*. 2020) that social as well as physiological factors need to be better integrated into heat–health models to provide more robust and useful information to policy-makers and others. In the USA historic policies of zoning known as 'red-lining'- (the historical practice of denying home loans or insurance to whole neighbourhoods based on a racially based perception of secure investments) have left a legacy of inadequate urban green space and consequently increased urban island effects (Hoffman *et al*. 2020). Temperature differences between formerly redlined areas and non-redlined neighbours are higher by as much as 7 °C. This issue of inequity will be discussed further in chapter 4 in the context of mitigation solutions for sustainable cities.

3.4.3 Labour productivity, economic activity and habitability

The current evidence (e.g. Watts *et al*. 2021) demonstrates that the high heat–health burden of excess mortality and morbidity is associated with effects on economic output. In part this is because of potential labour capacity during heat extremes, with Asian countries among the worst affected, and this could have deleterious global consequences for economic inequality and poverty (Diffenbaugh and Burke 2019). However, even small increases in temperature may reduce cognitive and physical performance and, hence, impair labour productivity and earning power, with further adverse consequences for health. Heat is an occupational safety and health hazard impacting many occupations and the productivity and health of workers both outdoors (e.g. agriculture and construction sectors (Orlov *et al*. 2019)) and indoors (EASAC 2019a) and could widen existing gender gaps in work (ILO 2019).

Because extreme humid heat may be highly localised in both space and time, it is often substantially underestimated (Raymond *et al*. 2020). Therefore, the serious challenge posed

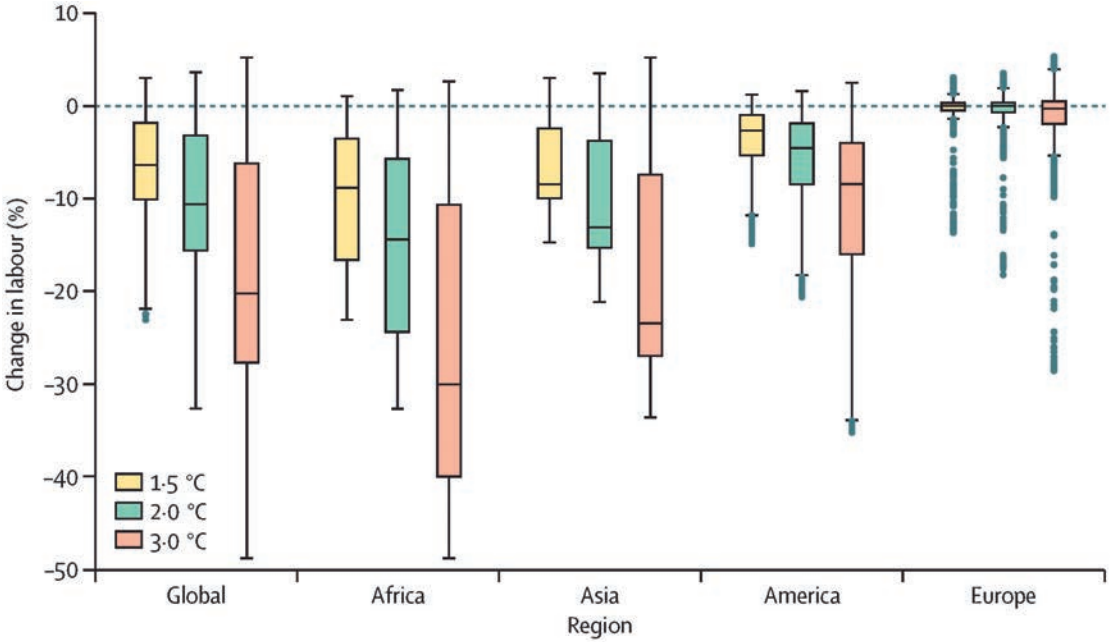


Figure 11 Regional assessments of changes in labour productivity at hotter temperatures: an empirical multi-model study based on micro-survey data regionally aggregated. See Dasgupta et al. (2021) for details and for discussion of methodologies for calculating labour productivity. Data are shown for scenario SSP2 at year 2100. The global labour reduction in low-exposure sectors (indoors and outdoors in shade) is computed to be 18% whereas in high-exposure sectors (outdoors in sun), 25%.

to labour productivity may be greater than has been hitherto assumed. Modelling to evaluate the implications for workability and survivability (Andrews *et al*. 2018) suggests that at 1.5 °C global temperature change approximately 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 of the year. This increases to approximately one billion people at 2.5 °C temperature rise. A multi-model study (Dasgupta *et al*. 2021; see Figure 11) confirms that both labour supply and productivity are projected to decrease under future climate change in most parts of the world, in particular in Sub-Saharan Africa and South and Southeast Asia, especially those countries around the equator. South America will experience the biggest effects in the Americas.

Although the aggregated results show much smaller impacts in Europe (Figure 11), studies suggest that, for temperature rises greater than 2 °C, labour productivity could drop by 10–15% in some Southern European countries (Ciscar *et al*. 2018).

Local effects on employment and economic activity will also be mediated by disruption in the tourism sector, currently a concern in Spain and Tunisia (EASAC *et al*. 2021). Although methodologies for estimating tourism impacts worldwide are still at a relatively early stage of development, tourism locations are likely to shift polewards (Amelung *et al.* 2007). There is a growing literature on probable impacts and responses in travel destinations and there are also implications for public health practice including surveillance and early detection of infection after travel (Semenza and Ebi 2019).

There are additional major concerns, apart from labour productivity and employment. Climate change will increase the risk of environmental conditions that exceed human thermoregulatory capacity, and this has implications for habitability (Ebi *et al*. 2021a). In the absence of migration and a 'business-as-usual' scenario, one-third of the global population may experience a mean annual temperature of more than 29 °C (Xu *et al.* 2020a).

3.4.4 Comparative impacts of heat and cold

Deaths due to moderately hot or cold weather have substantially exceeded those resulting from extreme heatwaves or cold spells (Gasparrini *et al*. 2015; Sera *et al* 2019). In temperate climates, mortality is higher in the winter than summer. Some commentators have suggested potential winter benefits of climate change but limitations in the original databases may have biased earlier assessments and reductions in cold-related mortality under a warming climate may be much smaller than some had previously assumed (Kinney *et al*. 2015; Huber *et al*. 2017). It has now been concluded from projections that climate change may alter the balance of deaths between winter and summer but it is unlikely to dramatically reduce overall mortality rates (Ebi and Mills 2013; Vardoulakis *et al*. 2014; Ebi 2015).

In some localities, warming might slightly reduce net temperature-related deaths in the short-term, by reducing cold-related deaths; but in the long run, climate change is expected to increase the mortality burden (Zhao *et al*. 2021b). Recent research projecting temperature-attributable mortality in 16 countries in Europe assesses that the increase in heat-attributable mortality will start to surpass the reduction of the cold-attributable fraction in the second half of the 21st century, especially in the Mediterranean and in the higher emission scenarios (Martínez-Solanas *et al*. 2021), substantiating previous European projections (EASAC 2019a). However, projections are contingent on assumptions about susceptibility trends (section 3.4.5). Reductions in cold-related mortality are less certain than increases in heat-related mortality because the deaths occur over longer periods and may be partly due to infectious causes such as seasonal influenza. This is a complex subject and more research is needed on the causes of cold-related winter deaths in temperate and other regions. The nature of cold waves is also discussed for countries such as Nepal, Bangladesh and China (AASSA 2021).

Might newer episodes of cold-induced excess mortality also be related to GHG emissions? There is evidence that sudden stratospheric warmings during boreal winters are associated with cold weather and increased mortality in the Northern Hemisphere (Charlton-Perez *et al*. 2020). Although the collection of evidence from modelling that might link sudden stratospheric warmings and other changes in the polar vortex to CO_2 concentrations is still at an early stage (Ayarzagüena *et al*. 2020), and the IPCC had assigned low confidence to the evidence (IPCC 2019a), recent assessment has linked Arctic warming with extreme winter weather in the USA, potentially attributable to the stratospheric polar vortex stretching that has markedly increased in past decades (Cohen *et al*. 2021b).

3.4.5 Changes in susceptibility

Data collected by Vicedo-Cabrera *et al*. (2018) demonstrated that mortality caused by increased heat had declined during the past decade in many countries, but these trends were not uniform. For example, in Europe the reduction in mortality due to heat in the past 20 years has been mostly observed in Europe's warmer regions close to the Mediterranean but not in Northern Europe where mortality associated with heat exposure has risen (EASAC (2019a) citing data from Poland contrasted with Spain). This issue was also discussed by the EMME-CCI Health Task Force (see footnote 8), '*Due to the dry and warm climate of the EMME, a large fraction of the population is acclimated to heat*'. However, high temperatures still disproportionately affect vulnerable population groups, and in EMME countries vulnerability is heightened by high rates of population growth, urbanisation and ageing.

Reasons for disparate susceptibility effects are likely to be complex: influenced by increasing population awareness, changing socio-economic development and demographics as well as by adaptation measures initiated, for example sustainable building design and climate-informed medical services.

Relevant observations are also reported from the other regions. For example, in Japan, populations appear to have become less vulnerable to heat stress over the past four decades, with an increase in the threshold for heat-related mortality (Chung *et al*. 2018; AASSA 2021), although mechanisms require further study. In the Americas there is evidence for some adaptation to heat exposure but it is more challenging in those countries, communities and households with reduced access to resources (IANAS 2022), highlighting the importance of equity considerations in response options (see chapter 4).

Recent evidence suggests that air conditioning only explains a small proportion of the decline in heat-related deaths using data from 311 locations in Canada, Japan, Spain, and the USA between 1972 and 2009 (Sera *et al*. 2020). It is also not known, although it would seem unlikely, whether a decline in heat-related deaths because of adaptation can continue at even higher temperatures.

3.5 Wildfires

Increasing temperature and decreasing precipitation (together with other consequences of climate change such as increased lightning incidence and changing vegetation cover) are likely to be significant factors in the origin of forest, heathland, peatland and other wildfires (Smith *et al*. 2020a). Although wildfires can play a natural role in the life cycle of ecosystems, they can also have a devastating long-term effect on ecosystems not adapted to such patterns of burning especially those already changed by humans. Substantial GHG emissions and habitat loss from wildfires are likely to accelerate climate change further, possibly leading to a self-reinforcing feedback loop (Xu *et al*. 2020b). Governments are not yet sufficiently prepared (UNEP 2022).

While it is usually relatively easy to evaluate the immediate accidental fatalities and injuries, measurement of exposure is a major challenge in quantifying and attributing the other health consequences. In a comprehensive global assessment of wildfires, climate change and human health (Xu *et al*. 2020b), it was suggested that particulate matter from wildfires may be more lethal than that from urban settings (further evidence for this is discussed in IANAS (2022); and see section 3.3.1). Other recent systematic reviews (Karanasiou *et al*. 2021; MacGuire and Sergeeva 2021) concur that smoke exposure is associated with increased risk of respiratory and cardiovascular disease and all-cause mortality, especially in children, the elderly, those with chronic diseases and Indigenous Peoples. A time series study used data on all-cause mortality and deaths from cardiovascular and respiratory causes collected from 749 cities in 43 countries and regions during 2000–2016 (Chen *et al*. 2021). It showed that 0.62% (95% confidence interval 0.48–0.75) of all-cause deaths annually with similar proportions of cardiovascular and respiratory deaths were attributable to the acute impacts of wildfire-related $PM_{2.5}$ exposure. In Brazil a 10 $\mu g/m^3$ increase in wildfire-related $PM_{2\cdot5}$ was associated with a 1.65% (95% confidence interval 1.51–1·80) increase in all-cause hospital admissions, and a 5.09% (4·73–5·44) increase in respiratory hospital admissions, in the 24 hours after the exposure. The effects were particularly high in young children and people aged 80 years and older (see Ye *et al*. 2021). An AASSA (2021) case study detailing the health effects of the 2019–2020 Australian bushfire, ranged from direct exposure to flames and extreme heat, prolonged smoke inhalation, contamination of food and waterways through to trauma (Australian Academy of Health and Medical Sciences 2020). This case study is also noteworthy in emphasising the point that the immediacy of the impact on many in the population led to an unprecedented public response with health protection (Vardoulakis *et al*. 2020) and political implications (Head 2020) and, potentially, momentum for transformative change, although policy-makers are not yet acting on the evidence (Beggs *et al*. 2021).

In some locations, for example in parts of the Asia-Pacific region, while forest fire numbers have increased, the area affected has decreased, possibly because of public awareness and implementation of prevention and control measures (AASSA 2021). However, the very large scale of recent fires suggests that, in some places, the limit to adaptation has been reached and wildfires are a threat throughout the AASSA region (e.g. Armenia, China, India, Malaysia, Russia and Turkey). Furthermore, wildfire smoke can be transported long distances and contributes to air pollution that transcends national boundaries.

The worldwide problem of deliberate fires associated with deforestation has been highlighted previously (IAP 2019a). Also, the burning of crop residues is prevalent in countries such as China and India (Wang *et al*. 2018) and Southeast Asia and contributes to significant air pollution. Climate change may exacerbate the consequences of biomass burning in forests and peatlands caused by human activity. For example, deaths in 2015 in the Asian region were attributed to fires set to clear peatlands for palm oil production (Marlier *et al*. 2019). These fires coincided with an El Niño year, which created drought conditions, and harmful pollutants (Pongsiri and Bassi 2021).

In Sub-Saharan Africa, there are more wildfires than in any other region (NASAC 2022). Although gathering reliable data without remote sensing is often unachievable, it is estimated that more than 40% of the annual global biomass burnt is in Africa, including fires associated with deforestation.

Evidence in Europe (EASAC 2019a) reveals that wildfires are increasingly occurring outside the traditional fire season and in countries where they were previously rare, although the most devastating fires still occurred in the Mediterranean region. The impacts of extended drought and massive fires have been aggravated in some instances by failure of governance, for example in maintenance and repair of electricity grids and water supplies. In turn, wildfires threaten essential infrastructure and risk triggering industrial accidents (JRC 2020).

An IANAS case study provides a detailed review of the literature on climate change, wildfires and respiratory health in Canada (where several thousand premature deaths have been attributed to short- and long-term smoke exposure annually (Matz *et al*. 2020)) and the USA. It is projected that there will be twice as many premature deaths from fire-attributable smoke exposure in the USA by late 21st century than early in the century. One focal point in this case study is mental health. IANAS (2022) summarised the regional evidence to show that wildfires increase both the short- and long-term risks for numerous mental health concerns, including anxiety, depression, post-traumatic stress disorder, insomnia, suicidal ideation and substance abuse. Related issues are also covered by AASSA and EASAC. Wildfires can also indirectly impact mental health by undermining the social and environmental determinants of health (IANAS (2022) examples from the Northwest Territories and California), by disrupting residents’ ability to participate safely in outdoor and culturally significant land-based activities. Anticipated risks of wildfire-related loss may also evoke strong emotional reactions such as ecological anxiety and grief.

3.6 Drought

Drought is an important driver for some of the climate change-related impacts already described (wildfires, airborne dust) or to be described later (food and nutrition insecurity, migration). The interaction between heat exposure and drought with potential for worsening effects on health is receiving growing attention (Anon. 2018). A systematic review of the earlier evidence was published in 2013 (Stanke *et al*. 2013).

According to IPCC projections, the Western Sahel will experience the greatest drought, but other parts of Africa may also receive less precipitation. NASAC (2022) discussed the findings from the EM-DAT database (https://www.emdat.be/database), assessing the effects of drought, including on mortality. According to this source, droughts in Africa

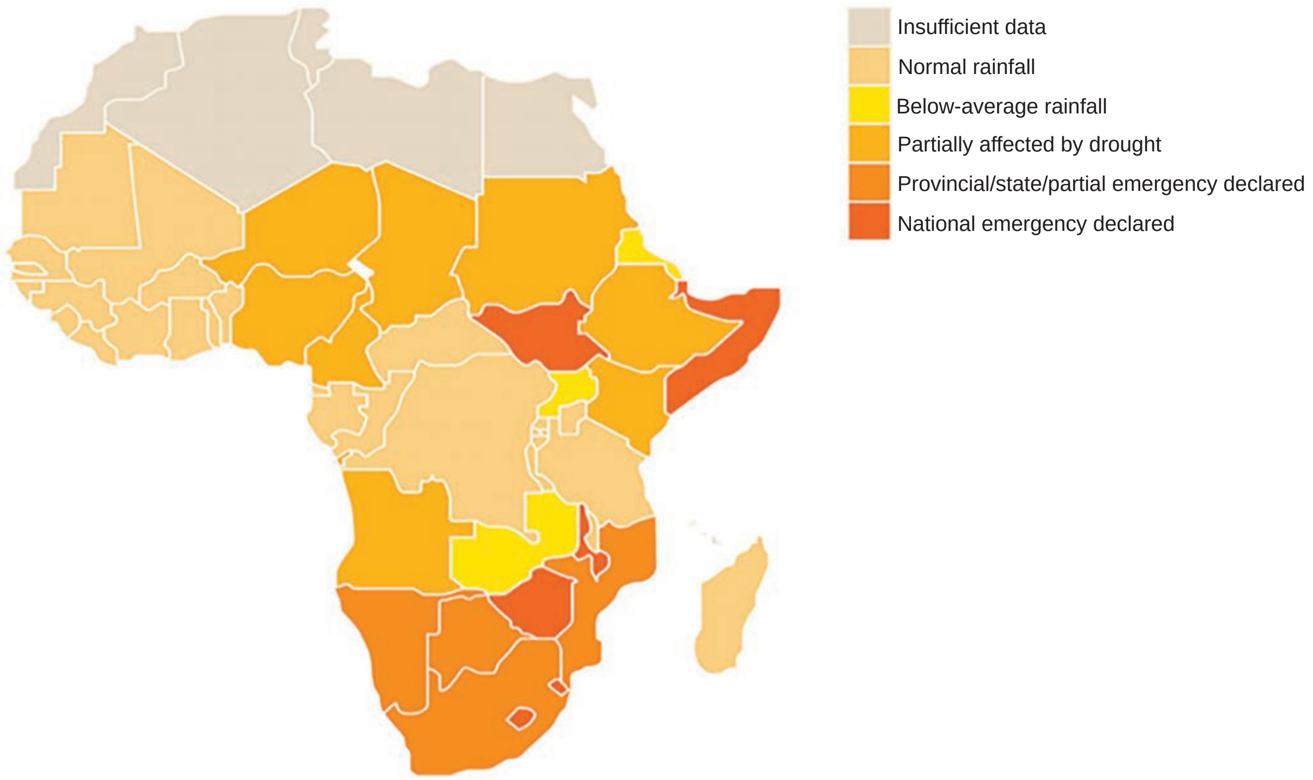


Figure 12 Drought in Africa. NASAC (2022) based on Fasemore (2017). See NASAC (2022) for further discussion. N.B.: more recent impacts (e.g. Madagascar 2021) are not included in this figure.

have become more frequent, intense and widespread during the past 50 years and it is predicted that the effects will increase, particularly impacts on food security, water scarcity and dust-, smoke- and heat-related health effects. However, the complex and highly variant nature of many physical mechanisms of weather such as the El Niño–Southern Oscillation, sea surface temperature, and land–atmosphere feedback, together with lack of technical capacity, adds to the daunting challenge of drought monitoring and forecasting in Africa (Masih *et al*. 2014). Figure 12 (from the NASAC (2022) report) portrays a recent comparison that highlights the widespread impact.

This assessment of drought in Africa can be set into the global context using the comprehensive data on drought risk assessment in a JRC report[10]. Other IAP assessments note that the Middle East and Southeast Mediterranean are among the world's regions with least water availability (EASAC *et al*. 2021); see Figure 13.

Under worst-case scenarios, a further reduction of up to 45% in precipitation can be expected by the end of the century in certain countries in the region. Because of their multiple problems, Somalia, Yemen and Afghanistan have been assessed as particularly high-risk countries for drought-related health problems. Problems for some countries in the Mediterranean region, such as Cyprus, attracting a large number of tourists, are magnified by the large increments in seasonal demand for potable water.

In the Mediterranean and Middle East regions, the drought-related health consequences from lack of drinking water and sanitation include diarrhoeal disease (especially in children); parasitic diseases such as schistosomiasis (see also Bellizzi *et al*. (2020) for concurrent effects with COVID-19); toxicity from chemical

[10] JRC, Atlas of the Human Planet, 2020, https://publications.jrc.ec.europa.eu/repository/handle/JRC122364

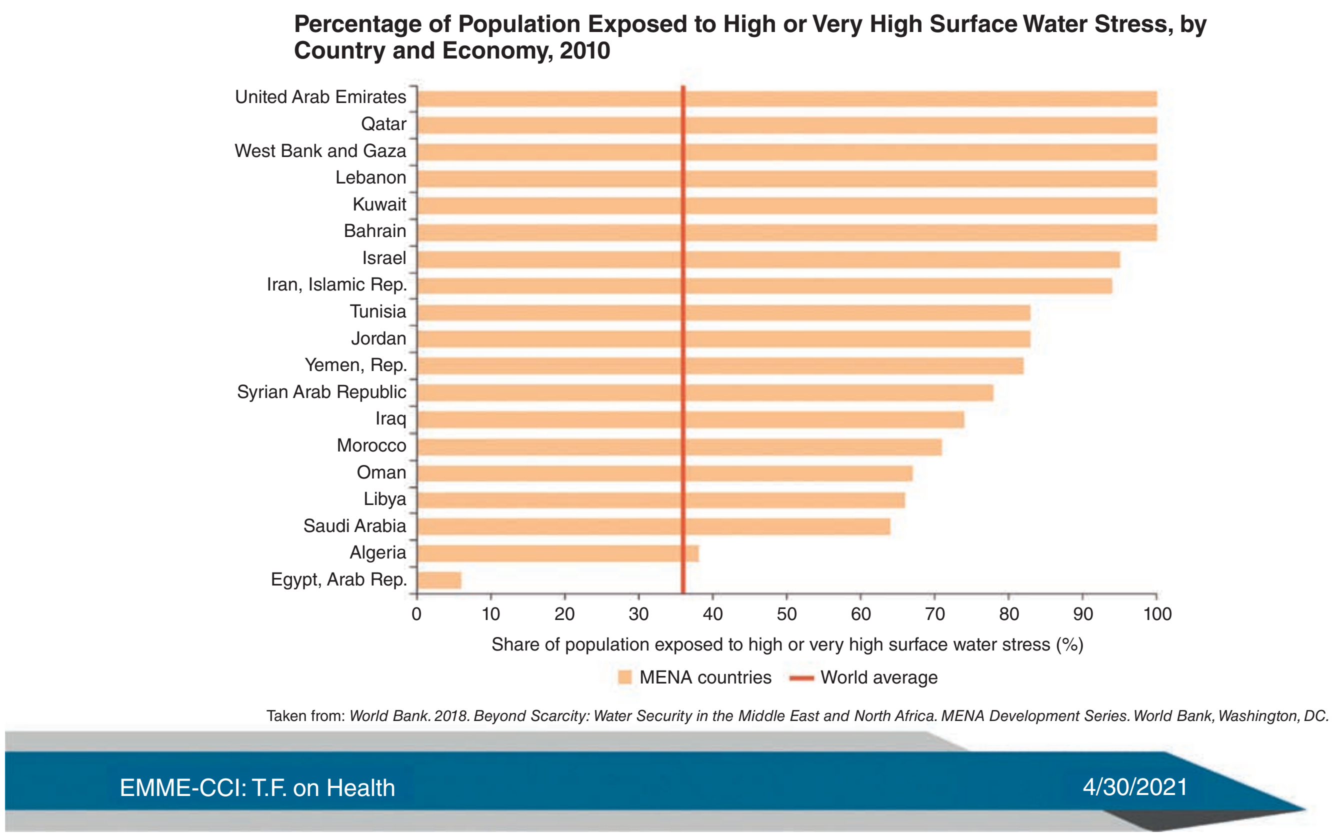


Figure 13 Water stress in the Middle East, from World Bank (2018) (see EASAC et al. (2021) for further discussion). The most widely accepted measure of water availability, the water stress index, establishes the threshold of 1,700 m^3 natural renewable water resources (NRWR) per capita per year: countries that fall below this figure are considered to experience water stress. In aggregate, Middle East and North African countries have only approximately 1,100 m^3 NRWR per capita per year (by comparison with 5,000 m^3 for Western Europe and more than 24,000 m^3 for Latin America).

contamination of water supplies with metals, pesticides and other organic compounds; and increasing prevalence of vector-borne diseases, because water storage creates new breeding sites for vectors (EASAC *et al.* 2021). Indirect health effects include those attributable to reduced agricultural productivity (both nutritional and economic impacts) and those associated with physical transportation of water from distant sources, a task often assigned to women and children (injuries, including sexual violence, and consumption of time otherwise useable for education or financially productive activities). Low-income groups are particularly affected because of their difficulty in purchasing safe water.

The other regional reports discussed similar and additional effects. IANAS (2022) assessed the association between drought and diarrhoea in terms of an increasing concentration of pathogens in water supplies (Kraay *et al.* 2020). The IANAS case study on health of Indigenous Peoples included the example of the Navajo Nation, USA, where droughts are becoming more common, forcing residents to travel longer distances for water for household use as well as contributing to decreased accessibility of Indigenous medicines for many Indigenous Peoples in the Americas.

Throughout the AASSA region, countries report drought as an effect of climate change. Health consequences are exemplified by the experience of major cities in Bangladesh where higher incidences of dysentery and diarrhoea are associated with the increased use of contaminated water as most suitable water sources had dried out. Drought in India is exacerbating the consequences of the current depletion of groundwater for many cities; for example a drought in 2019 caused the water supply to dry up in Chennai and led to a crisis

Box 5 WMO recommendations for global action

1. Invest in integrated water resources management, especially in SIDS and least developed countries.
2. Invest in drought and flood early-warning systems in at-risk, least developed countries.
3. Fill the capacity gaps in collecting data for basic hydrological variables which underpin climate services.
4. Improve interaction among national-level stakeholders to co-develop and operationalise climate services to better support adaptation in the water sector.
5. Fill the gaps in data on country capacities for climate services in the water sector, especially for SIDS.
6. Support Water and Climate Coalition[12] to promote policy development for integrated water and climate assessments, solutions and services.

in the city. The situation may get much worse and might even be regarded as a potential tipping point, insofar as Asia's glaciers currently protect large populations in the region from drought stress but these glaciers are shrinking (Pritchard 2019). Drought may also increase the risk of mental health problems, particularly in rural and farming communities (e.g. in southeastern Australia (Hanigan *et al*. 2018)).

The climate change-induced impacts on water scarcity are on a global scale and a recent WMO report (2021b) documents terrestrial water storage loss in many highly populated areas. The impacts of environmental phenomena are compounded by socio-economic factors including urbanisation and population growth such that more than two billion people currently suffer water stress. These numbers are expected to increase worldwide, threatening water resources sustainability and economic and social development. The WMO report (2021b) provides a comprehensive account of water-related hazards and weaknesses in integrated water resources management and makes six strategic recommendations (Box 5) to improve it, particularly in those 107 countries currently off track to hit the goal of sustainably managing their water resources by 2030 (SDG 6)[11].

3.7 Flooding

Previous estimates of the global flood-exposed population have been limited by a lack of observational data, relying instead on models. Recently, daily satellite imagery at 250-m resolution to estimate flood extent finds the global population exposed is much higher than previous assessments (Tellman *et al*. 2021).

Climate change-related flooding disasters create a high public health burden. There are multiple mechanisms for flooding associated with climate change, including sea level rise, melting glaciers and thawing permafrost, changes in monsoon systems, excess precipitation and other extreme weather events all of which may be compounded by land use changes, particularly urbanisation and deforestation. For example, some of the largest cities in India lie along the coastline, exposed to rising sea levels. Among the vulnerable groups are Indigenous Peoples: in New Zealand, some Māori communities are vulnerable because some of their sacred sites are on exposed erosion-prone coastal lands (AASSA 2021). The IANAS (2022) case study on Indigenous Peoples brings together a comprehensive account of literature sources on the effects of climate change on flooding as well as the consequences for physical and mental health transmitted by adverse effects on livelihoods, food security and water quality.

[11] UN-Water Integrated Monitoring Initiative 'Summary Progress Update 2021: SDG6 – water and sanitation for all', February 2021.
[12] https://www.water-climate-coalition.org/.

Multiple short-term health consequences include accidental injuries and death as well as waterborne diseases linked to impaired drinking water quality. Vector-borne diseases such as dengue and malaria may also increase in the aftermath of floods as a result of residual standing water but, in some cases, floods wash away mosquito breeding sites. There are also longer-term consequences ranging from ecosystem degradation, including chemical contamination and loss of land for crops, to cardiovascular and mental health impacts. Post-traumatic stress disorder caused by extreme weather events has been increasing in Sub-Saharan Africa (Hayes *et al.* 2018). The concomitant disruption of services by flooding, including those for health, sanitation and transport, may compound vulnerabilities.

Many of these effects are exemplified in the AASSA (2021) report. In China, half the population and one-third of the land area is under heavy threat of flooding. In southern China, in the past 30 years the frequency and intensity of extreme flooding in typical flood risk areas and small/medium-sized river basins have increased with effects on cardiovascular and all-cause mortality and an increasing incidence of infectious diseases. It has been estimated that flooding in China in the period 1950–2018 killed more than 280,000 people with direct costs of approximately US$6,000 billion between 1990 and 2018 (Guo *et al.* 2020), although the extent of attribution to climate change requires more research. By the end of this century, China is projected to be the country most impacted by flooding, with 40 million people affected and potentially causing US$150 billion damage each year.

Elsewhere in the AASSA region, and focusing on infectious disease, an increase in waterborne diseases in Nepalese children is associated with temperature and rainfall factors (Dhimal *et al.* 2017); in Bangladesh, diarrhoea among displaced populations due to floods is the most common cause of death for children under 5 years old (see Das *et al.* 2019). In Malaysia and Indonesia, frequent flooding resulting from extreme weather events has been associated with the expansion of breeding grounds for *Aedes* mosquitoes and an increased incidence of dengue (Hii *et al.* 2016). The unprecedented 'yellow floods' of 2014–2015 in Malaysia and 2018 in Indonesia are notable examples of extreme weather events, and computational simulation predicts increasing future flooding in the area from rainfall and its intensification by urbanisation (Li *et al.* 2020). In Malaysia, flooding was followed by increases in rodent-transmitted (e.g. leptospirosis, Radi *et al.* 2018) and vector-borne (e.g. dengue) diseases (Mudin 2015), diarrhoeal diseases and post-infectious irritable bowel syndrome (Yusof *et al.* 2017).

The AASSA (2021) report also covers impacts of flooding in westernmost parts of the region: Turkey, the Caucasus and the Russian Federation. The EASAC (2019a) report used Eurostat data to discuss how the largest effects of recent flooding in Europe have been observed in areas contiguous to the AASSA region in Southeastern, Eastern and Central Europe. Although flood projections are subject to considerable uncertainty (EASAC 2019a), for the temperature increase above 2 °C in the EU, sea level rise may result in fivefold more coastal flooding damage and threefold more people exposed to river floods (Ciscar *et al.* 2018).

Flooding following heavy rain is also a major challenge for Africa, and NASAC (2022) comprehensively discussed the recent situation in central-eastern parts of the continent (2019–2020), based on a case study in Burundi and other analyses (Figure 14 summarises the major effects).

NASAC (2022) also provided comprehensive assessment of storms, where health impacts are mostly caused by secondary events such as flooding, landslides and tornadoes. A case study of Cyclone Ida in Mozambique and Zimbabwe in 2019 described how this, among the deadliest storms ever recorded in Africa, killed more than 600 people, affected 1.8 million and caused an estimated economic

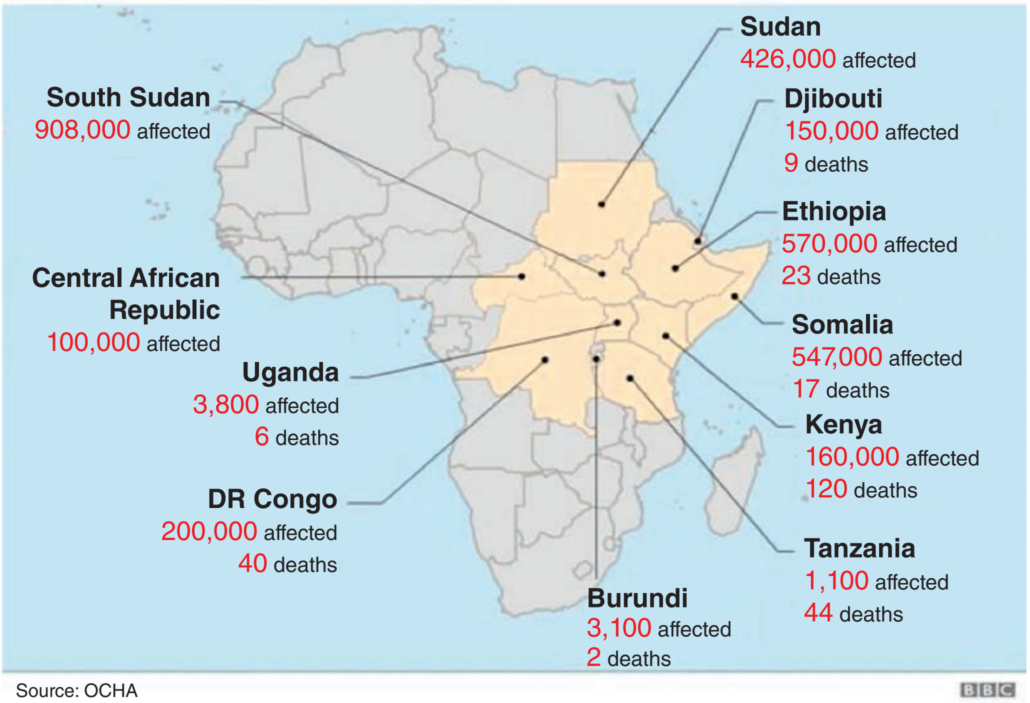


Figure 14 Assessment of 2019–2020 flooding in Africa (NASAC (2022) based on an assessment by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA)), highlighting those countries most affected. See NASAC (2022) for further discussion.

loss of US$770 million. Projections suggest that eastern and western Africa regions will be affected by increasing severity of cyclones and coastal floods.

The IANAS (2022) report provided detailed assessment of the increased risk of waterborne diseases, throughout the Americas, in consequence of increases in occurrence, duration and intensity of heavy rainfall. There are many different pathways: for example, flooding can transport pathogens from livestock manure applied to crops, human wastewater and industrial wastewater into drinking water sources; and heavy rainfall may also exceed sewage treatment capacity (Herrador *et al*. 2015). Evidence from Brazil, Canada, Ecuador and Peru (IANAS 2022) shows that heavy rainfall and other drivers of flooding are important factors in diarrhoeal disease. However, the evidence is not always sufficient to clarify the relative importance of mechanisms in terms of pathogens, transmission pathways and the influence of local conditions. Moreover, waterborne illness is substantially underreported in surveillance systems (Herrador *et al*. 2015). The disease threats are reviewed in detail in the IANAS case study from Peru, a country highly vulnerable to the health impacts of climate change as it has 71% of all tropical glaciers and is subject to the El Niño–Southern Oscillation, which contributes to heavy rains and flooding. The El Niño–Southern Oscillation has been linked with dengue epidemics and adverse effects on reproductive health. A study investigating the El Niño–Southern Oscillation and vulnerability in terms of rotavirus-linked childhood diarrhoea clinical visits (Delahoy *et al*. 2020) demonstrated the importance of measures to improve water and sanitation alongside rotavirus vaccination (IANAS 2022). Climate-sensitive (including flooding) outcomes in the Americas are unevenly and inequitably distributed, with the most affected being those who live in ecologically sensitive areas, those who rely closely on the environment for livelihoods, food and culture, those with chronic physical and mental health challenges, and those who are systematically marginalised and disadvantaged.

Global damage from floods and storms continues to increase, from an estimated US$94 billion in the 1980s to more than US$1 trillion in the 2010s (Hino and Nance 2021). These risks and impacts from flooding are disproportionately borne by marginalised households as economic, political and social systems distribute climate risk unevenly, and policies designed to help people recover leave out many of those most in need. Research studies on flooding (as on other effects of climate change) are often skewed towards resilient places and people, and there is need to do more to address this bias (Hino and Nance 2021) by the following means:

- Collecting the right data, for example to focus on data gaps on LMIC urban areas, and this requires approaches that engage with local communities. Therefore, the design and conduct of research must broaden participation by those who have been hitherto underrepresented.
- Choosing the right metrics; for example rather than relying on measurements of property damage (that favours wealthier areas, unless adjusted for differences in household wealth), metrics of well-being (including physical and mental health) should be introduced.
- Clarifying and tackling governance mechanisms and cultures that perpetuate inequity.
- Understanding who benefits or does not from new policy implementation.

One research priority is an inclusive assessment of the mental health impacts of flooding. Systematic literature reviews discussed by EASAC (2019a) provide a significant amount of information on mental health outcomes after flooding, including some in poorer socio-economic conditions (e.g. Zhong *et al.* 2018). However, there is a relative paucity of longitudinal studies and lack of control for confounding factors. And, as with other climate change research, there should be greater focus on vulnerable groups. A systematic scoping review of the global literature identified mental health outcomes in Indigenous Peoples, linked to both acute and chronic weather events, including flooding (Middleton *et al*. 2020). More research is needed on immediate responses to extreme events, including disruption of homes, infrastructure and cultural practices (IANAS 2022) and on how fear of flooding as a global environmental threat may create emotional stress and anxiety about the future (EASAC 2019a). IANAS (2022) also discussed how impacts on well-being in anticipation of potential effects, without direct acute or chronic exposure, can be related to media coverage, for example of impending hurricanes (see also Pihl *et al.* (2021) for recent research).

The systems-based approach to mental health research recommended by EASAC (2019a) (drawing on Berry *et al*. 2018) should include effects on community as well as individual health (American Psychological Association 2014).

3.8 Infectious disease threats

Links between climate change and diverse infectious disease threats have been observed worldwide (Romanello *et al*. 2021) in association with the other aspects of globalisation that drive changes both ecosystems and in human behaviour (Academy of Medical Sciences *et al*. 2020). Examples will be provided in the following sections, but there is potentially an additional threat – from antimicrobial resistance – that could undermine therapeutic responses to infection more broadly. Increasing temperature is associated with increased antibiotic resistance for pathogens such as *Escherichia coli*, *Klebsiella pneumoniae* and *Staphylococcus aureus* (MacFadden *et al*. 2018) and the mechanisms for this association are becoming clearer, for example in terms of bacterial replication rates (Kaba *et al*. 2020; Rodríguez-Verdugo *et al*. 2020).

This is an important subject for further research worldwide on environmental pollution as well as human health[13] because current forecasts of the public health burden of antimicrobial resistance could be underestimated in the face of climate change (EASAC 2019a).

3.8.1 Vector-borne disease

The examples discussed here are drawn from the regional reports, and related literature, which provide detailed assessments of the current situation and future projections for vector distribution and disease burden.

Although the number of deaths from malaria has fallen markedly this century, estimates from the WHO predict rising deaths between 2030 and 2050 as a result of more favourable environments for mosquito vectors. Mosquito-transmitted viruses such as dengue, chikungunya and Zika are also becoming more common worldwide. Dengue virus was found in 9 countries in 1970 but more than 100 today and the projected trends are of great concern (Messina *et al*. 2019). A multi-model, multi-scenario intercomparison modelling study (Colón-González *et al*. 2021) confirmed that rising global mean temperatures will increase the climatic suitability for both malaria and dengue. According to this evaluation, the population at risk of both diseases might increase by up to 4.7 billion people by 2070 relative to 1970–1999. The areas at risk for malaria include Africa (tropical highlands), the Americas and Eastern Mediterranean, and, for dengue, lowlands in the Western Pacific region and the Eastern Mediterranean. The WHO Africa region currently contributes more than 90% of the global malaria burden and mortality but, as discussed by NASAC (2022), the effects of climate change can be complex to interpret, depending on both temperature and rainfall. For example, the 'drying trend' may lead to parts of southern Africa becoming free of malaria by 2040, while in central, eastern and western regions of Sub-Saharan Africa cases are predicted to increase. Other evidence (Murray *et al*. 2020) shows that the number of suitable months per year for the transmission of malaria in the African highlands has increased by about 30% in the past 5 years but, by contrast, other regions (e.g. African lowlands) do not show an increasing trend for malaria, potentially because of becoming too hot or experiencing shifts away from the combinations of temperature, rainfall and humidity that support high mosquito populations. NASAC (2022) discussed that for dengue, similar to malaria, western, central and eastern regions of Sub-Saharan Africa are likely to undergo the greatest increase in burden because of climate change.

Shifting distribution patterns of vector-borne diseases as a result of climate change are attributable both to the changing levels of pathogens, vectors and hosts in locations where the disease already exists, and to expansion into new areas: this complexity creates challenges for modelling scenarios (Rohr and Cohen 2020). Moreover, there has been insufficient research focus on human behavioural factors affected by climate change that may increase or decrease exposure to threats (Academy of Medical Sciences *et al*. 2020; Baker *et al*. 2021; Semenza and Paz 2021). In addition, because of their high mutation rates and short generation times, the increased number of infections caused by rising temperatures may increase genetic variability of arboviruses, with potential emergence of novel strains or serotypes with different properties of virulence and/or transmissibility (Tozan *et al.* 2020).

AASSA discussed vector-borne diseases transmitted by mosquitoes, ticks and fleas, including malaria, dengue, chikungunya, Zika, visceral leishmaniasis, tick-borne encephalitis, Japanese encephalitis, West Nile fever, tularaemia and Crimean-Congo haemorrhagic fever. Evidence was presented from countries including Armenia, Bangladesh,

[13] For example, the diversity and abundance of antibiotic resistance genes has been studied in the wetlands across the Tibetan Plateau (Yang *et al*. 2019).

China, India, Japan, Nepal and Pakistan and, although the relative contribution by climate change to the threat is not always clear, changing temperature and rainfall are often implicated: for example, in the northward expansion of various vectors (*Aedes albopictus*, *Culex vishnui*) in Japan and dengue cases in China (AASSA 2021). The example of Nepal demonstrates how vector-borne diseases continue to spread into localities previously thought non-endemic despite measures taken to control the spread in the past decade under the actions for Millennium Development Goals and the Roll Back Malaria Programme. Additional examples are presented in the AASSA (2021) country reports. The widening distribution of avian influenza may be associated with climate-induced changes in bird migration, and in Azerbaijan there is concern about climatic suitability increasing transmission of malaria once it has been introduced. Similarly, because of more favourable conditions for local vectors, climate change may also increase incidence in Japan once cases are imported by visitors from abroad, and a similar concern was expressed in Korea for dengue and Zika imported from abroad.

IANAS (2022) reviewed evidence that vector-borne diseases transmitted by arthropod vectors (mosquitoes and ticks) have increased both in incidence and distribution in the Americas and will be further affected by climate change. However, the detection and attribution of actual cause remains challenging because of the complexity of ecological and social systems having diverse climate-dependent and independent factors. Current and projected changes are reviewed for chikungunya, dengue and West Nile virus, with both potential for northward and southward expansion of vectors, according to different scenarios. Malaria vectors are projected to occur over almost half the South American continent by 2070 but modelling is complicated by the interaction between host, vector and environmental factors and by vector control efforts. For example, in South America, higher temperatures, less water availability and biome modifications are projected to reduce suitable habitat and thus decrease the distribution and abundance of the current primary malaria vector *Anopheles darlingi*. However, the geographical range of climate generalist mosquitoes (*Anopheles albitaris* complex) is projected to expand significantly and potentially become more important in malaria transmission (Laporta *et al*. 2015). For tick-borne diseases, IANAS focused on Lyme disease expansion and distribution in North America under climate change. Distribution of chagas disease, transmitted by triatomine bugs infected with the protozoan parasite *Trypanosoma cruzi*, is also forecast to expand under many climate change scenarios, although different vectors have different thermal preferences.

NASAC (2022) discussed also how yellow fever is expected to undergo particularly large increases in east and central Africa, with total deaths in the continent increasing by 10–40% according to climate change scenario (Gaythorpe *et al*. 2020).

EASAC (2019a) discussed how, under various climate change scenarios, Europe is susceptible to increases of some vector-borne diseases in humans, in particular dengue, chikungunya, West Nile virus and Lyme disease, as well as in livestock such as African swine fever (see also Semenza *et al*. 2016). For example, in the past decade, expansion of West Nile virus is continuing at a high rate from Southeastern Europe with expansion westwards and northwards, including into areas where no cases had been reported previously (Figure 15). Bird migration is one of the important variables in the spread of West Nile virus that may be affected by climate change.

Broadly analogous changes in distribution in Europe might be anticipated for other vectors and pathogens. For example, the distribution of *Aedes albopictus* mosquitoes, a known vector for chikungunya, dengue and dirofilariasis viruses, is expanding and has been implicated in chikungunya virus transmission in Italy and France, and dengue transmission in France and Croatia (EASAC 2019a). The

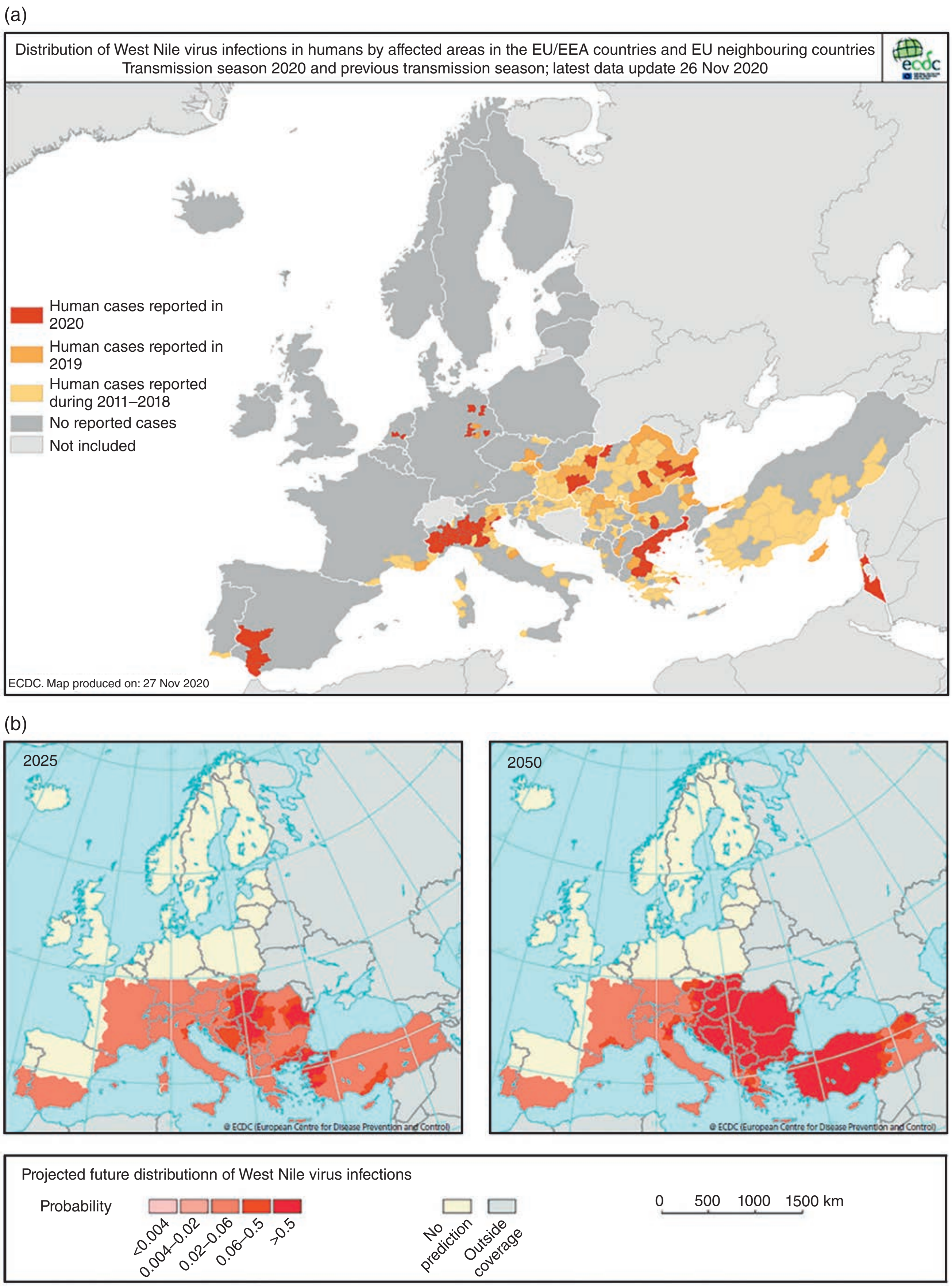


Figure 15 West Nile virus expansion in the EU and neighbouring countries. (a) Changes in the past decade. An unprecedented increase in south east Europe in 2010 was preceded by extreme hot spells and probably related to those high-temperature anomalies. There is also a progressively earlier start to the annual transmission season. See EASAC (2019a) for further details. (b) Projections 2025–2050, illustrating the magnitude of future dissemination that may be expected in southern and eastern parts of the region.

potential establishment of *Aedes aegypti*, a vector for dengue, chikungunya and Zika viruses, is also of concern in the Mediterranean area.

The vulnerability of the greater Mediterranean–Middle East region to climate change-induced increases in vector-borne diseases is compounded by increased urbanisation and disruption of ecosystems in the region (Paz *et al*. 2021). For endemic infections in the region, such as malaria, leishmaniasis and West Nile virus, clear correlations between disease incidence and environmental change have been established; for other vector-borne diseases, further climate variation could shift geographic spread and/or seasonality. Cases of local transmission of malaria have been recorded in Cyprus, Greece and Saudi Arabia. For leishmaniasis, modelling predicts changes in distribution for *Phlebotomus* spp. vectors: spreading to new areas adjacent to the Mediterranean but disappearing from previous habitats in parts of North Africa and the Middle East because of rising temperatures (see EASAC *et al*. (2021) for further detail). Algeria is another example of a country previously WHO-certified as free from malaria (in 2019) but now threatened with re-emergence. *Anopheles gambiae*, the main malaria vector in Africa, has been observed at the border with Mali and may now spread northwards, partly in consequence of climate change. Furthermore, a new malaria vector in Africa, *Anopheles stephensi*, confirmed in East Sudan, is spreading from the Arabian Peninsula and Horn of Africa, with resistance to higher temperatures and common insecticides, and tolerance to pollution such as from oil and sewage (Sinka *et al*. 2020). Algeria is also at risk from the arboviral viruses, dengue, chikungunya and Zika because of the cases occurring in the Eastern Mediterranean (Figure 15) as *Aedes albopictus* is still established in the north of the country (Benallel *et al*. 2016[14]). Similarly, in Tunisia, diseases such as malaria and leishmaniasis, assumed eradicated, are re-establishing where land use change results from climate change; and West Nile virus and dengue are emerging. These multiple examples of changing distributions emphasise the importance for neighbouring countries to work together to strengthen public health surveillance schemes and cross-border health threat alerts.

The examples from the greater Mediterranean region also emphasise the complexity of exposure pathways. In Egypt, research by the Egyptian Academy of Sciences and others on schistosomiasis discloses that the incidence is related to meteorological factors affecting both the movement of snails and the migration of farmers from the Nile Delta because of salination and land erosion (EASAC *et al*. 2021). In Israel, there is potential risk of dengue, chikungunya, West Nile and Zika viruses, again reflecting the proximity to expansion in Southern Europe (Figure 15). Cutaneous leishmaniasis has also increased recently, explained at least partly by the high ambient temperature of early night-time on activity patterns and northward expansion of sandfly vectors (Waitz *et al*. 2018). In Jordan, the increasing risk of malaria, schistosomiasis and leishmaniasis under climate change may be aggravated by the unintended consequences on vectors of water projects introduced to deal with drought. Malaria and arboviral diseases are increasing in Sudan in response to multiple environmental challenges, including climate change: little is known about the local epidemiology, distribution and dynamics of arboviruses despite their rapid increase and expanding distribution (EASAC *et al*. 2021). Moreover, their misdiagnosis as malaria or other febrile illness can lead to their underestimation alongside overestimation of malaria prevalence (Ahmed *et al*. 2020).

3.8.2 Arctic case study

Rapid climate change in the Arctic region has potential consequences for health both for

[14] And see the latest data for distribution of *Aedes albopictus*, October 2021: https://www.ecdc.europa.eu/sites/default/files/images/Aedes_albopictus_2021_10.png.

Box 6 Lessons from Arctic warming for tackling infectious disease worldwide

1. Valuable insights accrue when researchers meaningfully and ethically engage with Indigenous Peoples, prioritising Indigenous knowledge and Indigenous Rights. Indigenous self-determination in research is critical.
2. There are pressing needs to develop standardised and integrated surveillance systems. The One Health[15] perspective is helpful in constituting and coordinating reporting and response systems.
3. There are significant opportunities for improvement of the capacity for preparedness and responsiveness by connecting different public sector research networks and sharing novel technologies, for example for data mining of epidemiological datasets.
4. Basic research is vital, for example in understanding the determinants of pathogen transmission within and between species.
5. Research outputs must be better used to inform policy and practice at local, regional and global levels, for example to develop early-warning systems that use climate forecasts to predict infectious disease outbreaks well in advance.

See https://easac.eu/news/details/arctic-warming-and-microbial-threats-perspectives-from-iap-and-easac-following-an-international-academies-workshop/ and NASEM *et al*. (2020).

those living in the region (IANAS 2022) and for those elsewhere who may be susceptible to the wider consequences, for example from infectious disease transmission, as well as reduced access to marine protein impacting nutrition. Evidence suggests that a rapidly heating Arctic will affect the rate of development and survival of pathogens and thus increase the threats of tick-borne diseases, malaria, West Nile virus and *Vibrio* species in Europe, North America and Asia in consequence (Parkinson *et al*. 2014). Habitat encroachment may compound the effects of climate warming on (re-)emerging zoonoses in the Arctic and Boreal biomes, necessitating Indigenous Peoples' self-determination in monitoring, prevention and responsiveness (Keatts *et al*. 2021).

Thawing permafrost may release anthrax (Revich and Podolnaya 2011; Ezhova *et al*. 2021) and projections up to 2100 using the worst-case RCP 8.5 scenario indicate increasing potential for reactivation of soil anthrax reservoirs (Liskova *et al*. 2021).

Thawing permafrost also increases smallpox risk in former nomadic campsites and graveyards (Climate Crisis Advisory Group 2021). Potential microbial (fungal, bacterial and viral) threats may be present elsewhere in the terrestrial cryosphere (Edwards 2015) but much research is still needed to categorise cryospheric genomic diversity in melting glaciers and ice sheets. The microbial threats from thawing permafrost in the Arctic were discussed in detail in a report from a workshop (NASEM *et al*. 2020), and the lessons for adapting to the particular circumstances of the warming Arctic are, to a significant degree, generalisable worldwide (Box 6; see also Bogatov *et al*. 2021).

In addition to considerations of infectious disease, climate change brings other challenges for Indigenous Peoples in the Arctic region, for example in terms of food security (IANAS 2022); and thawing permafrost may release other hazards, including radioactive materials and toxic chemicals (Miner *et al*. 2021).

[15] One Health is a collaborative, multisectoral and transdisciplinary approach with the goal of achieving optimal health outcomes, recognising the interconnection between people, animals, plants and their environment. www.cdc.gov/onehealth/basics/index.html, and see also chapter 6.

3.8.3 Waterborne infections

Relevant evidence from IANAS, AASSA, NASAC and the EMME-CCI study (see footnote 8) has already been discussed in the sections on flooding and drought. The impact of climate change on diarrhoeal diseases is projected to be highest in Asia and Africa, reflecting the current burden of disease in these populations. By 2030, Sub-Saharan Africa is expected to have the greater burden of additional deaths due to diarrhoeal disease in children under 15 years old (NASAC 2022). In the AASSA region, the most common climate change-susceptible waterborne diseases are cholera, other diarrhoeal disease, hepatitis A, typhoid and viral gastroenteritis.

As noted previously, both temperature and rainfall factors are associated with waterborne disease outbreaks (e.g. Dhimal *et al*. 2017). Studies in the European Baltic region (EASAC 2019a) and in Japan have found increasing levels of *Vibrio* spp. (*V. vulnificus*, *V. parahaemolyticus*) (AASSA 2021) and a northward shift associated with increasing sea surface temperature. A global mapping study of non-cholera *Vibrio* spp. projects an expansion in season suitability of up to 4 months compared with the historical baseline (Trinanes and Martínez-Urtaza 2021). The geographical extent of expansion will not be uniform. In addition to the Baltic, high latitudes in the Northern Hemisphere, the Atlantic northeast, Alaska and parts of northern Russia showed strong increases under both scenarios (SSP2–4.5 and SSP5–8.5; Figure 16). Large regions of Southeast Asia showed a higher increase for SSP2–4.5 (Figure 16a) than for SSP5–8.5 (Figure 16b).

The conclusion of the analysis made by IANAS with reference to the case study in Peru and other evidence from the Americas (Herrador *et al*. 2015) is worth reiterating. While it is clear that climate change increases the risk of waterborne illness, (1) the mechanisms underlying this increased risk are complex; (2) it is important to understand the effect of local conditions when clarifying and comparing exposure and response pathways; and (3) challenges for data quality and integration (including reporting biases) need to be addressed. '*Taken together, future research should examine how factors, such as the type of microorganism, the geographical region, season, type of water supply, water source, and/or water treatment, modi fy the effect of warming temperatures and changing precipitation on waterborne illnesses.*'

NASAC (2022) reinforced the conclusion made by IANAS (2022) that the burden of both food- and waterborne diseases is underestimated because of under-reporting and the complexity of pathways involved in transmission. Therefore, attribution of waterborne disease to climate change needs to address issues for exposure and vulnerability and the complexities of climate change effects—including extreme weather events as well as changes in mean temperature and precipitation (Semenza 2020).

3.8.4 Foodborne infections

The regional reports also discuss how climatic conditions are often linked to foodborne illness—with associations between the prevalence of foodborne pathogens and temperature, precipitation, extreme weather events, and ocean warming and acidification (see EASAC (2019a) and IANAS (2022) for detailed discussion of the complexity of pathways and attribution of effects). An IANAS case study focused on foodborne illness linked to seafood consumption contaminated with pathogenic *Vibrio* bacteria. El Niño events have been linked to increases in *Vibrio parahaemolyticus* outbreaks on the Pacific coast of South America, and in Mexico the risk of *V. parahaemolyticus* in oysters is projected to be 11-fold higher in a high emissions scenario than a low emissions scenario (Ortiz-Jiménez 2018)[16].

[16] Recent FAO assessment of these risks is discussed in their 2021 meeting report 'Advances in science and risk assessment tools for *Vibrio parahaemolyticus* and *V. vulnificus* associated with seafood': https://www.fao.org/3/cb5834en/cb5834en.pdf.

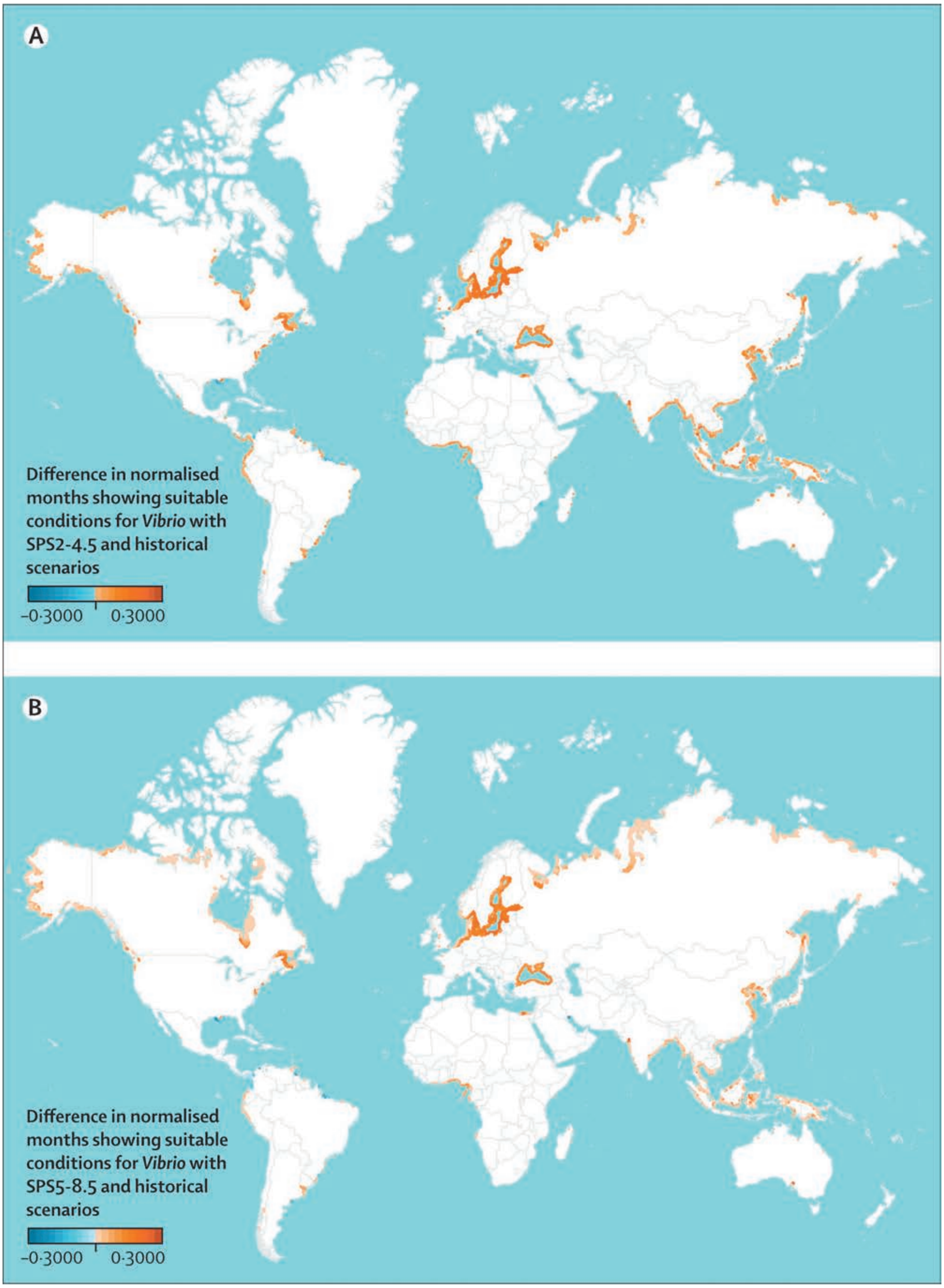


Figure 16 Global mapping of non-cholera Vibrio spp. Modelling, using a range of shared socio-economic pathways (SSPs), combined climate, population and socio-economic projections up to 2100 compared with historical simulations for 1850–2014. See Trinanes and Martínez-Urtaza (2021) for details. The projected increases in precipitation in parts of Africa, for example West Africa, where cholera is already endemic, may lead to more frequent outbreaks of cholera there (Niang et al. 2014; NASAC 2022).

The IANAS (2022) assessment also showed how climate change may affect pathogens at many steps in the food system, including, for example, pathogen release from livestock and transmission into the environment, increasing pathogen prevalence during food processing, distribution and storage, and during food preparation and consumption. Impacts on various steps in the food system are exemplified in the other regional reports. However, IANAS (2022) also cautioned that less is known about the magnitude of the impacts and few studies have examined climate change association with enteric illness that is directly attributable to food consumption distinct from contaminated drinking water, contact with animals and human-to-human transmission.

3.9 Food and nutrition security

An adequate and balanced diet, both in terms of calorie consumption and intake of essential nutrients, is critical for good health. Food systems – which encompass all the steps from the production of food through to its consumption (or waste) – are very sensitive to the effects of climate change. At the same time, they significantly contribute to anthropogenic GHG emissions, the pollution and degradation of natural resources and the loss of biodiversity, which in turn threaten health (Whitmee *et al*. 2015; Fanzo *et al*. 2018; Rockström *et al*. 2020; Watts *et al.* 2021).

3.9.1 Food systems

In 2018, emissions from food systems were estimated at one-third of the global anthropogenic total, with land use changes and the conversion of natural ecosystems to agricultural land accounting for one-quarter of food systems' emissions (Crippa *et al*. 2021; Tubiello *et al*. 2021). Figure 17 summarises recent statistics published by FAO, comparing emissions by country, continent and source, and these provide a basis for further discussion in this chapter and chapters 4 and 5.

These analyses also indicate that the IPCC categories used by countries to develop their National Inventory Submissions systematically underestimate the contribution of food systems because they can miss many important food-related emissions, such as those due to land use changes, fuel production, in-farm energy use, industrial processes, food packaging, food transport and food waste disposal. Emissions from energy use beyond the farm gate are expected to become an increasingly prominent component of total food system emissions in the coming decades (Tubiello *et al*. 2021). For example, although ultra-processed foods may often be based on comparatively low-emission commodities from agriculture, their processing is energy intensive yet the resultant high emissions are often unrecorded in food systems' emissions estimates (Royal Society and Academy of Medical Sciences 2021). However, the convenience benefit of ultra-processed foods to individuals must also be factored into policy considerations, particularly the reduced need for energy for cooking, longer shelf-life and ready availability when time and resources are scarce.

Dietary changes are already underway in some countries. For example, in the UK meat consumption has declined in recent years and consumption of plant-based alternative foods has substantially increased (Alae-Carew *et al*. 2022). An analysis of the National Diet and Nutrition Survey showed statistically significant trends in the proportion of individuals reporting consumption of any plant-based alternative foods that increased from 6.7% in 2008–2011, to 13.1% in 2017–2019. Compared with 2008–2011, plant-based alternative food consumption rose by 115% in 2017–2019. Females were 46% more likely than males to report consumption of plant-based alternative food, with millennials (age 24–39 years) the most likely generation to report its consumption.

A failure to drastically reduce emissions from the global food system is likely to hamper meeting the Paris Agreement targets to limit average global temperature increase to 1.5 or 2 °C (Clark *et al*. 2020).

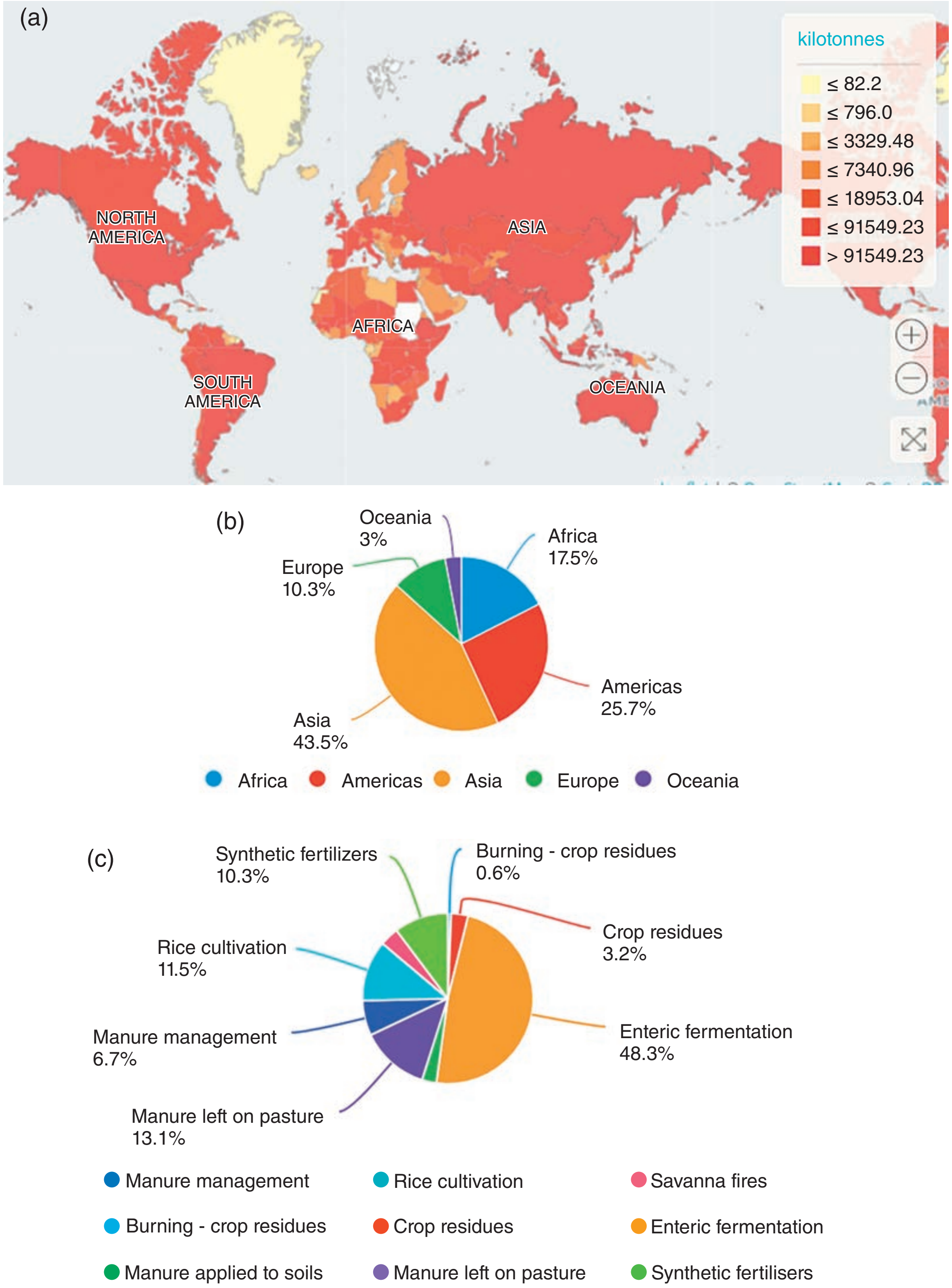


Figure 17 (a) Emissions CO_2 equivalent by country (IPCC Agriculture). (b) Share of emissions CO_2 equivalent by continent (IPCC Agriculture). (c) Share in world total (IPCC Agriculture). All data represent the average for 1990–2019 and are from FAO emissions totals: http://www.fao.org/faostat/en/#data/GT/visualize.

Current food systems are also largely failing to provide adequate nutrition for a large proportion of the global population. Malnutrition in all its forms, comprising undernutrition (itself comprising underweight, stunting (low height) and wasting (low weight adjusted for height)); overweight and obesity; and micronutrient deficiencies, is a challenge for all countries. Conflict, climate variability and extremes, and economic slowdowns and downturns, now exacerbated by the ongoing COVID-19 pandemic, are major drivers of food insecurity and malnutrition. These drivers continue to increase in both frequency and intensity, and are being experienced more frequently in combination, particularly by vulnerable populations.

National sustainability assessments of food systems and their response to climate change need to go beyond the impact within individual countries' national borders. For instance, the current EU adaptation strategy (European Commission 2018) focuses on the direct impacts of climate change on the EU territory only; however, Europe is heavily reliant on imports of products for animal feed, several tropical crops (such as coffee, bananas and cocoa) and commodities for processing (e.g. sugar and palm oil (EEA 2021)). EASAC (2019a) provides the examples of Switzerland and Finland, where the recent in-country reduction of the environmental impact of prevailing diets, rich in animal-sourced products, is largely offset by displacing the environmental costs of production to food and animal feed exporting countries. The blueprint for the new EU adaptation strategy includes reinforced global action for climate resilience as a priority area; however, no mention is made of the footprint of EU food systems and of the requirement to promote more sustainable diets and food consumption patterns in the continent, including a reduction in food waste, as part of the drive to increased sustainability (EC 2020). The displacement of environmental and social impacts through international trade from developed to developing countries is a global phenomenon that is not restricted to food and feed products (Wiedmann and Lenzen 2018).

At this time of increasing climate change impacts on ecosystems, recent analysis has confirmed the erosion of previous progress towards achieving Zero Hunger by 2030 (SDG 2) witnessed since 2016 (FAO *et al*. 2021). Close to 12% of the global population was severely food insecure in 2020, representing 928 million people, 148 million more than in 2019. Over half of the world's undernourished are found in Asia (418 million) and more than one-third in Africa (282 million). Moderate or severe food insecurity affects now about 30% of the global population, the incidence being 10% higher among women than men. Nearly one-third of women aged 15–49 years in 2019 were affected by anaemia, with no progress made since 2012 (FAO *et al*. 2021). LMICs account for nearly all the global burden of stunting, which affects about 22% of children under 5 years of age (149 million (FAO *et al*. 2021)), a problem identified by both AASSA and NASAC as significant in their regions (AASSA 2021; NASAC 2022). Wealthier countries are also affected: AASSA (2021) reports food insecurity affecting 5 million Australians in 2019, and another example is in the UK where COVID-19 has exacerbated socio-economic inequalities in access to food, impacting large segments of the population (Power *et al*. 2020). This changing behaviour also has consequences for LMICs: the UK, for example, is increasingly importing fruit and vegetables from climate-vulnerable countries (Scheelbeek *et al*. 2020) and this is likely to be the case for many other high-income countries.

Obesity is also increasing sharply in all countries, as the result of changes in the global food system which make less nutritious food cheaper and more accessible, and a decrease in physical activity as lifestyles become increasingly sedentary (Popkin *et al*. 2020a). EASAC (2019a) discussed this in the context of climate change. LMICs increasingly experience a double burden of malnutrition, where undernutrition and obesity occur simultaneously, both disproportionally affecting resource-poor individuals (see Swinburn *et al*. 2019; WHO 2019b; FAO *et al*. 2021). Unhealthy diets are the largest contributor to global morbidity and premature mortality, with diet-related chronic disease estimated to be responsible for 11 million premature deaths in 2017 alone (Afshin *et al*. 2019; Swinburn *et al*. 2019). Excess red meat consumption contributed to some 990,000 deaths in 2017, while in Africa a diet poor in fruit was responsible for the greatest proportion of deaths and disability-adjusted life years in the same year (Afshin *et al*. 2019). Obesity and impaired metabolic health are also important determinants of severe COVID-19, resulting in large increases in morbidity and mortality (Popkin *et al*. 2020b; Stefan *et al*. 2021).

The interconnectivity between undernutrition, obesity and climate change, and their devastating impacts on human health, have led to these collectively being referred to as the 'global syndemic': the synergy of health threats sharing common underlying societal drivers (Swinburn *et al*. 2019; Morgan and Fanzo 2020). A study assessing the interaction between food systems and climate change in Nigeria highlighted the importance of integrated interventions with multiple objectives to tackle the climate–nutrition–health syndemic, as opposed to siloed actions addressing individual components that may fail to achieve full benefit from win–win situations, or, worse still, have unintended negative effects on the food system as a whole (Morgan and Fanzo 2020).

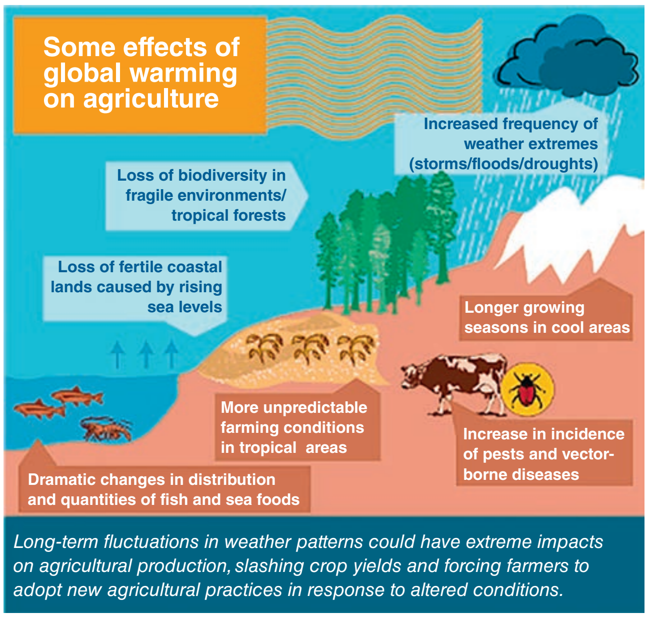


Figure 18 Overview of effects of climate change on agriculture in the Asia-Pacific region. See detailed country profiles in AASSA (2021). Although this figure, from AASSA (2021), draws on regional evidence, the issues are relevant worldwide and are discussed in the other regional reports. FAO. (1997). Some effects of global warming on agriculture. Retrieved from http://www.fao.org/News/FACTFILE/FF9721-E.HTM

3.9.2 Agriculture

Agricultural production, because of its reliance on climatic variables and on the use of natural resources (land and freshwater), is very sensitive to the impacts of climate change. The direct effects of climate change on production stem from rising atmospheric temperatures, changes in precipitation patterns and the increased incidence of extreme weather events (Figure 18). These effects are discussed in detail in the regional reports. Increasing atmospheric average temperatures will also make it increasingly hazardous for farmers to work outdoors for at least part of the year (Andrews *et al*. 2018; see also section 3.4.3) with consequences for declining worker productivity and increasing economic costs (Orlov *et al*. 2020, 2021). Increasing atmospheric concentrations of CO_2 also affect the nutritional value of crops (Dong *et al*. 2018; Ebi and Loladze 2019; Soares *et al*. 2019; Alae-Carew *et al*. 2020), leading to a reduction in protein, iron and zinc, potentially causing an additional 175 million people to be zinc deficient and an additional 122 million people to be protein deficient by 2050, assuming current population and CO_2 projections (Smith and Myers 2018).

Additional comprehensive discussion of current and future effects on agriculture is provided in IAP (2018) and in the updated material supplied by the four regional academy networks, together with a global Brief, to the UN Food Systems Summit Scientific Group[17] and in other assessments (in particular, IPCC 2019a). Because of the extensive discussion elsewhere, we have been comparatively succinct in dealing with agricultural productivity in the present report. Although it is difficult to summarise all crop risks (e.g. to cereal yield, fruit and vegetable nutritional content) from all causes (e.g. temperature, precipitation, extreme weather events, pests and diseases) in a composite image, Figure 19 portrays one summary from the global modelling literature.

[17] See https://www.interacademies.org/publication/iap-food-systems-summit-briefs.

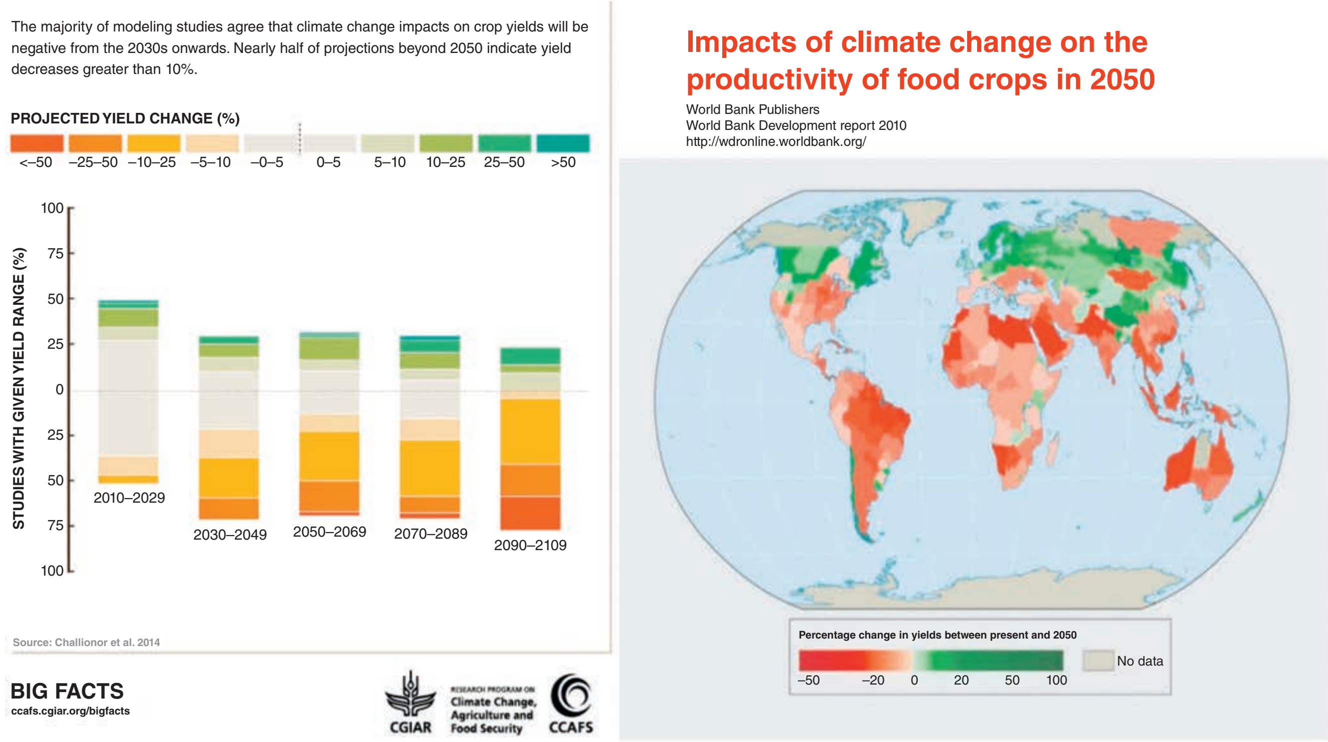


Figure 19 Projected impacts of climate change on agriculture, see CGIAR Research Program on Climate Change, Agriculture and Food Security: https:// cafs.cgiar.org/. Today, 3–40% of global crop yield is explained by climate-induced annual production fluctuations.

Climate change has already impacted crop productivity of the most important crops globally, including fruits and vegetables (Scheelbeek *et al.* 2018; Parajuli *et al.* 2019; Ray *et al.* 2019). Extreme weather events have been found to explain 18–43% of the global variance of crop yield anomalies caused more by temperature-related extremes than precipitation-related factors (Vogel *et al.* 2019). All of the IAP regional reports document negative impacts of climate change on agricultural productivity. In initial studies, global aggregate agricultural production had not been projected to decline before 2050, although suitable production zones will shift, annual yields will become more variable, and price volatility of agricultural commodities will increase (EEA 2021). For example, in the EU, crop productivity is expected to be most impacted in Southern Europe, initially compensated by an increased suitability for agricultural production in northern Europe, and by a shifting of the growing seasons into the winter (EASAC 2021b). However, using the new generation of climate and crop models (Jagermeyr *et al.* 2021), climate impacts on global agriculture emerge earlier. It is now projected that global maize crop yields will decline by almost a quarter by the end of the century and will not be offset by smaller increases in global wheat production, with poorer countries experiencing the sharpest declines in yields of their main staple crops.

Climate change is affecting the livelihoods of Indigenous Peoples who depend on the land for sustenance, since the loss of traditional foods as a result of declining biodiversity levels affects not only the nutritional status of communities, but also negatively impacts cultural continuity, language, mental health outcomes, self-determination and social cohesion (IANAS 2022).

Increases in atmospheric average temperatures and changes in precipitation patterns are also impacting the incidence and distribution of agricultural pests and pathogens. Yield losses to insects in wheat, rice and maize production have been estimated to increase 10–25% per 1 °C of warming. Resource-poor farmers and households whose diet is very dependent on staple crops will be most affected (Deutsch *et al*. 2018). NASAC (2022) described the recent (2019–2020) outbreak of desert locust infestations in East Africa. Changing climatic conditions favoured insect reproduction and the rapid generation and spread of swarms, causing severe damage to agricultural and pastoral land. The recent crisis affected 23 countries with a combined population of 1 billion people, and 53 million hectares have been treated since the start of the upsurge[18]. The outbreak compounded the impacts on food security and livelihoods in the region of severe floods and the COVID-19 pandemic (Kassegn and Endris 2021).

The need to control more frequent outbreaks of insect pests is leading to a greater use of pesticides. For example, demand in Kenya (a major importer of pesticides from China and the EU) rose from 6,400 tonnes to 15,600 tonnes between 2015 and 2018. Increased pesticide use is damaging both to health and to the environment as well as increasing the risk of generating pesticide resistance (Deutsch *et al*. 2018; EASAC 2019a; NASAC 2022). Unfortunately, the demand for effective insect control options is encouraging the export of pesticides banned within the EU, because of their high toxicity, to developing countries with weaker pesticide risk regulations (Sarkar *et al*. 2021). The capacity to regulate the sale of illegal, unapproved, counterfeit and unlabelled pesticides in rural markets in developing countries is very limited (Sarkar *et al*. 2021).

Insect damage is one of the factors affecting the establishment of fungal pathogens and the accumulation of mycotoxins in crops, a problem that impacts the health, food security and trade sectors (Perrone *et al*. 2020). Aflatoxins are highly toxic and carcinogenic mycotoxins that currently contaminate up to a quarter of the global food supply, particularly in developing countries. Climate change is predicted to result in an expansion of the regions exposed to food aflatoxins, to include also Southern Europe (Assunção *et al*. 2018). All regions have identified a rise of the threat of food pathogens and associated food safety vulnerabilities (comprising both foodborne infections and toxins) driven by climate change as an important health concern. The development of improved surveillance and integration of plant, animal and human surveillance systems (One Health) are important priorities for the preservation of food safety.

Climate change will also impact the number and distribution of beneficial insects (pollinators and biological control agents), with important consequences for agricultural production and food security. The impact of climate change on individual species cannot be considered in isolation, because of the indirect effects arising from complex interspecies interactions within ecosystems and food webs (Hamann *et al*. 2021; IANAS 2022). Climate change-induced reductions in crop yield could be exacerbated by losses of pollinators.

The impacts of climatic and non-climatic shocks on agricultural productivity could exacerbate problems of inadequate nutrition and the increased incidence of disease in vulnerable populations, because they further compromise the ability of poor households to produce and purchase food (Fanzo *et al*. 2018). Most studies on the risks in agriculture focus on production, while those related to markets, institutions, finances and personal risks have received less attention. Currently, risks are typically considered in isolation so a key research priority is understanding the impact of multiple, simultaneous types of risk, and how they can limit the effectiveness of adaptation planning for climate change (IPCC 2019a; Komarek *et al*. 2020); see chapter 5.

3.9.3 Livestock

Climate change is already impacting the livestock sector, through direct effects of higher temperatures, climate variability and increased incidence of extreme events

[18] http://www.fao.org/emergencies/crisis/desertlocust/en/.

on animal productivity and health, and impairing the capacity of animals to mount a response to disease (Ezenwa *et al*. 2020). A changing climate will continue to affect the epidemiology of infectious diseases and change the distribution of animal pathogens and their vectors. Issues related to the role of the livestock sector in global nutrition, its contribution to climate change and mitigation options are discussed in chapter 4.

3.9.4 Fisheries

Fisheries and aquaculture play important roles for food supply, food security and income generation. Seafood is a very important source of nutrients for many countries, including SIDS where it contributes 50% of total animal protein consumed (Farmery *et al*. 2021). Coastal resources are also crucial for the almost 30 million coastal Indigenous Peoples, whose per capita seafood intake is nearly four times the global average, and 15 times more per capita than of non-Indigenous Peoples in their respective countries (Cisneros-Montemayor *et al*. 2016). Climate change-induced changes in ocean temperatures and acidity are projected to impact the distribution of marine species, affecting the yield of fisheries, catch composition and revenue, which in turn will negatively influence a wide range of socio-economic factors, including food security, livelihoods and public health, with low-income countries being particularly vulnerable (Lam *et al*. 2016; Blasiak *et al*. 2017). Other impacts are also relevant: climate change is projected to increase the risk of ciguatera fish poisoning in some regions: for example, the abundance and diversity of *Gambierdiscus* and *Fukuyoa* species (marine dinoflagellates that produce ciguatoxins) in the Gulf of Mexico and along the US southeast Atlantic coast are likely to increase as a result of warmer water (Kibler *et al*. 2015; IPCC 2019b).

3.10 Migration

A bibliometric review of the literature up to 2019 (Milán-García *et al*. 2021) notes the accumulating evidence for climate change as one contributing factor to forced displacement, although some of the evidence has been controversial. Migration is currently, and will increasingly be, influenced by environmental degradation and climate change. The number of migrants will increase substantially by the end of the century without significant further action on climate change. The International Organization for Migration provides detailed assessments of migration in response to environment and climate change (https://www.iom.int/migration-environment-and-climate-change): for example, the publications on internal displacement (IOM 2020a) and on most vulnerable countries (IOM 2020b).

Climate change-induced increases in migration can occur through a variety of different environmental, social and political pathways (Schutte *et al*. 2018; Anon. 2019; Hoffmann *et al*. 2020; McMichael 2020) including population displacement by heat, sea level rise, extreme weather events and exacerbation of food and water security concerns. Assessment of the globally aggregated data suggests that climate change is a more important driver than the combined effects of income and political freedom in the originating countries (Wesselbaum and Aburn 2019).

The migration responses to climate change are diverse (e.g. Schwerdtle *et al*. 2018) and there are complex connections between migration, climate change and health. For example, there is evidence that some migrants (whether for social, economic, political or demographic reasons) move into new locations of high climate risk, such as moving from Nepal to Qatar where occupational exposure to high temperatures was associated with increased cardiovascular mortality in the migrants (McMichael 2020). An equivalent concern was raised in India (Hari *et al*. 2021) about inter-state migration within the country when vulnerable migrants lack the necessary resources to respond to climate change risks in megacities.

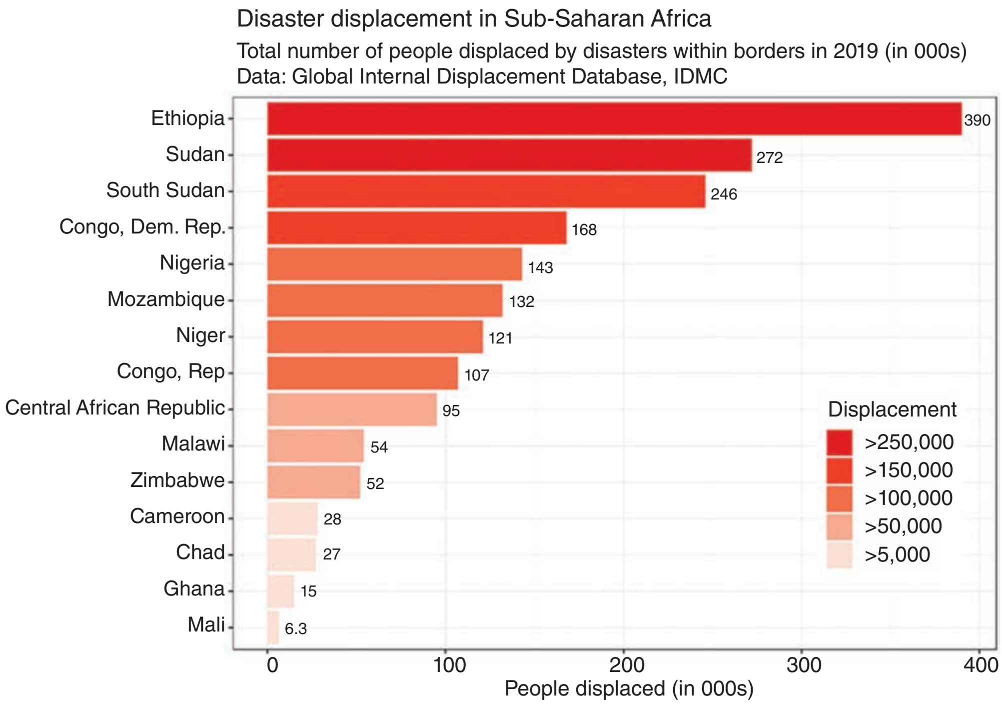


Figure 20 Internal population displacement, from NASAC (2022). N.B.: this assessment aggregates displacement for all disaster-associated reasons and further work would be needed to assess relative contribution by climate change.

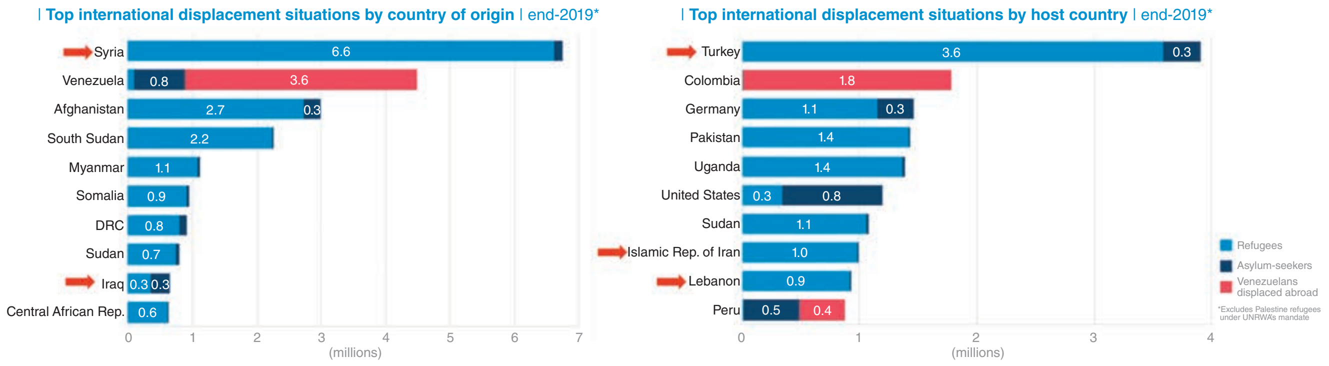
In addition to regional issues arising from migration across borders, a study from the World Bank (Rigaud *et al*. 2018) on Sub-Saharan Africa, South Asia and Latin America concludes that climate change will push tens of millions of people to migrate within their own countries by 2050 (up to 3% of the population) and then accelerate further (see also IOM 2020a); see Figure 20, reproduced from NASAC (2022). However, it must also be emphasised that many displaced people migrate for reasons other than climate change. These trends for the poorest and most vulnerable, together with the population changes from migration across boundaries, will have major implications for the adequacy of social support and health systems.

The following discussion focuses on issues for forced migration (recognising that there are multiple drivers) taken from the regional reports and related literature.

In Africa, the Sahel is likely to continue to be a major area of concern in terms of migration (NASAC 2022): the five Sahel countries of Burkina Faso, Chad, Mali, Mauritania and Niger are experiencing some of the worst climate change impacts, with increased temperatures, more frequent droughts, prolonged heatwaves, soil degradation, increased flooding and reduced agricultural productivity and food security[19].

EASAC (2019a) discussed the evidence that, in Syria, a reduction in national capacity to deliver food and nutrition security, in consequence of drought, was one factor leading to civil unrest, conflict and forced migration, both internally and to other countries including its neighbours in the EU. However, as also discussed by EASAC (2019a), there are methodological challenges in evaluating the links between climate change, conflict and migration, and controversies remain (Mech *et al*. 2019) although it is likely that intensifying climate

[19] Mbiyozo A, 'What does the climate refugees judgement mean for Africans?': https://issafrica.org/iss-today/what-does-the-climate-refugees-judgment-mean-for-africans



Taken from: The United Nations Refugee Agency (UNHCR). 2020. *Global treands: forced displacement in 2019.* UNHCR Global Data Service, Copenhagen, Denmark

Figure 21 Forced migration in the Middle East–Eastern Mediterranean region. From EASAC et al. (2021).

change will increase further risks of conflict and migration. The EMME-CCI Health Task Force (see footnote 8) agreed that, while the association between climate and socio-political factors is complex, it is apparent that efforts at reducing the direct effects of climate change may also help reduce socio-political tension. Countries in the Middle East–North Africa region have some of the largest share of forced migration anywhere in the world, both in terms of country of origin (e.g. Syria, Iraq) and as recipient countries (e.g. Turkey, Lebanon, Iran) (see Figure 21); however, again, it must be emphasised that climate change is only one of the contributors.

A report by the International Committee of the Red Cross (ICRC 2020) discussed how countries that are most vulnerable to climate change are also much troubled by conflict, for example Afghanistan, Democratic Republic of Congo, Mali and Yemen, stimulating internal displacement as well as migration across borders. For example, in Mali, social unrest coupled with a lack of grazing due to floods led to problems for farmers. Nomadic farmers, worried about travelling with their flocks because of attacks by armed groups, moved to gather in areas close to water sources, which created tensions with settled farmers and fishers. Similar experience of community tensions in other Sahel countries, where herders shifted migration routes in response to climate change in order to seek grazing land to avoid livestock losses, was reviewed by NASAC (2022). In particular, the case study on criminal activity in Nigeria documented clashes between herdsmen in search of pasture because of the loss of grazing owing variously to flooding, drought and high temperatures, and farmers/settlers in the north–central region of the country.

The AASSA (2021) report noted that countries most affected recently by migration included the Philippines, India and China, as well as Turkey. Although other countries in the region, for example Armenia and the Russian Far East, have experienced significant migratory flows for economic reasons, the influence of climate change as a driver has been less studied. Other evidence, discussed by EASAC (2019a), supports the association between climate change and migration. For example, an analysis of weather variations in 103 countries for the period 2000–2014 (Missirian and Schlenker 2017) found that when temperatures in the growing season of source countries deviated from the moderate optimum, asylum applications to the EU increased in a nonlinear fashion.

However, the impacts on health are less easily quantified. One significant factor is the living conditions that are allowed for migrants. In the EU, the institutional response to migrants, including provision of health services, has been suboptimal, failing to address specific vulnerabilities (Puchner *et al*. 2018) and often leading to unmet health needs both for locals and for migrants. The housing of refugees often in densely packed, makeshift dwellings, which lack appropriate access to

Table 1 Health concerns for migrants worldwide. The evidence summarised here is taken from the Middle East and extended Mediterranean region (see footnote 8) but it is also relevant globally

Type of health effect (with multiple interactions between categories)	Major concerns
Direct	Injuries and trauma during displacement or in host country dwellings. Poor living conditions associated with respiratory, gastro-intestinal and skin conditions, malnutrition and continuing vulnerability to climate extremes.
Infectious diseases	The environment for diarrhoeal, vector-borne and parasitic diseases created by poor living conditions is compounded by lack of immunity if not previously vaccinated. HIV (human immunodeficiency virus) is an increasing problem but social stigma and threat of forcible deportation create barriers to testing and reporting in displaced populations.
Non-communicable diseases	Problems are compounded by lack of access to medicines, language and other barriers to obtaining health care. High prevalence of non-communicable diseases can present significant economic and logistic problems for host countries. Stress associated with forced migration can increase unhealthy behaviours, for example tobacco use, physical inactivity, poor diet.
Sexual and reproductive health	Including sexual violence and exploitation, associated with elevated risks of sexually transmitted diseases and pregnancy (and increased maternal and neonatal harm).
Mental health	High prevalence (15–50% of refugees), for example post-traumatic stress disorder, depression and anxiety, because of origins and processes of forced migration, aggravated by separation from usual social and material environments and by scarcity of psychological support. Children are highly susceptible and effects are long-lasting, possibly even trans-generational.

basic resources including medical care, render this group extremely vulnerable to the health impacts of climate change.

Drought and resultant food shortages and loss of livelihood (e.g. for coffee growers) in the Central American countries of Guatemala, El Salvador, Honduras and Nicaragua has been a major factor in driving migration northwards (Masters 2019). Despite the broad implications of the climate crisis for clinical practice in North America (Salas 2020), there are worries (Sabasteanski 2020) that the USA to date has not pursued meaningful action for health system preparedness, either for internal migrants or those received from other countries.

Strengthened national health systems must be both climate-resilient and migrant-inclusive but restrictive policies at potential destinations (including criminalisation of asylum-seekers) exacerbates migrant vulnerabilities (Anon. 2019). The health of displaced populations is subject to multiple direct and indirect effects (Table 1, summarised from EASAC *et al.* (2021)).

4 Mitigation policy options

Summary of emerging points in chapter 4

Mitigation opportunities to protect and promote human health under climate change are discussed, highlighting the importance of valuing mitigation solutions based on their health co-benefits. A greater integration of mitigation and adaptation interventions is also required, and effective mitigation would make the most cost-effective adaptation measures more feasible. The availability of good baseline and evaluation data is important for identifying and implementing appropriate interventions, and regional evidence should be shared to identify and spur good practice. Mitigation efforts should be led by the countries responsible for high levels of greenhouse gas (GHG) emissions, while low-emitting countries should prioritise low-carbon development strategies. Effective mitigation will not be possible without international partnerships through trade and investment, research, technology cooperation, finance flows and capacity development.

Parties to the Paris Agreement must include GHG targets in their nationally determined contributions (NDCs). Although health is explicitly included in a proportion of the NDCs submitted, consideration of the issues often lacks detail; interventions are not properly aligned with the reduction of emissions and with other complementary policies, and proposals are inadequate in their ambition. Prioritising health outcomes in NDCs will require (1) adequate monitoring of the health co-benefits; (2) coherence between climate change and health policies; (3) comprehensive action to deliver net-zero emission climate-resilient health systems.

Health equity must be an explicit policy goal of achieving net-zero emissions. Key areas of interventions are described:

1. *Reducing air pollution. The decarbonisation of energy sources by transitioning from burning fossil fuels to clean renewable energy is likely to have the biggest impact on health. Coal combustion continues to be the largest contributor to emissions from the energy sector. The reduction of short-lived climate pollutants (including black carbon, tropospheric ozone and methane) should also be priorities through actions by a range of sectors including agriculture, transport and energy. Interventions need to be properly designed and integrated to capture potential synergies for attaining multiple Sustainable Development Goals (SDGs) and avoiding unintentional negative consequences. These include conflicts in the use of resources, the worsening of socio-economic inequalities, and the exclusion of vulnerable populations. Fossil fuel subsidies, which result in unfair market competition with renewable energy sources, should be removed. Good practices for reducing pollution include public engagement to promote the uptake of policies; consideration of transboundary issues; involving local community in policy design and implementation; clarifying inadvertent consequences and trade-offs; quantifying returns for investments; reducing household air pollution in areas with strong reliance on the burning of biomass for cooking; and innovative monitoring technologies.*

2. *Nature-based solutions. The conservation, restoration and improved land management of forests, wetlands, grasslands, and agricultural lands could provide approximately one-third of the cost-effective climate mitigation. However, constraints to implementation need to be carefully considered and addressed to realise this potential.*

3 *Sustainable cities and the built environment. Urban activities contribute approximately [illegible]% of energy-related GHG emissions. Health benefits are derived from the provision of accessible public transport options; promotion of physical activity, zero emission vehicles; improved and equitable access to green spaces; and improvements in household insulation and ventilation and building design. Pathways to impact are complex as socio-economic factors increase the vulnerability of poorer populations. Interventions to create more sustainable cities also require coordination across multiple sectors and supply chains, and the examination of the potential for inadvertent consequences.*

4. *Sustainable food systems. Healthy, sustainable diets are a requirement for meeting emission reduction targets and for health improvements. In countries where agriculture is one of the main economic activities, the sector could provide many opportunities for adaptation-mitigation synergies, as well as health, socio-economic and environmental co-benefits. Agricultural emissions are dominated by the livestock sector, responsible for over half of emissions, and responsible for large increases in the atmospheric concentration of methane and nitrous oxide, two very powerful GHGs. Multiple interventions to reduce the environmental footprint of food systems are described. Since currently healthy diets are unaffordable to about 3 billion people, proposed mitigation measures need to avoid worsening the food and nutrition security status of resource-poor populations. While excess meat consumption is both a global environmental and health concern, the livestock sector is critical for the livelihood and nutrition of rural populations and vulnerable groups, in particular children, in many parts of the world. Therefore, the development of appropriate policies in the sector requires the careful consideration of trade-offs, for example between food, animal feed and biofuel production. An integrated, whole-systems approach that considers potential implications for attaining the SDGs and provides increased social and spatial granularity in policies and recommendations is required, with a focus on the implications for vulnerable populations. Sustainable consumption patterns and waste reduction are key to reducing emissions.*

5 *Sustainable health sector. Health-care systems contribute directly and indirectly to GHG emissions due to the provision of care, energy use, transport and related to the provision of hospital meals, pharmaceuticals, medical devices and other hospital equipment. This contribution has increased in recent years; however, there is a drive to reduce the sector's current carbon footprint. Evidence suggests that in many cases high-quality outcomes for patients could be achieved with considerably reduced emissions. Interventions must also address the factors driving demand for health care, which requires integrated policy support across multiple sectors.*

4.1 Defining solutions

Although in chapter 3 it was possible to cite only a proportion of the evidence from the regional reports and other sources, the intention was to be sufficiently representative to be confident in the relevance of shared solutions for all regions. There are many similarities between regions although there are also significant differences in scope and scale. What then are the solutions to protect and promote human health under climate change?

The IPCC defines climate change adaptation as the '*adjustment in natural or human systems in response to actual or expected climate 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*'. An adaptation action might be taken proactively to reduce harm in advance of an impact or reactively in response to a perceived or real health risk (Haines and Frumkin 2021). Adaptation becomes more feasible when there is decisive mitigation and there will be limits to adaptation beyond which adverse impacts cannot be prevented;for ex ample when heat stress becomes severe enough to prevent physical labour outdoors even in the shade, subsistence farmers will be unable to maintain their livelihoods (see also section 5.2.5). Identification and comparison of mitigation and adaptation policy options require good scientific data, and the implementation and monitoring of interventions require good baseline data. Both mitigation and adaptation approaches are needed and increasingly they should be integrated with the aim of achieving resilient, net-zero emission societies[20]. Furthermore, while both approaches require more research in various respects, as detailed in the following sections, we emphasise that there is enough evidence to act now.

Our focus in this report is not on the selection of mitigation actions or policy instruments (such as carbon taxes and negative emission technologies; Appendix 4) in general[21] but rather the role of health co-benefits in helping to prioritise mitigation options. Guidelines for modelling and reporting health effects of climate change mitigation actions are being developed (Hess *et al*. 2020). Health equity must be an explicit policy goal of achieving net-zero emissions[22] and an evaluation in the UK (Munro *et al.* 2020) identifies four key areas for action in pursuit of health equity: minimising air pollution;bui lding energy-efficient homes; promoting sustainable and healthy food; and prioritising active and safe transport. These UK recommendations are relevant to other countries when assessing mitigation priorities (see later).

Effective mitigation reduces climate risk to a much lower level than continued high emissions of GHGs and makes the most cost-effective adaptation measures more feasible (EASAC 2019a). However, much of the current debate on strategies is based on principles and modelling rather than empirical evidence. In this chapter we address mitigation options in terms of potential health co-benefits;i n the next chapter we focus on adaptation options. Appendix 4 provides a general discussion of available policy instruments.

Employment is a core driver of human health outcomes and the transition to net-zero GHG emissions requires large-scale changes in the number and nature of jobs across economies. Countries need to develop a long-term vision for ‘green’ jobs, taking account of well-being and occupational health issues. Employment and health considerations were not a primary focus within the scope of the IAP project but are discussed elsewhere (Royal Society and Academy of Medical Sciences (2021) for UK and global evidence; Romanello *et al*. (2021) for global assessment of changes).

4.2 Nationally determined contributions

Parties to the Paris Agreement are required to include both a mitigation and an adaptation contribution in their nationally determined contributions (NDCs) and, in this context,

[20] Although evaluation of geoengineering was not within the scope of the present project, exploratory research in this area attempting to reduce CO_2 levels must also take into account potential effects on human health (NASEM 2021). There may be inadvertent consequences of the various geoengineering options for reflecting sunlight back into space, reducing the trapping of thermal radiation, or increasing carbon storage in terrestrial or marine sinks. For example: (1) *ocean fertilisation* for carbon capture might trigger massive phytoplankton blooms, driving zooplankton increases and the potential for cholera outbreaks (EASAC 2019a);(2) *marine cloud brightening*, which alters the planet's water cycle, may have complex impacts mediated by water stress (Parkes *et al*. 2015) on different crops in different regions that may possibly undermine food and nutrition security in some at-risk populations.

[21] Project drawdown (www.drawdown.org) provides a resource that highlights climate solution objectives to reduce GHGs for a wide range of sectors, including electricity generation;food, agri culture and landscape;i ndustry;trans portation;bui ldings;l and sinks;c oastal and ocean sinks; engineered sinks;and heal th and education. Systematic review of the global literature (Gao *et al*. 2018) reveals that actions in the different sectors often, although not always, bring co-benefits for public health.

[22] See, for example, the commitment to equity as a key value incorporated in the Pathfinder Initiative on good practice for a net-zero society: https://www.lshtm.ac.uk/research/centres-projects-groups/pathfinder-initiative.

it is important to take account of the large opportunities for public health gains (WHO 2019a;s ee also Howard *et al*. (2020) for further information on NDCs and health implications). Policies proposed to mitigate climate change provide global health benefits through reduced impacts but can also lead to localised improvements in the health of those populations undertaking the mitigation (Haines *et al.* 2009; Milner *et al*. 2020). Although the current use of the term 'co-benefits' for these health gains assumes that the primary purpose of policy action is climate change mitigation, it is now essential for policy-makers to consider the potential multiple benefits for health, and other outcomes, when designing mitigation and implementing actions (Royal Society and Academy of Medical Sciences 2021).

Modelling scenarios analysing the potential health co-benefits of NDCs to meet the Paris Agreement for selected countries in Africa, Asia, the Americas and Europe (Hamilton *et al*. 2021) project reductions of premature deaths related to modulation of air pollution, diet and physical activity. For example, adoption in these countries of a current sustainable pathway scenario (i.e. existing NDCs and related pathways) could result in reductions by 2040 of 1.18 million (air pollution-related), 5.86 million (diet-related) and 1.15 million (physical activity-related). Adopting more ambitious health-in-all-climate-policies could result in further reductions of 462,000 (air pollution), 572,000 (diet) and 943,000 (physical activity) deaths (see Hamilton *et al*. (2021) for further details).

Identifying health protection and improvement as priority outcomes in the NDCs requires the following (WHO 2020):

1. Continuing commitment to measuring and monitoring the health co-benefits.

2. Enabling policy coherence between climate change and health policy processes.

3. Ensuring that health actions in the NDCs are comprehensive enough to build climate-resilient health systems.

It is noteworthy that, for example in the EU, health co-benefits are now explicitly considered when developing climate change mitigation policies but it appears that their influence on final policy outcomes has, so far, been limited (Workman *et al*. 2019). However, the momentum is increasing. The 'Healthy NDCs Scorecard' of the Global Climate and Health Alliance highlights those countries now incorporating health into NDCs (https://climateandhealthalliance.org/initiatives/healthy-ndcs/ndc-scorecards/) and individual examples are discussed in detail in the *Lancet* Countdown (Romanello *et al*. 2021; Watts *et al*. 2021). IANAS (2022) provide a detailed analysis in the Americas. Confirming the scorecard assessment, a recently published analysis (Dasandi *et al*. 2021) of health engagement in NDCs in 185 countries demonstrated that poorer and climate-vulnerable countries that contribute least to climate change are more likely to engage with health in their NDCs (Figure 22).

However, in many cases, the level of NDC detail on health is rather superficial and not clearly aligned with achieving emissions reduction commitments, or it may represent an inadequate climate ambition.

Those who are currently the highest GHG emitters bear a major responsibility in contributing to the projected changes in short-term warming (up to 2030) and extreme hot years (Beusch *et al*. 2022), as well as to previous changes. As a general principle, those countries that are the biggest GHG emitters should lead mitigation efforts, recognising that there may be major differences in their sectoral contributions to GHG emissions and it may be challenging to quantify effects and select the location and scale of solutions. Countries that are not currently high GHG emitters should pursue low-carbon development pathways: the ambition of LMICs to pursue a long-term low emissions development strategy (while also addressing other national objectives) requires international partnership through trade and

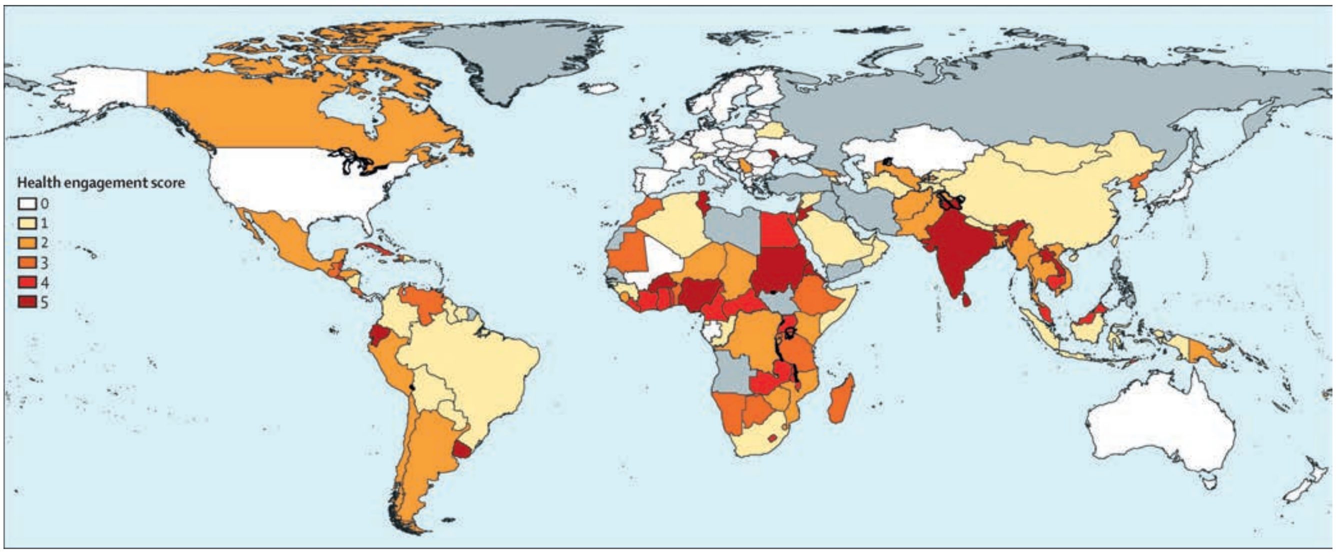


Figure 22 Health engagement score by country: evaluation of how health is incorporated in NDCs. Grey indicates countries that are not parties to the Paris Agreement or have not submitted an NDC as of January 2020. A health engagement score of 0 indicates no health reference in NDC;5 s highest score. See Dasandi et al. (2021) for further details of scoring system. Countries that did not mention health in their NDCs were clustered in higher-income regions. Variation in health engagement was found to be greater than for other climate-related issues and reflects wider differences in countries' approaches to NDCs.

investment, research, technology cooperation, finance flows and capacity development[23].

In the following sections we discuss examples from the regional reports and related literature.

4.3 Reducing anthropogenic air pollution through use of clean, renewable energy sources

To reiterate, policies to promote access to non-polluting and sustainable sources of energy have great potential to improve public health and to mitigate climate disruption (Haines *et al*. 2007). Measures to mitigate emissions of GHGs, together with short-lived climate pollutants, can contribute to attaining multiple SDGs (Haines *et al*. 2017). However, while mitigation solutions can benefit multiple SDGs, poorly designed ones may incur harm, for example by generating resource conflicts or excluding communities (Honegger *et al*. 2021). Some have expressed concern (e.g. Markkanen and Anger-Kraavi 2019) that as decarbonisation goals are increased to meet the Paris Agreement targets, so does the potential for adverse social outcomes. Further discussion of issues for the SDGs is presented in section 6.6. In addition to the large health benefits that occur from reducing air pollution co-emitted with carbon dioxide there are also large health benefits from reducing the emissions of short-lived climate pollutants (black carbon and tropospheric ozone) (Shindell *et al*. 2017). Methane reduction brings health benefits by virtue of its action as an ozone precursor (see also UNEP 2021a,b).

Impacts from air pollution and the implications for tackling climate change were discussed in detail in section 3.3. Although everyone is exposed to air pollution, the elderly and the young tend to be disproportionately affected worldwide (section 3.3 and Yin *et al*. 2021). Given the general trends in population ageing, the mortality/morbidity burden and economic costs of poor health are expected to continue rising. Although interventions could in principle be targeted to vulnerable groups, for example advice to reduce outdoor exposure on a highly polluted day, more upstream air quality management approaches are more likely to be effective, not least because there is no safe

[23] For example, Indonesia's LEDS 2021, as discussed in SDG news, 10 August.

Figure 23 The 10 most important short-term steps to limit warming to 1.5 °C. Climate Action Tracker (2016)[24]. Copyright 2021 by Climate Analytics and New Climate Institute. All rights reserved. N.B.: even if the 1.5 °C target is not achieved (see chapter 1) it is still important to implement policies to get as close as possible to it.

level of air pollution and many deaths occur in populations with relatively low levels of air pollution (section 3.3 and Yin *et al*. 2021).

Figure 23 summarises some of the short-term priorities for achieving the climate change target of 1.5 °C that are also likely to bring co-benefits for health including from reduced air pollution. Coal combustion continues to be the largest contributor to emissions from the energy sector and, generally, decarbonisation of energy production by transitioning from burning fossil fuels to clean renewable energy sources is likely to have the biggest impact. It is important to note, however, that although in some countries (e.g. USA) there has been a transition away from coal in the energy mix, tackling the adverse health impacts of wood and biomass combustion is still a challenge (Buonocore *et al*. 2021).

A combination of increased public transport, reduced dependence on private cars and encouragement of modes of increased active travel (cycling and walking) is likely to be a cost-effective strategy for decarbonising road transport sector particularly in urban settings (Jensen *et al*. 2013). In high-income countries most of the health benefits in the transport sector come from increased physical activity but in locations where transport-related air pollution is a major problem, reduced health burdens from air pollution plays a larger role (Woodcock *et al*. 2009). Increasing energy efficiency through improved ventilation control and insulation in residential and non-residential buildings is also a priority. These and other (Figure 23) priorities will be exemplified subsequently. Broader discussion of the policy issues for increasing energy efficiency as a key part of tackling climate change can be found in the work of major international bodies[25] and see Appendix 4.

Alongside aggressive fossil fuel reductions, natural climate solutions, for example conservation, restoration and improved land management, that increase carbon storage

[24] https://climateactiontracker.org/global/cat-thermometer.

[25] For example, International Energy Agency 2019 'Multiple benefits of energy efficiency': https://www.iea.org/reports/multiple-benefits-of-energy-efficiency;W orld Economic Forum (Florence, T) 2019 'Energy efficiency and the fight against climate change': https://www.weforum.org/agenda/2019/09/why-investing-in-renewable-energy-is-good-for-the-environment-and-society;I PCC (Lee, H and Birol, F) 2020 'Energy is at the heart of the solution to the climate challenge': https://www.ipcc.ch/2020/07/31/energy-climatechallenge/

and/or avoid GHG emissions from global forests[26], wetlands, grasslands and agricultural lands may be able to provide approximately one-third of the cost-effective climate mitigation to stabilise warming (below 2 °C (Griscom *et al.* 2017)); see also section 6. However, although reforestation is a promising nature-based climate solution, a study on degraded land in Southeast Asia (Zheng *et al.* 2020) notes various financial, land use and operational constraints are such that only a small part (0.3–18%) of the potential may be currently achievable. Such constraints are not unsurmountable, but this evidence emphasises the need for careful planning to attain effective landscape-scale reforestation.

The health co-benefits of reducing combustion of fossil fuels and agricultural emissions to mitigate climate change were emphasised in a collective statement by individual academies of science and medicine (Academies of Science and Medicine 2019) and in all the project regional reports. Table 2 bring together some of the strategic points raised in the regional reports to illustrate the breadth of issues that need to be considered globally in mitigation (some of these diverse issues are explored further in chapter 6). Further detail on specific sectors is discussed subsequently. Although broader discussion of energy system transformations is beyond the scope of this project, we emphasise the importance of taking account of health issues when considering those policies, for example for bioenergy and carbon capture and sequestration technologies, because there may be inadvertent consequences on health (see discussion of net-zero GHG strategies in California (Wang *et al.* 2020)). The report from the Royal Society and Academy of Medical Sciences (2021) discussed the health impacts of various non-fossil fuel technologies and, while agreeing that displacing fossil fuel power sources will have significant health benefits, emphasised the need for life-cycle assessments to understand and prevent possible adverse impacts and avoid 'lock-in' effects when investing in large-scale infrastructure.

The cost of renewable energy has fallen rapidly and, in many cases, is now competitive with fossil fuels, but in many countries fossil fuel subsidies result in unfair competition (Guerriero *et al.* 2020). Indonesia and Iran have acted to eliminate these subsidies and use the savings to finance health coverage and other social priorities (Gupta *et al.* 2015). This should be an important policy objective particularly for other countries who still support high fuel subsidies but have no universal health coverage scheme. It is equally important to ensure that carbon pricing mechanisms, aiming to curtail emissions of CO_2, act in a progressive, redistributive way (Appendix 4). This is particularly important given that climate change aggravates existing inequalities: a carbon tax could be used, for example to fund public transportation or energy efficiency measures and to help fund universal health coverage (Cuevas and Haines 2016). A recent modelling of policy options (Buchs *et al.* 2021) emphasises the importance of taking environmental and energy poverty impacts of compensations for unfair distributional impacts of climate policies into account at the design stage. Such compensation measures can achieve higher emission reductions and reduce energy poverty if they involve an expansion of the provision of green goods and services, and if everyone is given fair access to these.

4.4 Sustainable cities and the built environment

About 75% of energy-related GHG emissions arise from urban activities. In addition to pollution control, health benefits can be obtained, variously, by providing accessible public transport and infrastructure to encourage physical activity, by reducing noise levels, facilitating safe access to green space, and improving housing insulation and

[26] See IUCN (2021) 'Forests and climate change': https://iucn.org/resources/issues-briefs/forests-and-climate-change.

Table 2 Linking science advice and policy in tackling anthropogenic sources of air pollution: using regional evidence to share and implement good practice. The specific examples are taken from the regional assessments but are relevant worldwide and further discussion of the issues can be found in all the regional reports.

Region (see regional reports for details)	Factors to take into account in developing science-based strategies for mitigation action: addressing barriers and supporting facilitation
Europe	*Transboundary issues*, for example effects on neighbours of coal combustion in the western Balkans (Matkovic Puljic *et al.* 2019). *Health implications in policy design for replacement fuels*, for example modelling of potential pollutants in renewable sources (UK; Williams *et al.* 2018). *Public engagement to promote policy uptake,* for example providing evidence for near-term health value encourages mitigation actions (German National Academy of Sciences Leopoldina 2015). *Updating NDCs*, for example North Macedonia's revision to NDC now covers additional sectors (such as agriculture and land use), analyses synergies/trade-offs for all SDGs and uses CaRBonH tool (WHO Europe 2018a) to quantify physical health and economic consequences.
Asia-Pacific	*Increasing energy efficiency, decreasing GHGs* in countries throughout the region (e.g. China (Cai *et al.* 2020) for carbon capture and storage). *Promoting renewable energy*, for example fossil fuel substitution by ethanol from sugar cane in Nepal (Silveira and Khatiwada 2010), which might also bring local health benefits if less sugar is consumed although there may also be considerations for competition for land use. *Community forests for mitigation and adaptation*, for example Nepal (Pandey *et al.* 2016). *Engaging local community in policy design and implementation*, for example Lebanon and Spain case study (Cyprus workshop report (EASAC *et al.* 2021)). *Developing regional science-based solutions*, for example to cover transboundary pollution (Climate and Clean Air Coalition of UNEP 2019). *Clarifying inadvertent consequences and trade-offs* for example Pavogoda Solar Park in India is world's largest with potential health benefits from reduced pollution and increased local employment but concern about high metal waste toxicity, and large-scale replacement of crops by glass has raised local temperature.
Americas	*Evaluating return on investment*, for example one estimate in the USA suggests US$30 in benefits has been returned for every US$ invested in air pollution control since 1970 (Landrigan *et al.* 2018). *Assessing negative environmental and health implications of every stage in fossil fuel use*, for example coal mining, processing, combustion and disposal of waste products. Although countries in the region (e.g. USA, Chile, Guatemala) still rely heavily on coal, investments in capacity are declining (e.g. USA, Brazil). *Aligning policies for climate change and air pollution*, for example incomplete evidence from region-specific air pollution monitoring should not be a barrier for action to reduce emissions and exposures and recognising combined problem of anthropogenic drivers of air pollution and climate change. *Collaboration on research in environmental health*, for example GEOHealthHub in Peru (www.geohealthperu.org) with local and US universities, covering issues for indoor and outdoor air pollution, clarifying opportunities for research partnerships to inform locally specific solutions.
Africa	*Including efforts to tackle household air pollution*: in Africa more than 600,000 annual deaths are attributable to these sources. Household solid fuel burning is a major cause of mortality worldwide from ambient air pollution (Chowdhury *et al.* 2022). *Adoption of innovative energy technologies*, for example rapid uptake of renewable energy approaches to avoid lock-in to previous generation (fossil fuel or biomass) approaches, and potential for increased competitiveness. *Innovative technology approaches to monitoring*, for example crowdfunding and citizen science initiatives for reducing exposure to air pollution. Community action for climate change litigation is also becoming more common as an approach to tackle air pollution[27].

[27] For example, in South Africa, see Levetan 'Climate change litigation is hotting up': https://www.ensafrica.com/news/detail/4411/climate-change-litigation-is-hotting-up, 22 June 2021. See chapter 6 for a general discussion of recent climate litigation activity.

ventilation to increase efficiency of heating/cooling systems and reduce the adverse effects of moulds (Milner *et al*. 2020). However, mapping of research on urban case studies finds that cities with the highest mitigation relevance are systematically underrepresented (Lamb *et al*. 2019). Moreover, by using methods from computational linguistics to build a systematic overview of research on transport, buildings, waste management and urban form (Lamb *et al*. 2018), it appears that not all relevant evidence is captured, for example, in IPCC literature assessment. That is, the epistemic core of mitigation-focused urban literature is centred on urban form and emissions accounting, while extensive research into demand-side options remains overlooked, including congestion and parking policies, active travel, energy efficiency and waste management.

Greater ambition in setting goals is critically important. Deficiencies in generating and using the evidence base also emphasise the need for more studies in vulnerable, often low-income and ethnic minority communities who may have highest exposure to heat and other hazards (e.g. Murage *et al*. 2020; Hsu *et al*. 2021;and s ee Table 3). In addition, new forms of evidence synthesis are needed to bring together different strands of urban research for policy relevance (Acuto *et al*. 2018; Lin *et al*. 2021). Broadly, urban health requires a transdisciplinary science action plan to deal with complexity and systemic risks (ISC *et al.* 2021). Increasing the pace and scale of urban transformation requires evidence-based changes in political, social and economic systems (Crane *et al*. 2021), community heat action plans (Jay *et al*. 2021) and clean air zones (Vardoulakis *et al*. 2018).

Pathways for impact are again complex. Climate change and air pollution in urban areas interact with other social determinants such that action to improve health may be attributable to effects on several different pathways. For example, the effect of green space as a modifier of mortality associated with heat (Sera *et al*. 2019) might be mediated variously by local cooling effects, by reduction in air pollution or by improved physical and mental health. However, even if the actual mechanisms require further clarification, it is important to act on the association between green space and reduced heat-related mortality. Some of the issues arising from case studies discussed in the regional reports are listed in Table 3, chosen because of their possible generalisability. Although more research may be needed to resolve discrepancies, recommended actions are increasingly substantiated by a robust evidence base. For example, systematic review of the global literature (Mueller *et al*. 2015) concludes that active transport can provide substantial health benefits irrespective of geographical context (although active travel becomes more difficult in tropical cities). Much of the projected benefit comes from increased physical activity rather than reduced air pollution (but see also section 4.3 and Woodcock *et al*. (2009)). The report from the Royal Society and Academy of Medical Sciences (2021) provides detailed assessment of issues (for the UK) for active travel, low-emission road vehicles and public transport options in cities as well as for shipping and aviation. Equitable access to transport options is essential to avoid exacerbation of social exclusion and optimise participation.

Individual city initiatives are also now often part of collective activity to raise ambitions worldwide, for example the Global Covenant of Mayors and the C40 Fossil-Fuel-Streets Declaration (discussed in EASAC 2019a)[28]. However, the benefits of urban electrification, as a strategy to move towards low-carbon energy systems, will only be realised if the demands of the built environment, institutional

[28] Awareness of collective activity is now aided by the streamlining of local and regional government reporting on climate action: https://data.cdp.net/.

Table 3 Focus on urban opportunities and challenges. As for Table 2, the specific examples are taken from the regional assessments but are relevant worldwide and further discussion of the issues can be found in all the regional reports.

Region (see regional reports for details)	Examples of good practice and factors to be taken into account in developing science-based strategies for mitigation action for sustainable cities
Africa	*Recognising that vulnerability is a combination of exposure and local socio-economic factors*, for example Cote d'Ivoire case study (NASAC 2022) on greening strategies in urban planning.
Americas	*Tackling inequity of marginalised communities experiencing greatest urban risk*, for example historical housing policies in USA ('redlined' neighbourhoods) may be directly responsible for disproportionate exposure to current heat events. Redlined areas still receive less investment in managing risks (see also discussion of urban inequity by Chakraborty *et al*. (2019); Witze (2021)). The Mexico City case study (IANAS 2022) discusses the importance of integrating equity considerations (reducing poverty) in planning strategies. *Waste as a resource from sustainable services*, for example reducing emissions when implementing new, more efficient, water and sanitation services, such as to capture methane (CH_4) from wastewater treatment plants[29]. *Active transport*, for example INSPIRES 2020[30] on health and economic benefits of bicycle lanes in 15 Latin American countries. See also Herrick de Sa *et al*. (2017) for health impact modelling of different travel patterns in São Paulo, Brazil.
Asia-Pacific	*Active transport*, for example New Zealand modelling study on replacing vehicle trips by walking and cycling (Mizdrak *et al*. 2019). Cycling initiatives have been introduced elsewhere in the region, for example Indonesia. *Nature-based solutions,* for example Clean Green Pakistan Index (Pakistan country report) city tree planting as part of national initiative. *Sustainable city transport,* for example Delhi metro and Klang Valley Mass Rapid Transport System, Malaysia. *Sustainable buildings,* for example New Zealand (country report) retrofitting for improved insulation and health. *Integrated climate-resilient urban planning,* for example Israel where urban mitigation action is part of Disaster Risk Reduction Strategy for climate change (EASAC *et al*. 2021).
Europe	*Meeting current standards,* for example study of data for 25 EU cities estimated that life expectancy could be increased by nearly 2 years if long-term $PM_{2.5}$ concentration was reduced to WHO guidelines in most polluted cities (WHO Europe 2017). *Added value impacts*, for example comparison of EU and Chinese cities (Sabel *et al*. 2016) found that specific policy impacts were often rather limited, depending on quality of current environmental standards, possibly countered by high emissions continuing from industry surrounding cities. *Identifying trade-offs,* for example Austrian city study (Wolkinger *et al*. 2018) showed substantial health gains from increased physical activity and improved air quality as a result of active travel policies, but potential negative effects on employment and economic growth. *Maximising value of green space,* for example Barcelona superblock model (Mueller *et al*. 2020) to provide safe access, especially when physical improvement to green space is coupled with social engagement and participant programmes (WHO Europe 2017). *Integrating sectoral assessments,* for example see also EASAC (2021b), EASAC (2019b) (decarbonising transport) and EASAC (2021a) (decarbonising the built environment) for additional evaluation, Fisk (2015) for health co-benefits of modifying buildings, and Royal Society and Academy of Medical Sciences (2021) for discussion of housing and other indoor environments.

[29] For further information on the Global Methane Initiative 'Municipal wastewater methane: reducing emissions, advancing recovery and use priorities' see https://www.globalmethane.org/documents/ww_fs_eng.pdf.
[30] INSPIRES 2020 Ciclovias recreativas y salud: en Latin America, ISGLOBAS and Colorado State University: www.isglobal.org/-/inspires.

constraints and the carbon intensity of energy sources are addressed (Pihl *et al*. 2021).

Specific actions to create sustainable cities require coordination across multiple sectors and supply chains, and the examination of the potential for inadvertent consequences. For example, global concrete production contributes significantly to $PM_{2.5}$, PM_{10} and NO_x (Miller and Moore 2020) and it is vital to reduce this contribution while avoiding inadvertently increasingly local air pollution from other building materials. Another example is the inadvertent consequence of increasing green space in cities, to improve air quality and microclimates (Szaraz 2014) if the plants augment pollen exposure or introduce new allergens (EASAC 2019a) or increase emission of biogenic volatile organic compounds. Increasing biodiversity in cities might also present an increased risk of disease vectors and pathogens (see Lohmus and Balbus 2015). Increased green space could create more urban sprawl, increasing transport-related GHG emissions. Urban planning strategies that provide essential services within a short walking or cycling distance of homes can help reduce unnecessary private car use.

4.5 Sustainable food systems

The global burden of non-communicable diseases is predicted to worsen in consequence of the effects of climate change on food systems. The policy goal is to reduce malnutrition in all its forms while also reducing the contribution that food systems make to total GHG emissions. Agriculture is expected to provide many opportunities for adaptation-mitigation synergies, as well as health, socio-economic and environmental co-benefits (Suckall *et al*. 2015). An analysis of 162 intended NDCs established that 148 countries have included agriculture in their mitigation contributions, and the sector featured prominently in African NDCs (84%; FAO 2016).

4.5.1 Methane and nitrous oxide are particular concerns

Agricultural GHG emissions are dominated by methane production from the livestock sector, which accounts for over half of the global total, with ruminants responsible for over 68% of agri culture emissions (as enteric fermentation plus manure; Figure 17c and FAO (2021)). In 2018, the level of methane in the atmosphere reached 2.6 times higher than pre-industrial values (Saunois *et al*. 2020). The livestock sector is estimated to emit 65 teragrams[31] of nitrogen (nitrous oxides and ammonia) annually, equivalent to one-third of current human-induced N_2O emissions and sufficient to meet the planetary boundary for nitrogen. Of that amount, 66% is attributed to Asia (Uwizeye *et al*. 2020). Emissions of nitrous oxide, due to the use of synthetic nitrogen fertilisers and the treatment of manure, has increased quickly in the past five decades (Tian *et al*. 2020). The recent growth in N_2O emissions exceeds some of the highest projected emission scenarios, highlighting the urgency of mitigating N_2O emissions. The need for an intergovernmental coordination mechanism on nitrogen policies has been recognised in the 2019 United Nations Environment Assembly resolution on sustainable nitrogen management.

Methane and nitrous oxide have an effect on global warming about 25 and 300 times higher than carbon dioxide, respectively (comparing 'pound for pound' over a 100-year period)[32]. Methane emissions contribute to the production of ozone, stratospheric water and carbon dioxide, although methane's lifespan in the atmosphere is shorter than carbon dioxide (Shindell *et al*. 2012; Myhre *et al*. 2013; Saunois *et al*. 2020). A reduction in methane emissions would result therefore in a relatively rapid stabilisation or reduction of its atmospheric concentration and its radiative forcing. For this reason, reducing methane emissions is considered an effective option for a relatively rapid (in the order of decades)

[31] 1 teragram = 10^{12} grams.
[32] https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

climate change mitigation, although eventual peak warming depends primarily on the level of CO_2 emissions (Shindell *et al*. 2012; Nisbet *et al*. 2020).

4.5.2 Selecting and implementing mitigation actions in food systems

Potential mitigation actions, which must be carefully designed and adjusted to local circumstances (Frank *et al*. 2017), include the following:

- Shortening food supply chains (IANAS 2022).
- Reducing the burning of crop stubble, for example in India, a practice that contributes to the emission of GHGs, pollutes the air and deteriorates soil health, eventually compromising the productivity of agricultural lands (Abdurrahman *et al*. 2020; AASSA 2021).
- Improving other agronomic practices and reducing waste: this includes regulating industry to curb excessive use of inputs and to limit the production and sale of animal products linked to deforestation and other negative impacts in the production, processing and distribution steps.
- Increasing consumption of predominantly plant-based diets (Jarmul *et al*. 2020) as part of rebalancing consumption. This could include the use of taxes for 'worst products' in terms of carbon and biodiversity costs for populations at risk of overconsumption. Disincentives must be accompanied by nutrition programmes that increase consumption of nutritious foods in sectors of the population that currently are unable to do so, including the provision of school meals (see also Royal Society and Academy of Medical Sciences (2021) for discussion of ways to support behaviour change and examples of policy instruments, such as dietary guidelines).

Significant agronomic change is possible. For example, a background paper prepared in 2020 for the Subsidiary Body for Scientific and Technological Advice (SBSTA) of UN FCCC COP[33] explored agronomic case studies (in South America, Asia, Africa and Europe) for managing nitrogen pollution-GHGs and improving manure management to decrease GHGs and benefit the environment. A second example (AASSA 2021) discusses how puddle-transplanted rice is a significant source of CH_4 emissions that can be reduced by the alternative of direct seeded rice cultivation. However, the latter may have problems with increasing risk of pathogen infection and high weed infestation. Alternate wetting and drying of rice paddies is another strategy that reduces methane emissions and may yield co-benefits[34]. The effect of this approach on malaria transmission is currently under investigation. A third example is provided by the recent implementation in China of a policy to promote potato as a staple food. Research on life-cycle inventories of China's staple crops (Liu *et al*. 2021) finds that, in general, potato has lower GHG emissions than other staple crops (rice, maize, wheat) on a per-calorie basis. The potato policy has the potential to reduce carbon impacts of agriculture but may have inadvertent consequences for global burden shifting, for example if reduced domestic rice production led to increased rice imports (Liu *et al*. 2021), as well as the nutritional and health implications of substituting staple crops.

If climate change mitigation policies are carelessly or improperly designed then there may be negative trade-offs with food security. For example, increasing bioenergy production may increase land rent costs with adverse consequences for farmers (Fujimori *et al*. 2019), compounded if biofuel crops are grown in competition with food crops (Hasegawa *et al*. 2018; Muscat *et al*. (2020) for a systematic review of food-feed-fuel competition; and Haines (2021) for the most

[33] SBSTA 52nd Session 2020 'Improved nutrient use and manure management towards sustainable and resilient agricultural systems' FCCC/SB/2020/1.

[34] https://ccafs.cgiar.org/news/five-non-mitigation-benefits-alternate-wetting-and-drying, 2019.

recent assessment). Coordinated mitigation action to counter the climate change effects on food systems is necessary to avoid unintended negative effects.

4.5.3 Issues for livestock farming

A reduction in meat consumption (in particular red meat) in high-consuming populations would have clear co-benefits for human health and for the environment (IAP 2018; Willett *et al*. 2019; Watts *et al*. 2021). The opportunities and challenges for doing this are discussed in detail in the regional reports. By 2050, climate change is projected to lead to per-person reductions of 3.2% (standard deviation 0.4%) in global food availability, 4.0% (0.7%) in fruit and vegetable consumption and 0.7% (0.1%) in red meat consumption. These changes will be associated with estimated 529,000 climate-related deaths worldwide (95% confidence interval 314,000–736,000). Healthier diets, with greater consumption of vegetables, fruit, nuts and seeds, but less meat and lower overall calorie content, would result in a reduction of deaths in all regions of the world in the year 2050 (Springmann *et al*. 2016). However, this study also identified underweight as the primary cause of diet-related deaths associated with climate change in Africa and it is important to consider the particular needs of vulnerable groups. A study in Tanzania, the country with the highest undernutrition burden of Eastern and Southern Africa, identified poor infant and young child feeding practices as the main causes for undernutrition, and established an association between consumption of animal-sourced foods and reduced stunting among children (see Khamis *et al*. 2019). In view of the nutritious qualities of animal-sourced foods, low consumption by low-income populations, in particular children, is a serious public health concern, especially when the prevailing diet lacks nutritional diversity and is over reliant on a handful of starchy crops. Proposals for dietary change must be culturally sensitive and adapted to circumstances. For example, some vulnerable groups consume traditional sustainable and low emissions diets that are meat-based, for example Inuit Indigenous Peoples in the Arctic (IANAS 2022), although these practices are now being undermined by climate change that is affecting the habitats of traditionally hunted animals.

As previously noted, diets rich in animal-based products are responsible for a large proportion of food systems' GHG emissions (Figure 17 and FAO 2021). However, livestock also plays a very important role in terms of the livelihood and nutrition of over 800 million people globally, in particular vulnerable populations (see Smith *et al*. 2013; Molina-Flores *et al*. 2020; Mehrabi *et al*. 2021). The Southern African Development Community, for example, is home to 345 million people, of which 31% are severely food insecure, 8% malnourished and 50% live on less than US$ per day. The region is also home to 64 million cattle, and three-quarters of the animals are kept in smallholder farming systems (Mapiye *et al*. 2020). In South Africa, the consumption of livestock products by the rich and poor often differs by tenfold (Mapiye *et al*. 2020).

Livestock is also a vital rural livelihood option in arid and semi-arid regions of the world, which include nearly 40% of the land surface of East Africa that is unsuitable for crop production (Sutie *et al*. 2005). Most of the meat and milk (60% and 75%, respectively) and a significant proportion of key staple crops in developing countries are produced in mixed crop–livestock farming systems (Herrero *et al*. 2013; Thornton and Herrero 2015; Ghahramani and Bowran 2018), which are critical for food security. It is worth noting that increasing the proportion of livestock production in mixed farming systems has been proposed as a climate change adaptation and risk avoidance strategy both in industrialised and in developing countries, because livestock gross margins are less sensitive to changes in climate than crops (Descheemaeker *et al*. 2018; Ghahramani *et al*. 2020). In the context of African countries, this increase should be achieved by an improvement in the productivity of animals rather than an increase in their numbers (Descheemaeker *et al*. 2018). Although

Africa accounts for the smallest regional share of total anthropogenic GHG emissions (Figure 17), about half of this contribution is linked to agriculture and is experiencing the fastest increase of all regions (Tongwane and Moeletsi 2018). This acceleration reflects increases in food demand driven by population growth, changing lifestyles (in particular, a high demand for animal-sourced foods) and increasing African agricultural exports.

The positive interactions between the livestock sector and the sustainable development of vulnerable populations are frequently overlooked by studies that focus on the environmental impacts of excessive animal-sourced food consumption in more affluent countries and by wealthier sectors of the population. Livestock affects at least 58% (10 out of the 17) of the SDG goals and 16% (28 out of the 169) of the SDGs targets (Molina-Flores *et al*. 2020; Mehrabi *et al*. 2021). However, the varying functions of the livestock sector make decision-making complex, and therefore the formulation of appropriate policies in the sector requires the careful consideration of trade-offs. This necessitates an integrated, whole-systems approach that considers potential implications for attaining the SDGs and provides increased social and spatial granularity in policies and recommendations;and a foc us on vulnerable populations (IAP 2018; NASAC 2018; Adesogan *et al*. 2020; Salm *et al*. 2021). Agricultural mitigation solutions should aim at decoupling increases in productivity from increases in emissions (i.e. reducing emission intensities);pr eserving the environment; promoting more sustainable consumption patterns and reducing waste in all the components of food systems (Wiebe *et al*. 2019). It is also essential to consider barriers to implementation of proposed mitigation solutions and to strengthen the financial support and social protection mechanisms for vulnerable populations. Some mitigation solutions in the livestock sector will be associated with increased costs to both producers and consumers (Rust 2019). As noted by Wiebe *et al*. (2019), the mitigation of climate change needs to be considered as a public global good, and therefore it must be adequately financed.

At the same time, climate change is already impacting the livestock sector, through direct effects of higher temperatures, climate variability and increased incidence of extreme weather events on animal productivity and health. Furthermore, it impairs the capacity of animals to mount a response to infectious diseases (section 3.9.3 and Ezenwa *et al*. 2020). A changing climate will continue to affect the epidemiology of infectious diseases such as Rift Valley fever and change the distribution of animal pathogens and their vectors. Diseases can also increase methane outputs associated with animal production, resulting in a potentially vicious climate–disease cycle (Ezenwa *et al*. 2020). Quantifying the effects of pathogens on methane emissions will be important for predicting the contribution of endemic and newly emerging livestock diseases to future changes in global climate.

The widespread adoption of existing but not widely used technologies and practices in the livestock sector that increase productivity would result in significant global reductions in emissions (Gerber *et al*. 2013; Mottet *et al*. 2017). Research priorities for increasing the sustainability of livestock production include the development of baselines, and the improvement in measurement and attribution methodologies, as well as in animal nutrition and health (Mehrabi *et al*. 2021). In terms of livestock, research on small ruminants, poultry and fish to improve productivity and decrease the environmental footprint of their production is also needed (e.g. Kosgey and Okeyo 2007; Khobondo *et al*. 2015; Mmanda *et al*. 2020); see further discussion in chapter 5.

Overall, there are significant opportunities for mitigation bringing health co-benefits in agriculture. However, currently, healthy diets are unaffordable for around 3 billion people, owing to the high cost of nutritious food coupled with persistent high levels of income inequality (FAO *et al*. 2021). It is imperative to avoid climate change mitigation policies and interventions that risk increasing food and nutrition insecurity in vulnerable populations (Canales Holzeis *et al* 2019; Fujimori *et al* 2019). Unfortunately, in proposing recommendations for policy solutions, issues for accessibility and affordability of proposed healthy and sustainable diets are often overlooked (Hirvonen *et al*. 2020). The potential role of insects and other food sources (including those local food sources that had been neglected as a result of globalisation) for sustainable and healthy diets has been receiving increasing attention (Parodi *et al*. 2018;s ee also IAP 2018). The topic of alternative meat sources, including insects, is currently being examined by EASAC (report expected to be published in early 2023).

4.6 Sustainable health sector

The health-care sector is itself rarely included in decarbonisation public policy discussions even though its current carbon footprint worldwide is equivalent to 4.6% of country net emissions, a rise of 6% from 2016 (Health Care Without Harm 2019; Salas *et al*. 2020; Lenzen *et al*. 2020; Watts *et al*. 2021). Nonetheless, there is a momentum within the health and social-care sectors for hospitals and other organisations to measure and publish their carbon footprint together with their plans for reducing it to net-zero as rapidly as possible (Smith *et al*. 2020b). As progressive goals for this sector cannot be considered in isolation from other sectors, the health sector should now play a more prominent part in integrated strategies for decarbonisation (EASAC and FEAM 2021). However, efforts to reduce GHGs must not occur at the expense of health-care quality or equity. Mitigating the health-care footprint requires interventions both to the health-care system and to the factors driving demand for health-care: that is, strategies to reduce the incidence and severity of disease, thereby decreasing the amount and intensity of care required and received, if the supply of health services matches demand (MacNeill *et al*. 2021). Prioritising mitigation within the health sector will also bring local and near-term benefits to health, for example through greener hospitals, improved diets and new models of care (EASAC and FEAM 2021).

There is increasing concern worldwide about the health-care sector contributing to GHG emissions and, thereby, damaging health (see, for example, the World Bank (2017) and the US experience (Eckelman and Sherman 2018; Eckelman *et al*. 2020). Data on country per capita GHG emissions associated with health care and their variation as a function of time, affluence and the proportion of national economic output spent on health care have been presented in the *Lancet* Countdown initiative (Watts *et al*. 2021). Plotting per capita GHG emissions versus health outcomes reveals similar health-care access and quality levels are attained with vastly different emissions profiles, suggesting that in many cases high-quality outcomes for patients could be achieved with considerably reduced emissions. However, definitive conclusions also need to take account of the relative effects of national policies on the social and environmental determinants of health through action in a range of sectors.

While differing in scale, each country's health-care sector directly and indirectly releases GHGs when delivering care, and when procuring products, services and technologies from a carbon-intensive supply chain. Detailed analysis (Health Care Without Harm 2019; Salas *et al*. 2020) estimated that of the sector's worldwide footprint approximately 17% can be accounted for by health-care facilities and vehicles, 12% from purchased energy sources and the remaining 71% from carbon embodied in the health-care supply chain, such as for food, pharmaceuticals, medical devices and other hospital equipment. Approximately one-quarter of all health-care emissions are generated outside the country where the health care is delivered. The main contributions are illustrated by the assessment of the National Health Service (NHS) in England (Figure 24). Systems change in the sector requires institutions to adopt a culture that values sustainability, tracks GHG emissions and shares good practice for change at local national and international levels.

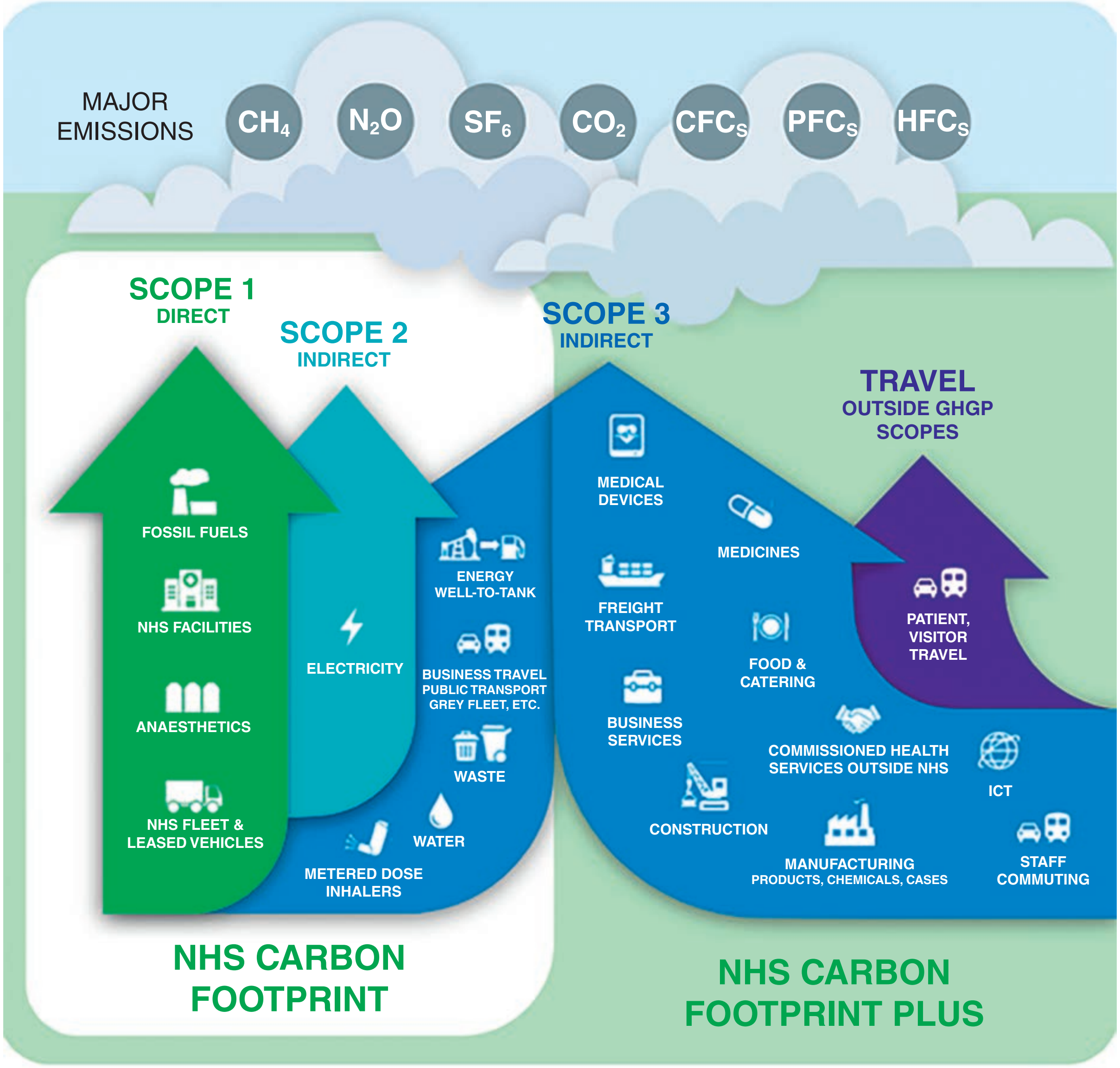


Figure 24 NHS England analysis of sources of major GHG emissions (Tennison et al. 2021). Based on quantification of emissions within Scopes 1 (direct emissions from health-care facilities), 2 (emissions from purchased energy) and 3 (other emissions) of the Greenhouse Gas Protocol as well as patient and visitor emissions, 1990-2019. Of the 2019 –footprint, 62% came from the supply chain, 24% from direct delivery of care, 10% from staff commute and patient and visitors travel, and 4% from private health and care services commissioned by the NHS.

Other case studies at the institutional level, for example for hospital construction, employee travel and supply chain interventions, have been documented (Salas *et al*. 2020). National-level activities in other countries (based on the regional project reports and other sources) are exemplified in Box 7[35]. Focusing on opportunities within the health-care sector also enables health professionals to take a stronger lead (Atwoli *et al*. 2021) in promoting action for all sectors. Health ministers worldwide are being encouraged to declare their ambitions both to decarbonise and to improve the resilience of their health-care sectors, as an initiative of the UK Presidency of COP26 together with the United Nations Framework Convention on Climate Change (UNFCCC) Climate Champions Team. At the time of COP26, 52 countries had signed up to this

[35] Other activities, for example in Germany and Western Australia, are discussed by Watts *et al*. (2021).

Bx 7 Examples of decarbonisation potential for the health-care sector

Worldwide. Examples are presented in the comprehensive platform supported by Health Care Without Harm (https://noharm-global.org).

Country examples include the following:

Argentina. The first country to include health-care decarbonisation in its NDC[37].

Indonesia. The AASSA (2021) country report describes the national project to introduce telemedicine to improve health care in remote areas. In addition to the possible health benefits, the decreased requirement to transport patients to central facilities is expected to decrease GHGs.

Romania. The Romanian academy (EASAC *et al*. 2021) highlighted that although there is a national building renovation plan, systematic rehabilitation of health system buildings has not been discussed at government level and advised that there is a role for health professionals in leading discussion about the opportunities and driving action.

USA. The National Academy of Medicine initiative of 'Climate Change and Health Opportunity Grants' is assessing ways to reduce the carbon footprint of the US health-care sector[38], including identification and implementation of mitigation strategies, as well as to educate health-care providers about the potential benefits of improving health-care practices and infrastructure[39].

WHO initiative[36] on resilient health systems but only 14 had agreed a deadline by which to achieve decarbonisation. There is need for more work to define what 'resilient' means in this context, what is the timetable, and how implementation will be monitored.

The European academies of science and medicine advised that the priorities for action should include interventions at both primary care level and in secondary and tertiary care, sustainable procurement, and innovative models of care (see EASAC and FEAM (2021) for detailed discussion). However, although the health sector can do much for itself, more can be done with a supportive public policy environment. Some of these opportunities are listed in Table 4.

Table 4 Transformational changes for decarbonisation: European examples of linking health sectoral action and integrated policy support across multiple sectors

Focus for health sector	EU policy relevance
Greater EU-level ambitions in health policy	European Health Union
Supply chains:	
PPE and medical equipment	Sustainable public procurement criteria
Pharmaceuticals	Pharmaceutical strategy and HERA initiative
Food and catering	Farm-to-Fork strategy
Greening health-care estate, for example hospital buildings	Renovation Wave (European Green Deal) (Haines and Scheelbeek 2020)
New models of health care, for example telemedicine	Digital health strategy

[36] WHO COP26 Health Programme. Overview of initiatives and commitments on climate change and health. https://www.who.int/initiatives/cop26-health-programme.
[37] News item on https://noharm-global.org, 24 February 2021.
[38] https://nam.edu/programs/climate-change-and-human-health/.
[39] Health sector leadership for climate change action is now being emphasised in many other countries, for example India: https://healthyenergyinitiativeindia.wordpress.com/.

Specific policy development can be aligned with other strategies for the circular economy and bioeconomy. The supply chain example of food supplies to health-care facilities illustrates both the opportunity to reduce GHG emissions in sustainable food systems, such as by increasing plant-based dietary consumption, and the accompanying benefits to health through reduction in non-communicable diseases (see section 4.5). Although there has been a long but not always successful history of trying to improve nutrition in hospital meals, there is now momentum to deliver change for patients and cultivate longer-term dietary change habits after discharge from hospital. The examples presented in Table 4 are discussed in detail by EASAC and FEAM 2021.

5 Adaptation policy options

Summary of emerging points in chapter 5

Many countries have developed national adaptation plans (NAPs), and establishing linkages with nationally determined contributions (NDCs) is important to support integrated mitigation and adaptation interventions, increase accountability and avoid duplication of governance structures. The development of climate-resilient health systems also needs to be supported by the development of a national health and climate change strategy. While several countries have identified climate-related health risks and started to implement early-warning systems, the focus is narrow and mostly pertains to heat-related impacts and infectious disease risks. Concerns remain about the low level of political commitment and lack of ambition in developing responses;l imited allocation of human and financial resources;poor l inkages with the Sustainable Development Goals (SDGs); lack of prioritisation; poor use of evidence to inform policy-making;l ow level of implementation. We emphasise that there is enough evidence to act now with adaptation solutions.

The health services in 8c ountries are now connected with the corresponding national meteorological services to assist in health adaptation planning, including through heat–health early-warning systems. Cross-sectoral action is essential to realise potential for adaptation, integrating interventions on health infrastructure, urban planning, housing and building design, nature-based solutions, early-warning systems, policy and management, and perception and behaviour. Adaptation plans also have to be tailored to the specific circumstances of target communities. Solutions that benefit human health, the environment and social equity should be prioritised.

Measuring the impact of adaptation interventions is complex because of the absence of recognised attribution metrics and the lack of consensus on what adaptation success entails. Although health adaptation initiatives are increasing, evidence for their success remains mixed. Poor design of interventions and inadequate monitoring can result in maladaptation practices that worsen the problem they seek to address, and reinforce, redistribute or create new sources of vulnerability. Common problems include a weak understanding of the context; poor definition of how successful outcomes are defined;i nequitable stakeholder participation in design and implementation of the intervention, in particular vulnerable populations;and the retrofitting of adaptation measure into existing development agendas.

Limits to adaptation can be physical (such as the ones derived from geographical characteristics of habitable areas, for example low-lying islands and drying of rivers), behavioural, political or financial, with their relative contribution being dependent on the local circumstances.

Currently, premature deaths due to increased heat exposure can be partly addressed by providing appropriate infrastructure and adequate policies. Heat adaptation approaches focus on both the short- and longer-term and include technological, behavioural, institutional, economic and societal interventions. Options for adaptation include heat–health warning systems;green s tructures and infrastructure;s caling up for sustainable cities;i mproving occupational health, in particular in the agricultural sector;and addres sing inequity and poverty. Care must be given to avoid negative consequences of adaptation solutions, for example the use of air conditioning to lower indoor temperatures contributes to the emission of greenhouse gases (GHGs), reinforcing the importance of integrated adaptation-mitigation solutions.

Adaptation interventions related to wildfires include clear and consistent public advice to identify, manage and treat health impacts, including targeted information and plans for vulnerable groups. Policy action is needed across different scales – local, national and regional – to counter cross-border pollution threats from wildfires and to reduce demand for the commodities whose production drives fire-induced land clearance, such as beef, soybean, palm oil and biofuels.

Adaptation to flooding also requires cross-sectoral interventions. Interventions include improved urban planning, building of coastal defences (including river barrages), and the relocation of health facilities away from locations at risk of flooding. Responses should include nature-based solutions (wetland and mangrove restoration) as well as the physical engineering measures, shifting from reactive responses to better preparedness, and taking care to avoid negative inadvertent consequences.

Improved surveillance of infectious diseases together with early-warning systems can minimise impacts to health and help sustain economic activities, as brought sharply into focus by the ongoing pandemic. Efforts to prevent the climate-related spread of vector-borne infectious diseases require reducing the environmental risk of exposure, and individual preventive behaviours to reduce human–vector contact based on vector and disease surveillance. Examples of relevant interventions and strategic research priorities are reviewed.

The development of more sustainable food systems requires integration between multiple sectors and policy objectives. Governments should play a greater role in promoting healthier and more sustainable diets through the development of guidelines, food labelling standards that include environmental sustainability as well as nutritional content, and incentives to promote consumption of healthy, sustainable dietary choices. Policies must protect vulnerable groups and populations and avoid increasing poverty and socio-economic inequity, important drivers of food insecurity. Adaptation and mitigation interventions for both the production and demand sides in food systems need to be integrated, and solutions identified as having co-benefits for health and development should be prioritised. Adaptation approaches for food systems described include developing climate services with the direct involvement of the communities targeted, and improving the capacity to act of the information shared; prioritising production and preservation of nutritious and climate-resilient crops;i ncreasing the nutritional value of crops;enhanc ing farm management practices for a better use of natural resources (water and soil nutrients and neglected local crops);and i mproving post-harvest handling and food preservation practices to minimise waste. Interventions in the livestock sector should aim to increase productivity while reducing emissions. Priorities comprise breeding for improved resistance to environmental stresses and diseases;and i mproving animal nutrition. Opportunities for innovation and advances in the biosciences need to build on and be embedded within agroecological and other sustainable agricultural approaches to transformative, sustainable, food systems. Regulatory systems need to be science-based, flexible and proportionate, considering not only possible risks but also the cost of non-adoption. The lack of regulatory coherence in gene editing is discussed as a specific example.

Regional policy for transboundary cooperation to address the health impacts of climate change is important since threats typically transcend national borders (e.g. pollution and unsustainable use of resources). Furthermore, unilateral national actions can also have negative effects in the region or other parts of the world. One example is the shifting of environmental unsustainability from importing to exporting countries through trade. Regional policy for transboundary cooperation is also important to make best use of shared resources and the available evidence base, and to determine trade-offs and set priorities.

5.1 Introduction to national adaptation strategies and plans

The adoption of the 2030 Agenda for Sustainable Development (introducing the SDGs) has been followed by many countries developing a national adaptation plan (NAP). There is significant opportunity for countries to create linkages between NAPs and NDCs which should help to support integrated mitigation and adaptation actions, build political accountability and avoid duplication in governance structures (GIZ 2017). Examples of content and objectives in NAPs or related national strategies, and the current status of planning, are presented in the AASSA (2021) report for many countries in the region.

The WHO (2019b, 2021b) reports on tracking global progress on health and climate change found that an increasing number of countries reported having a national health and climate change strategy/plan (although not necessarily identified as a formal component of a NAP) and regarded it as a key tool in promoting leadership and in guiding climate-resilient health systems. More than two-thirds of these countries have identified health risks that include heat stress, injury and death from extreme weather, food-, water- and vector-borne diseases. Concomitantly, countries are beginning to implement early-warning systems and health sector responses to a range of climate risks, particularly heatwaves, flooding, and poor air quality. However, there are considerable concerns about the level of political commitment for making these responses: although over half of the respondent countries have assessed their public health risk from climate change, many of these reported that their findings have little or no influence on the allocation of human and financial resources to meet their adaptation priorities for protecting health. Implementation of the plans has been low, often because of financial constraints but also because of lack of prioritisation, lack of multi-sectoral collaboration (e.g. between health, transportation, electricity generation, household energy sectors) and a lack of sufficient evidence for informed decision-making (see further discussion in section 5.2.3).

This analysis reinforces the concerns expressed about NDCs and the previous assessment of adaptation ambitions by EASAC (2019a). Concrete actions in plans and commitments are often missing and links with SDGs are weak. An earlier assessment by OECD (Austin *et al*. 2016) noted that national adaptation goals on climate change and health were focused relatively narrowly on infectious disease and heat-related risks, and there was insufficient cross-sectoral collaboration and coordination between different levels of governance or evaluation to establish what health adaptation would look like in practice.

These weaknesses remain widespread. For example, insight can be gained from the WHO Europe Pagoda report (2018b) that draws several lessons for good practice for strengthening health adaptation measures, cross-sectoral coordination and sharing, and communication of data and messages. For example, there are recommendations on the design and implementation of heatwave early-warning and response systems, particularly with regard to the needs of the most vulnerable groups and linkage to coordination of responses when heatwaves occur. Several general weaknesses were confirmed from the European experience: for example, in translating scientific evidence into action where few of the national communications to the United Nations Framework Convention on Climate Change (UNFCCC) described observed and projected health effects due to climate change, using recent national evidence. And certain strategic areas remain weak, for example developing integrated climate, environment and health surveillance and building climate-resilient health structures. For low-to-middle-income countries (LMICs), WHO (2021a,b) confirms the concern that the evidence base for effective adaptation strategies to protect public health is weak (see also Scheelbeek *et al*. 2021), and recommends a range of activities for strengthening health systems resilience through the NAP process[40] that include health national adaptation plans (HNAPs). NASAC (2022) provided integrated assessment of HNAPs together with NAPs and NDCs but also concludes that in many of the plans it is still not clear how the public health sector is going to be strengthened and how it will link to SDGs (see also Nhamo and Muchuru (2019), who extensively explore objectives and contents of these plans). The most recent *Lancet* Countdown report (Romanello *et al*. 2021) confirmed disparities in preparedness: the degree of implementation of national health emergency frameworks is lowest in low-income countries.

There may be various barriers to implementing adaptation plans for example economic, institutional capacity and availability of skilled human resource;nonethel ess a potential co-benefit of many adaptation measures is the spur to innovation, new employment and economic revival (AASSA 2021). Health services in 86 countries are now connected with their equivalent meteorological services to assist in health adaptation planning (19 in Africa, 16 in the Americas, 7 in Eastern Mediterranean, 23 in Europe, 8 in South East Asia and 13 in the Western Pacific (Watts *et al*. 2021)).

The regional reports noted a particular need for climate–health education for health professionals. For example, based on the observation that health professionals across the Americas lack the preparedness and confidence to assess effectively mitigation and adaptation responses to climate–health threats, IANAS (2022) discussed a range of educational initiatives to overcome barriers. These initiatives include integration of climate–health competencies into the existing curriculum;appl ication of knowledge in problem-solving and practical capabilities;c ontinuing professional education programmes;and better c ollaboration in use of existing educational resources. As discussed by AASSA (2021) with the example of the Russian Federation Far East (Bogatov *et al*. 2021), a new medical specialty has emerged: environmental medicine, with new methods of rapid diagnosis and monitoring of the health status of residents of ecologically disadvantaged areas. In addition to education for health professionals, it is also important to promote public education: improving education generally can enhance individual adaptive capacity and research-based adaptation learning support can accelerate social and policy change (Feinstein and Mach 2019). There are instructive examples available of public education outreach programmes on climate change adaptation and resilience (Payton *et al*. 2017)[41].

In examining national plans, NASAC (2022) reviewed and exemplified different classes of adaptation measures: for disaster risk reduction, social and behavioural modification, institutional support, also emphasising the value of integrating responses (see Box 8), but in many cases health issues need greater prominence.

IANAS (2022) discussed multiple responses as complementary approaches to a given hazard. For example, adaptation to heat can be technical (e.g. insulation, green walls, green infrastructure), societal (e.g. urban greening), physiological (e.g. individual acclimatisation), institutional (e.g. within public health services), economic (e.g. subsidies in building and renovation) and behavioural (e.g. seeking cooler environments). Integrated preparedness and responsiveness require decision-makers

[40] Recommendations for strengthening NAPs include the following:
- The inclusion of health in integrated vulnerability and adaptation assessments for various sectors.
- Improved institutional capacities and arrangements.
- Synergies across the NAP processes and mainstreaming consideration of health outcomes into policy areas.
- Systematic improvement through NAP iterations.
- Development of a health national adaptation plan (HNAP).

[41] See also UN Climate Action ‘Education is key to addressing climate change’ https://www.un.org/en/climate-solutions/education-key-addressing-climate-change.

Box 8 National and multinational approaches to integrating issues for climate policy in Africa: including efforts on integrated water resource management and coastal zone management, disaster risk reduction, land use planning, and agriculture

Ethiopia's programme of climate change adaptation covers national, regional, and local community responses.

Mali is also integrating adaptation into many sectors.

Rwanda has a National Strategy on Climate Change and Low Carbon Development.

Niger, Zambia and Mozambique are involved in a pilot programme for climate resilience.

Zambia's 6th National Development Plan (2011–2015) and the new Economic and Social Investment Plan in Niger reflect some integration of climate resilience measures in national development plans.

Climate adaptation is also reflected in broader policy frameworks for example Namibia's National Policy on Climate change and Zambia's Climate Change Response Strategy and Policy.

Other regional initiatives, such as the 20-country Africa Adaptation Programme launched in 2008, foster cross-sectoral adaptation planning and risk management.

For details see NASAC (2022).

to address both shorter-term (e.g. education and awareness-raising) and longer-term (e.g. city planning) interventions, involving different levels of governance, including local authorities.

5.2 Clarifying the global context for selecting adaptation options

Later in this chapter, we present some examples from the regional reports and other sources to characterise the range of potential solutions (see also Appendix 4). First, however, we discuss some general issues to set the overall context for adaptation.

5.2.1 Cross-sectoral integration

Health adaptation is not a matter only for the health sector but is relevant to objectives for many other sectors, for example urban planning, construction, transport, agriculture and tourism. A systematic review of the health benefits of urban climate change adaptation (that also encompasses mitigation (Sharifi *et al*. 2021)) reinforces the importance of combining actions on health infrastructure, urban planning, housing and building design, nature-based solutions, early-warning systems, policy and management, and perception and behaviour. Perspectives from NASAC and IANAS have already been mentioned. A similar perspective is exemplified by an initiative in Japan (AASSA 2021) where the government, together with academics, is rethinking strategies to deal with the multifactorial health impacts of climate change. In an alternative approach, national stakeholder consultation in Indonesia (Oktari *et al*. 2022) has helped to review science-based adaptive strategies for priority groups and underpin interlinkages across sectors and policies.

Integrated approaches must be tailored to local circumstances. The AASSA (2021) report describes a community-level initiative, the Haryana climate-smart villages in India, combining a range of adaptation and mitigation measures, bringing together actions for climate forecasting, water management, agricultural reforms, other land use management, and renewable energy, all underpinned by shared farmer learning

CLIMATE-SMART VILLAGE/FARM					
Weather smart	**Water smart**	**Carbon smart**	**Nitrogen smart**	**Energy smart**	**Knowledge smart**
• Seasonal weather forecasts • ICT-based agro-advisories • Index-based insurance • Climate analogues	• Aquifer recharge • Rainwater harvesting • Community management of water • Laser levelling • On-farm water management	• Agroforestry • Conservation tillage • Land use systems • Livestock management	• Site-specific nutrient management • Precision fertilizers • Catch cropping/ legumes	• Biofuels • Fuel-efficient engines • Residue management • Minimum tillage • Solar solutions for agriculture	• Farmer-farmer learning • Farmer networks on adaptation technologies • Seed and fodder banks • Market information • Off-farm risk management — kitchen garden

Figure 25 Haryana climate-smart villages. See AASSA (2021) for further details.

(Figure 25). This initiative has brought together farmers, national and international researchers, local government leaders, policy-makers, planners and private sector organisations to identify and develop site-specific interventions to reduce carbon emissions coupled with greater resilience in food security and reduced malnutrition. Using local knowledge and supported by local institutions, the Government of India has now expanded climate-smart villages across five other states (AASSA 2021).

5.2.2 Triple wins for health, equity and environmental sustainability

The triple win objectives apply to adaptation as well as mitigation solutions[42]. Adaptation solutions should be prioritised if they are value-creating and sustainable in the long-term, avoiding allocating support to prolonging the life of practices and business models responsible for high GHGs and excessive resource consumption or that jeopardise public health and environmental sustainability (Guerriero *et al*. 2020). The primary principle is to seek and select those evidence-based solutions that benefit human health, the environment and social equity.

A review of community-level interventions (Bell *et al*. 2019) confirms the importance of inculcating the triple win mindset and concludes that this requires transdisciplinary support for a broad evaluation framework.

5.2.3 Measuring impacts

The evaluation of the impact of science-based interventions and their attribution to research outputs is challenging and there is a large literature on the topic (see Ari *et al*. (2020) for a review of the literature). Integrating health benefit measurement and evaluation into policy requires commitment to continued research into mechanisms of impact using longitudinal data collection, scenario modelling and better surveillance, and integration of datasets (EASAC 2019a). There are particular challenges for measuring adaptation impact: unlike mitigation where the effectiveness of policy action can be measured in terms of 'GHG emissions reduced', no universally accepted metric for assessment of adaptation effectiveness exists (Stadelmann *et al*. 2011). Many approaches to assessing adaptation tend to use intermediate outcome indicators but not final impact metrics and these surrogate measures may be unconvincing to policy-makers and the public. Challenges remain because of differing views on what adaptation success entails, its timescale and who would define it (Dilling *et al*. 2019; and Whitmee *et al*. (2021), who also consider similar issues for measuring impact of mitigation). Among the earlier quantitative approaches proposed for generic adaptation effectiveness metrics are (1) wealth saved from destruction from climate change impacts and (2) disability-adjusted life years saved (Stadelmann *et al*. 2011), and it is health indicators that we primarily focus on in this

[42] See examples: https://www.inherit.eu/triple-win-cases/.

chapter. Nonetheless the economic impacts justify investing in adaptation plans (see subsequently and chapter 6 and the regional reports).

Although health adaptation interventions are increasing, evidence for their success remains mixed (see, for example, Watts *et al*. (2021) and UNEP (2021a) for discussion of the challenges for measuring interventions and monitoring progress in national adaptation plans). Moreover, because there is no single definition of what constitutes successful adaptation and because of the changing nature of climate risk, current adaptations that are effective at improving health outcomes may become inadequate over the longer-term (IANAS 2022)[43]. There is more to be done to reconcile different views, and, in appraising the examples we will present for adaptation, we observe that it is important for a commitment to measurement and quantification be made at the onset of an intervention and for desired endpoints to be evidence-based. This has not always been the case[44]. The evidence base in LMICs is very limited: a systematic review of peer-reviewed literature reporting the effects on health of climate change adaptation responses (Scheelbeek *et al*. 2021) could find only two (out of 99 studies on 66 LMICs) that were *ex ante* evaluations. A systematic global stocktake of published evidence on human adaptation to climate change using machine learning methods (Berrang-Ford *et al*. 2021b) revealed that adaptations were largely fragmented, local and incremental with only limited evidence of transformational adaptation and negligible evidence of risk reduction outcomes. More research is needed to inform policy options: for example, on whether and how adaptation is happening, with what dynamics, whether it is leading to lower risks and vulnerability, what are the limits to adaptation and how the private sector can contribute.

Challenges in quantifying solutions are part of the bigger complexity and uncertainty relating to quantifying climate impacts. Although there is a pool of options – climate vulnerability assessments, risk assessments, economic and/or sustainability impact assessments – the processes have not been integrated to create a comprehensive risk management system to underpin climate-resilient development[45]. The UN University is currently developing an innovative and flexible framework, the Economics of Climate Adaptation, to develop cost–benefit criteria to recommend different adaptation measures, and studies are being piloted on urban floods (Honduras, Vietnam) and drought (Ethiopia). In related context, the NASAC (2022) case study in Benin on economic impacts of climate change also provides important stimulus for additional research. This case study evaluates both direct costs such as the number of working days lost to climate change and weather-induced diseases, and indirect costs such as those relating to disease treatment, loss in water quality and undernutrition. One important finding was the large cost in terms of working days lost because of children's illness in the family (see NASAC (2022) for comprehensive discussion of the methodology and key messages).

5.2.4 Maladaptation

Without impact measurement it is difficult to know whether an intervention is appropriate for sharing as good practice more widely or, indeed, if there is potential for the intervention to worsen the situation (Lin *et al*. (2021), and see the example of air conditioning discussed below). Many concerns have been expressed

[43] IANAS (2022) discussed the range of methods and metrics for tracking progress on adaptation: including comparative analyses of policy options and laws;s ystematic review of the adaptation literature;moni toring and evaluating programmes and projects at different scales.
[44] One example to illustrate the broad problems that can arise is taken from animal health, relevant to One Health (Vicente *et al*. 2019). The response by national authorities to the spread of African swine fever in Europe, which may be partly attributed to climate change (EASAC 2019a), has been drastic but probably ineffective because the defensive measures (including culling wild boar populations and building border fences) disregarded the science of wildlife management.
[45] UN University 'Economics of climate adaptation ECA)': an integrated approach to climate change adaptation. https://ehs.unu.edu/news/economics-of-climate-adaptation-eca-an-integrated-approach-to-climate-change-adaptation.html.

(e.g. Lisa and Schipper 2020; Eriksen *et al*. 2021; Lin *et al*. 2021) that some internationally funded interventions aimed at climate change adaptation and vulnerability reduction may inadvertently reinforce, redistribute or create new sources of vulnerability. IANAS (2022) emphasised the concern '*that adaptations designed without sufficient attention to equity and the needs of those who are most vulnerable to climate change may actually increase risks or shift risks to other groups.*'.

According to Eriksen *et al*. (2021), four mechanisms drive maladaptive outcomes:

- Weak understanding of the context.
- Inequitable stakeholder participation in design and implementation of the intervention.
- A retrofitting of adaptation into existing development agendas.
- A lack of critical engagement with how adaptation success is defined.

Aside from wasting time and money, maladaptation is a process through which people become even more vulnerable to climate change (Lisa and Schipper 2020). While new ways to thinking may be required to enable transformational adaptation interventions (Eriksen *et al*. 2021), there is a clear, immediate need for more equitable engagement with vulnerable populations. The IANAS (2022) report provided comprehensive assessment, including specific examples from Canada, Bolivia, Peru and the Arctic region, of how understanding and tackling the adaptation requirements of vulnerable Indigenous Peoples must include a basis in Indigenous knowledge and expertise.

Improving the practical value of approaches to adaptation, for example those based on early-warning systems for air quality, disease threats, food insecurity, pollen forecasts, heatwaves and other extreme weather events, will benefit from co-design of systems with the community involved (EASAC 2019a). As highlighted by AASSA (2021), '*without the participation of the people, policies will be ineffective*.'. Community engagement is also important in the realisation of the adaptation plans progressed by other sectors, for example agriculture and construction, to strengthen the community response to climate impacts, including by fostering optimism (American Psychological Association 2014). Different stakeholder groups, for example religious organisations and community activists, have varying influences on the community, but the value of involving these stakeholder groups in local action must depend also on their willingness to change in response to the climate crisis (as discussed in the Lebanon country study (EASAC *et al*. 2021)). Knowledge production as part of community collaboration can be a valuable resource both to inform the integrated policy requirements and to raise patient/citizen awareness of the risks in conjunction with health professionals.

5.2.5 Limits to adaptation

Limits to adaptation, for example in responding to heat, have been discussed earlier. Limits may also apply in exposure to other hazards. For example, in seeking adaptation to flooding there may be physical limits (e.g. low-lying islands or other localities), behavioural limits (e.g. for populations living in vulnerable areas), technological limits (e.g. nature of flood defences) and financial limits (e.g. who pays and what are the cost–benefit considerations). The contribution of different limits to the overall balance of constraints on adaptation will vary according to the context. For example, a national case study on public water supplies adapting to climate change (EASAC 2019a) illustrated physical limits (drying up of rivers), economic limits (affordability), socio-political limits (construction of water storage reservoirs may not be acceptable because of local environmental impacts) and institutional limits (inadequate capacity of water management agencies). In addition, as discussed by EASAC, strategic limits may be self-imposed by lack of ambition in scope in national and regional adaptation strategies. A lack of ambition, whether in adaptation policy or research, can be surprising given the requisite expertise for policy advocacy that exists (e.g. in South Africa (Chersich and Wright 2019)). Although capacity building requirements for health system delivery are often acknowledged, less well appreciated is the requirement for capacity building in use of evidence in health policy-making. One example of good practice in this respect is the WHO-EMRO (WHO Regional Office for the Eastern Mediterranean) framework for use of such evidence in improving national institutional capacity in the Eastern Medicine (www.emro.who.int/rpc/evipnet, see EASAC *et al*. (2021)).

Adaptation limits are discussed further by IANAS (2022) in terms of the value of the IPCC 'burning ember' representations to illustrate risk and adaptation limits as a decision-making tool. This approach was used recently (Ebi *et al*. 2021b) to characterise limits to adaptation to heat-related morbidity and mortality, O_3-related mortality, malaria, dengue and Lyme disease, when temperature increases exceed 2 °C.

5.2.6 Health system resilience

A broad operational framework for building climate-resilient health systems has been developed by WHO (2015) and this guidance helps health professionals and decision-makers in other health-determining sectors such as nutrition, water and sanitation.

Responses to reduce risk of the negative burden of health may be implemented at several levels (IANAS 2022): by specific individual or population level adaptation interventions or by strengthening the resilience of the system that enables it to respond effectively to a perturbation, returning to a state equal to or better than its previous condition. The regional reports agree on the importance of building social capital and resilience in health systems and infrastructure, especially when there are cases of market failure. As discussed by EASAC (2019a), in developing better resilience, more can be done to integrate health into the alternative socio-economic futures (SSPs, shared socio-economic pathways;s ee also Sellers and Ebi (2017), and further discussion in chapter 6) and other scenario planning. Adaptation in health-care systems will need to vary according to SSPs. For example, for early-warning systems, hospital preparedness and training are needed for all SSPs, but their relative effectiveness may vary in more unequal societies. IANAS (2022) examined SSP–RCP frameworks to ascertain the point that understanding of mortality burdens according to different trajectories of mitigation and adaptation will be critical in allocating resources (see Sellers (2020) and O'Neill *et al*. (2020) for further discussion). AASSA (2021) noted how the SDGs have direct influence in shaping development pathways. Unfortunately, it is also the case that even highly ambitious SSPs currently used in modelling do not meet all the SDGs (sustainability gaps) and fail to provide information on some of them (knowledge gaps) (Zimm *et al*. 2018).

In seeking additional evidence to provide the resource for scenario development, NASAC (2022) explored various country experiences. For example, modelling in Tanzania, where agriculture accounts for about half the gross domestic product (GDP) and employs 80% of the labour force, indicates that climate change could increase poverty. Scenarios for Namibia demonstrate that annual losses to the economy associated with impact of climate change on the country's natural resources could range up to almost 5% of GDP. Ghana's economy and agricultural sector are also particularly vulnerable because cocoa is the single most important export and it will be affected adversely by climate change (see NASAC (2022) for further discussion of these country assessments). The African Climate Policy Centre projections[46] for declining GDP

[46] African Climate Policy Centre 'Climate change impacts on Africa's economic growth', UNECA (2017): https://repository.uneca.org/handle/10855/23850.

compare temperature increases of 1, 2, 3 and 4 °C: western, central and eastern areas of Africa are expected to exhibit higher impacts than southern or northern Africa, and labour productivity effects have been suggested to account for up to 60% of these projected economic impacts.

Improving health system resilience must be integrated with improving resilience of other sectors. The economic importance of broadly increasing resilience of systems to hazards was emphasised by the report of the UN Economic and Social Commission for Asia and the Pacific (2021), estimating that annual costs of improving resilience under worst-case climate change scenarios would be only one-fifth of estimated annualised losses.

5.3 Heat

Current heat-related morbidity and mortality are partly preventable, given access to adequate infrastructure and appropriate policies (Vanos *et al*. 2020). As observed by IANAS, adaptation efforts are projected to reduce substantially the mean percentage change of heatwave-related excess deaths including in Brazil, Canada, Chile, Colombia and the USA under high emission scenarios (Guo *et al*. 2018). However, there will be limits (section 5.2.6) and adaptation cannot indefinitely keep pace with future warming. As previously described, some parts of the world may reach the limits to survival later this century under high emission scenarios.

Heat adaptation approaches focus on both the short- and longer-term and include technological, behavioural, institutional, economic and societal interventions. Among the heat adaptation options and issues are the following.

5.3.1 Heat–health warning systems

These systems trigger responses and resources to reduce the amount of time that people are exposed to extreme heat. A systematic review of the literature (Toloo *et al*. 2013) concluded that the weight of evidence suggests that heat warning systems are effective in reducing mortality and, potentially, morbidity but that effectiveness may be mediated by cognitive, emotive and socio-demographic characteristics, for example the individual's perception of heat dangers, and affordability of air conditioning. Recent literature provides further examples of successful impacts (saving lives), for example Witze (2021) and the AASSA (2021) discussion of the heat early-warning initiative in Ahmedabad, India.

Among current topics for research on early-warning systems are the optimum timescale for the forecast, how to tailor warnings (e.g. targeted for occupational exposure) and what should be the heat warning threshold—the definition of what is a hot day varies according to location (as discussed in the Tunisia country study, Cyprus workshop report (EASAC *et al*. 2021)). AASSA (2021) also noted the importance of piloting programmes and using the data from the pilots to inform policy and to plan improved practices. There will be limits to the numbers of deaths that can be prevented by early-warning systems because many occur at above-optimal temperatures outside 'heat waves'. Integrated approaches are needed across sectors and at different spatial scales. Figure 26 provides an overview from a comprehensive account of the various approaches to reducing the health effects of hot weather and heat extremes (Jay *et al*. 2021).

5.3.2 Green structures and infrastructure

Such intervention can be an effective means of reducing urban heat stress on large scales (Zhao *et al*. 2021a) and AASSA (2021) discussed examples from Armenia and Nagpur, India. As well as green spaces, interventions can include green facades and vegetative cover to reduce temperature and relative humidity (Thomsit-Ireland *et al*. 2020). However, the metrics for measuring intervention and for defining 'green space' are still at a relatively early stage of development. Moreover, the implementation of innovation requires not only advances in technology and nature-based

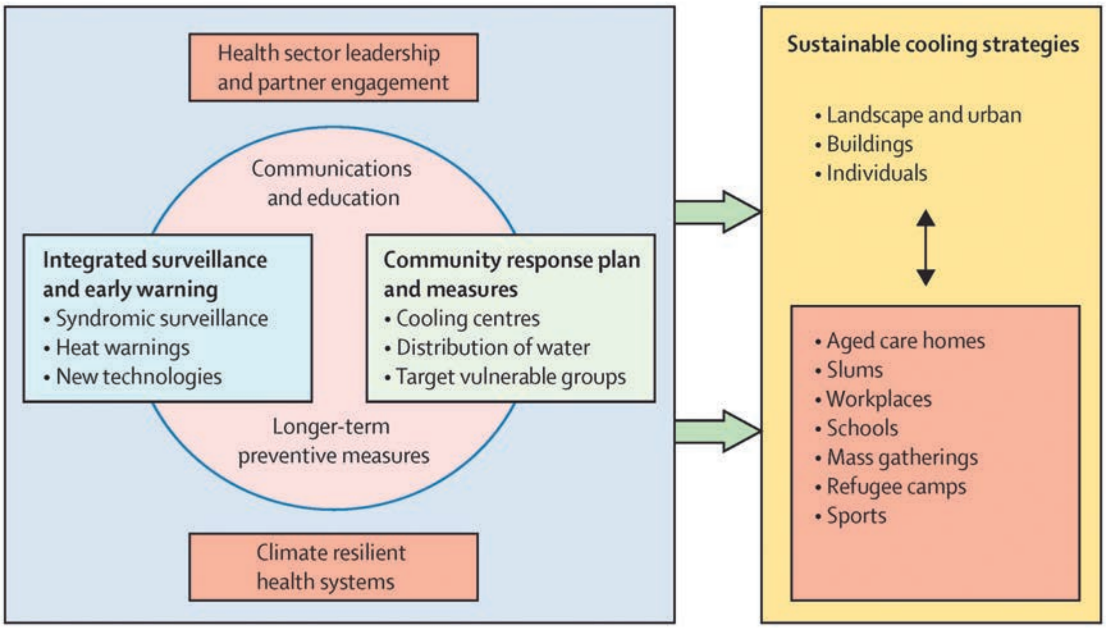


Figure 26 Community heat action plan elements and preventive actions to reduce heat-related health risks; see Jay et al. (2021) for discussion.

solutions but also a science-based and flexible regulatory system that supports innovation. Innovative building protection techniques, for example 'cool roofs' painted white or covered with energy-reflecting materials, can be effective in reducing inside temperatures (Anon. 2021a). Current building regulations in some countries may prevent the transfer of benefit (such as reduction in humidity) from outside to inside a building because of standard construction techniques (such as inclusion of layers of damp-proof membranes).

The NASAC (2022) case study on vulnerability to flood and heat in Cote d'Ivoire advised that greening strategies should be based on understanding current socio-economic disparities in urban planning (adaptation and mitigation, Table 3) in order to guide distribution of new green spaces, and that private planting of vegetation at the household level should also be encouraged. Recognition that risk represents a combination of exposure with local socio-economic factors helps to underpin the importance of collaboration among local authorities across city precincts. In 2019 only 9% (of 468) global urban centres had very high or exceptionally high levels of greenness, 10% were at the opposite end of the spectrum with very low levels of urban green space.

In all but 6 of the 175 largest urbanised areas in the continental USA, the average person of colour lives in a census tract with higher surface urban heat island intensity than non-Hispanic whites (Hsu *et al*. 2021). A lack of urban green space is an important contributory factor to these disparities often linked to racist zoning laws (red-lining, see also Table 3) that denied mortgages to homeowners in areas inhabited predominantly by people of colour. Low-income populations also experience higher urban island effects when ethnicity is taken into account.

5.3.3 Scaling up for sustainable cities

Scale-up is essential for significant impact and this requires government action with the construction industry to incorporate heat reduction in their building projects and/or subsidies for green buildings (Anon. 2021a), and to ensure monitoring for impact and accountability. The building renovation agenda needs to include vulnerable groups, for example to adapt long-stay care facilities for the elderly to cope with higher temperatures, and there is an important priority to identify at-risk, marginalised neighbourhoods to target for adaptation projects (see also chapter 4 for similar mitigation priority). Other actions for cities should include adaptation of transport networks to reduce anthropogenic heat exposure (Capon *et al*. 2019).

5.3.4 Occupational health

Improving the capacity of workplaces to adapt to rising temperatures is a responsibility of government at the regulatory level but the involvement of employers' and workers' organisations is also crucial to the successful implementation of measures to facilitate behavioural change (International Labour Organization 2019). About 60% of the reduction in working hours projected to take place worldwide by 2030 as a result of heat stress is concentrated in the agriculture sector. Options for reducing impact may include promoting mechanisation but there is a crucial role for raising awareness and skill development (International Labour Organization 2019). For example, new education programmes are part of the increasing efforts in adaptation for farmers and other outdoor workers in Nepal (see AASSA (2021) for details).

5.3.5 Addressing inequity and other negative consequences

Interventions may not easily be accessible by some households, communities and regions, particularly in low-resource areas, and greening strategies may increase vulnerabilities of low-income communities (e.g. in context of gentrification (Shokry *et al*. 2022)). The IANAS (2022) discussion of case studies for adaptation including in Mexico City (urban planning) and Argentina (early-warning system for heatwaves) concluded that, in addition to the specific adaptation measures, initiatives to reduce poverty and inequity will play a critical role. Some heat adaptation success to date is attributed to the increased use of air conditioning and fans but, although effective, air conditioning may only be responsible for a relatively small part of the decreased risk in some areas (Sera *et al*. 2020) and the most vulnerable remain exposed to extreme heat. For example, in Nicaragua, approximately two-thirds of workplaces have no cooling systems with the consequence that indoor air temperatures exceed the local standards for safe work with moderate exertion: this proportion of the work force at risk is projected to increase to 80% by mid-century (Sheffield *et al*. 2013, discussed in IANAS 2022). Air conditioning also carries negative consequences for energy use: future projections suggest that continuing to use air conditioning as an adaptation strategy, for example in the USA, will significantly increase air pollution-related mortality (Abel *et al*. 2018). In 2018, air conditioning accounted for 8.5% of total global electricity consumption and on hot days can be responsible for more than half the peak electricity demand locally, also emitting waste heat that contributes to the urban heat island effect (Watts *et al*. 2021). Widespread dependence on air conditioning is currently escalating GHGs and its use worldwide is expected to increase dramatically as incomes rise and temperatures grow (Biardeau *et al*. 2020). More sustainable cooling solutions are needed (Capon *et al*. 2019; Jay *et al*. 2021), for example requiring air to be moved more and chilled less, and the potential for accumulation of heat to be reduced by reflecting more thermal radiation and facilitating latent heat loss by evaporation.

In conclusion, the initiatives for adaptation to heat reinforce again the importance of addressing adaptation and mitigation together, working across disciplines and sectors, and taking account of equity and social justice when developing and implementing the health interventions.

5.4 Wildfires

Some recommendations relevant to adaptation were introduced in section 3.5, discussing the AASSA (2021) case study on Australian bushfires. These emphasised the need for clearer and more consistent advice to the public on how individuals and their communities identify, manage and treat health impacts, including targeted information and plans for vulnerable groups. Policy action is needed at regional as well as national and local levels in order to counter cross-border pollution threats. Specific adaptation requirements (AASSA 2021) are as follows:

- Better early-warning systems.
- Improved fire management practices, including using information from, and working with, Indigenous Peoples (IANAS 2022).
- Research on the health consequences of different pollutants as well as long-term follow-up for the mental health consequences of displacement and loss (EASAC 2019a) to inform improved adaptation measures.
- Integration of public health and health-care services into disaster planning, especially for remote areas, including using digital methodologies for warning, monitoring and delivery of services.
- Increased national commitment to the conservation of forests and peatlands as carbon sinks and avoiding the use of fire to remove crop residues. Systematic change requires incentives and subsidies to recognise the value of ecosystem services based on research to clarify the value of those ecosystem services (Dasgupta 2021).
- Concerted international policy action to reduce consumer demand in developed countries for the commodities (e.g. beef, soybean, palm oil and biofuels) whose production is based on land clearance by fire in the LMICs (IAP 2019a).

5.5 Flooding

Cross-sectoral action is again required. For built environments, this includes addressing priorities for urban planning, coastal defences (including river barrages) and for relocating health facilities away from locations at risk of flooding (see AASSA (2021) for further discussion of infrastructure and skill requirements in Malaysia).

Responses should include nature-based solutions such as wetland and mangrove restoration as well as the physical engineering measures, while always taking into account the possibility of inadvertent health consequences (Guo *et al*. 2020). For example, action to increase wetlands may provide new sites for infectious disease vectors (EASAC 2019a).

Flood-related policy initiatives and guidelines, including construction standards and choice of location of utilities and medical facilities, often lack consideration of future risk (Mehryar and Surminski 2020). Climate change and disaster risk management should continue to be increasingly integrated, as part of the Sendai Framework of Disaster Risk Reduction (Kelman 2015; Bowen *et al*. 2021). If, hitherto, policy-making on flooding has often focused on reactive strategies, it must now be more anticipatory (see also Appendix 4). Policy-makers should take account of whether planned infrastructure projects are equipped to cope with climate change impacts such as floods as a condition to receive public funding, for example as recently introduced in the EU (European Commission 2021). Flood protection measures could and should also be supported by information for adapting the behaviour of individuals, for preparedness and responsiveness, and their communities (Guo *et al*. 2020), and there are examples of good practice in enlisting community participation to manage and reduce flood risks[47]. Working at the community level to raise awareness by local authorities and building institutional and other capacities are also recommendations emanating from the Burundi case study modelling vulnerabilities to advise on implications for land use and to strengthen adaptation capacities (NASAC 2022). An important first step is mapping of flood-prone areas to assess community vulnerabilities.

[47] Somalia: strengthening resilience to climate shocks, Cities Alliance, 2020: https://www.citiesalliance.org/newsroom/news/cities-alliance-news/somalia-strengthening-resilience-climate-shocks.

Small Island Developing States (SIDS) need a different response to flooding, and the loss and damage implications of sea level rise are discussed in detail by Martyr-Koller *et al.* (2021)[48].

5.6 Infectious diseases

There has been sustained interest in evaluating the potential of climate-based disease early warning (see early review by Kuhn *et al.* (2005)). Early-warning systems and other interventions have high intersectoral relevance because they improve public health and help to sustain economic output that is otherwise reduced by the consequences of infectious disease outbreaks. Opportunities and challenges for worldwide infectious disease policy integration have been accentuated by the COVID-19 pandemic, which has exerted very large pressures on the health sector and revealed a lack of preparedness at many levels in many countries. The converging crises of climate change and COVID-19 will be discussed further in chapter 6.

Food- and waterborne infectious diseases. Many of these threats can be countered by action on water, sanitation and food systems as discussed in chapter 3;further i nsight, including evidence from predictive models, can be found in the regional reports. An example discussed by IANAS (2022) illustrates how early-warning systems, for example for higher sea water temperatures or strong El Niño events, could trigger adjustment to regulations and practices, including harvesting of seafood from deeper and colder water, to reduce pathogen level at harvest, accompanied by improved temperature control post-harvest (Ortiz-Jiménez 2018).

Vector-borne infectious diseases. Current adaptations to prevent climate-related increases involve reducing the environmental risk of exposure and individual preventive behaviours to reduce human–vector contact, and these are based on vector and disease surveillance (see section 3.8.2). The considerable interest in early-warning systems (Fu *et al*. 2017) is stimulated by the rapid pace of advance in science and technology to generate new capabilities to forecast climate and monitor other variables (such as vegetative cover) to predict future disease outbreaks, for example using NASA resources to monitor chikungunya activity worldwide and climate-based forecasting of risk[49]. However, there is need for more research to clarify the role of different meteorological factors and their interplay in early-warning systems. Examples of early-warning systems currently being tested and implemented are discussed in all the regional reports. To indicate the interest worldwide, Box 9 lists some of those examples and other literature relating to attempts to forecast dengue outbreaks.

As discussed by all the regional reports, early-warning initiatives and increased surveillance for vectors, hosts and pathogens must be accompanied by other research to provide the resource for innovation and to inform practice to prepare for and respond to infectious disease threats. These include the following strategic research priorities:

- Supporting fundamental research in advance of a crisis (see Box 6 for Arctic case study).

- Connecting research and innovation, including developing new business models for public-private partnership to pursue priorities for novel diagnostics, therapeutics and vaccines. Because extreme weather events can disrupt infrastructure such as roads and bridges and interrupt the supply of medicines to patients, research and innovation is also important in supporting new technologies to provide additional means of access, for example using drones

[48] See also WHO (2018a) for comprehensive assessment of climate change and health in SIDS.
[49] See the work of the Universities Space Research Association, https://vbd.usra.edu, and Anyamba *et al.* (2019) for other examples of how global satellite monitoring of climate variables can identify regions at risk of a wide range of disease outbreaks.

Box 9 Early-warning systems for predicting dengue outbreaks

Pilot studies in Europe demonstrate that early-warning systems based on monitoring of climatic and other factors can help to predict dengue (and other vector-borne disease threats such as malaria and West Nile fever) (Semenza 2015; EASAC 2019a).

In French Guinea, where climate-based models were not available to develop early-warning systems, data on oceanic and atmospheric conditions were used to help predict outbreaks locally (Adde *et al*. 2016).

In Malaysia, the national dengue strategic plan includes structured early-warning and surveillance systems with real-time monitoring (AASSA 2021).

In Ecuador, introduction of a climate-dengue surveillance system and, at border of Ecuador and Peru, a multinational climate-dengue surveillance system.

In Brazil, during preparation for the 2014 FIFA World Cup, the importance of real-time seasonal climate forecasts was recognised (Lowe *et al*. 2014).

More generally in the Americas, using seasonal and El Niño forecasts enabled prediction at the start of the year for the entire dengue season (Lowe *et al*. 2017).

See also WHO (2018b) 'Operational guide: the early-warning and response systems (EWARA) for dengue outbreaks'.

to deliver essential health care (NASAC 2022).

- Collaboration between veterinary and public health sectors for One Health. A study in Sudan (EASAC *et al*. 2021) shows that the value of disease surveillance is increased by involvement of farmers and herdsmen to provide local information anticipating zoonotic disease transmission.
- Promoting collaboration in research and surveillance among neighbouring countries[50] and this should include increased commitment by developed economies to support national and regional capacity building for LMICs.
- Recognising the importance of connecting research between disciplines to prepare, prevent, respond and recover, discussed in detail in the work of the academies (e.g. Academy of Medical Sciences *et al*. 2020).

5.7 Migration

The earlier section (3.10) on forced migration discussed the importance of strengthening host country health and other systems to be climate-resilient and migrant-inclusive, for example thereby enabling provision of comprehensive screening and vaccination services (FEAM and ALLEA 2020). It is, of course, also of primary importance to address the multiple problems at the migrants' country of origin to reduce pressures to migrate. Conflict and migration within a country require multiple approaches to finding solutions. The NASAC (2022) case study on Nigeria discussed

[50] For example, in the European region, the recent strategic initiative by the European Commission to form the European Health Union will help to augment the European Centre for Disease Prevention and Control agency capabilities to deal with cross-border health threats. The more recent inception of the Centres for Disease Control and Prevention in Africa is an important initiative that should be strengthened (NASAC 2022). A different example of good practice is the Middle East Consortium on infectious disease surveillance, between Israel, Palestine and Jordan (https://www.cordsnetwork.org/networks/mecids/), founded in 2003 with intentions to expand network membership to all countries in the region.

previously led to recommendations for new types of land use, for example a ranching system to replace uncontrolled open grazing, accompanied by community measures to reduce stress.

Migrant accessibility to basic services at their destination, alongside other provisions relevant to social cohesion, are already specified under the UN Global Compact for Safe, Orderly and Regular Migration (A/RES/73/195 2018), which should be applied more explicitly, while continuing to respect issues for national sovereignty (Anon. 2019). In reviewing the priorities for the scientific community to help tackle the consequences of migration, the FEAM and ALLEA report (2020) emphasises the importance of multi-sectoral and multi-stakeholder collaboration (including the academies) and better linkage of migration and health policies. The academies also highlight the opportunity for better communication of research findings to inform communities that migration does not pose a threat to the health of citizens in the host country.

5.8 Food systems

Actions to transform food systems under climate change have multiple sectoral implications, policy objectives and interlinkages, summarised in Figure 27. Whereas a previous strength in many countries' food policies has been the focus on how to protect consumer health from contaminated food, it is now clear that there must also be more attention given to the degree to which the state should use health and environmental considerations to regulate the marketing of food (Godfray *et al.* 2018). For example, government policies can support rebalancing consumption by introducing various measures including dietary guidelines, food labelling (for environmental sustainability as well as nutritional content (Brown *et al.* 2020)) and incentives/disincentives (pricing and taxation) to promote consumption of healthy, sustainable dietary choices, while protecting vulnerable groups (see also chapter 4). Sustainable food systems can be promoted

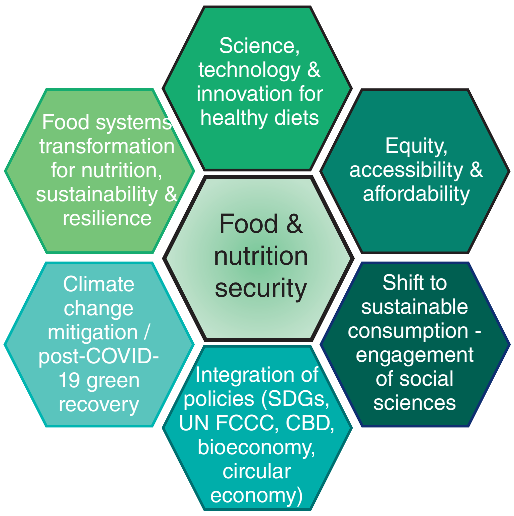


Figure 27 Matrix of policy objectives for food and nutrition security. See Canales and Fears (2021) for further details.

through signalling and remuneration for good management practices, including the introduction of sustainable stewardship, and labelling and certification schemes. Consumer behavioural change requires changes to infrastructure and pricing systems that currently support unhealthy, unsustainable behaviour (Marteau *et al.* 2021).

Poverty and inequality are critical underlying factors that amplify the negative impact of the major drivers of food insecurity and translate to an unfair distribution of vulnerability (Salm *et al.* 2021). IANAS (2022) noted the particular vulnerability of Indigenous People to the impact of climate change and the loss of biodiversity, in particular for communities who depend on their land for sustenance. The decline in the availability and use of traditional food species and their replacement with purchased food can lead to a reduction in the intake of nutrients, and negatively impact cultural continuity, mental health outcomes, language, self-determination and social cohesion, which are critical determinants of Indigenous Peoples' health (Jaakkola *et al.* 2018; Mabhaudhi *et al.* 2018; Marushka *et al.* 2019; Whitney *et al.* 2020). Supporting Indigenous Peoples' ability to adapt to climate change will require transforming the current governance model into one that acknowledges Indigenous social, cultural, and food needs and how these relate to

Box 10 FAO recommended pathways to follow for more resilient food systems that can provide affordable and sustainable healthy diets

1. Integrating humanitarian, development and peace-building policies in conflict-affected areas.
2. Scaling up climate resilience across food systems.
3. Strengthening resilience of the most vulnerable to economic adversity.
4. Intervening along the food supply chains to lower the cost of nutritious foods.
5. Tackling poverty and structural inequalities, ensuring interventions are pro-poor and inclusive.
6. Strengthening food environments and changing consumer behaviour to promote dietary patterns with positive impacts on human health and the environment.

In addition, coherence in the formulation and implementation of policies and investments among food, health, social protection and environmental systems is also essential (FAO *et al*. 2021).

the use of natural resources and territorial management rights (Marushka *et al*. 2019). Understanding how different forms of inequity interact with climate change and adverse nutritional outcomes, and the impact of multiple feedback loops, is an important research priority to guide effective policies and interventions that needs to be addressed by transdisciplinary teams (Salm *et al*. 2021).

The transformation of food systems for the sustainable provision of adequate nutrition for all will not be possible unless these underlying drivers of malnutrition in all its forms are addressed (Adesogan *et al*. 2020; Hirvonen *et al*. 2020). Box 10 summarises key issues emphasised by the Food and Agriculture Organization of the Uniited Nations (FAO) for a broad strategy on resilient food systems.

NASAC (2022) described the importance of developing climate services (the generation, provision and contextualisation of information and knowledge derived from climate research) to support the adoption of adaptation strategies, which will also require addressing barriers to the access and use of this information and incorporating the perspectives of smallholder farmers (Conway *et al*. 2019). Previous IAP work in Africa and elsewhere (IAP 2018) reviewed the broad regional adaptation priorities for agriculture under climate change and the strategic importance of integrating activities for mitigation and adaptation with co-benefits for health and development. Solutions in Africa as elsewhere must decouple, as far as possible, increases in livestock and crop productivity from GHG emissions (Tongwane and Moeletsi 2018), together with reducing waste and promoting sustainable consumption patterns (Laar *et al*. 2020);s ee the further discussion in section 4.5.

Adaptation strategies for sustaining the nutritional quality of crops include breeding for increased micronutrient content (biofortification), incorporating legumes in cropping systems, improving farm management practices, the utilisation of microbial inoculants that enhance nutrient availability in the soil, and improvements in post-harvest handling and in the preservation of fresh fruits and vegetables (Parajuli *et al*. 2019; Soares *et al*. 2019). Agricultural production must, in addition, be transformed qualitatively to deliver an increased proportion of nutrient-rich foods (vegetables, fruits, seeds and nuts) and fewer starch and oily crops (Mason-D'Croz *et al*. 2019), and by promoting the use of neglected and underutilised crops (Mabhaudhi *et al*. 2018; NASAC 2018; Hunter *et al*. 2019).

There are many challenges but also many innovation opportunities for adaptation to achieve climate-resilient pathways for equitable and sustainable food and nutrition security worldwide, discussed in detail in previous IAP work (IAP 2018), the regional reports and elsewhere (e.g. see WHO 2019c; Gerten *et al.* 2020, UN Secretary-General 2021). Emerging conclusions from the UN Food Systems Summit Scientific Group (von Braun *et al.* 2021) list a range of novel science-based approaches that might be deployed to adapt to the effects of climate change and other drivers of food and nutrition insecurity. We exemplify one of those here relating to the biosciences[51] – capitalising on recent advances in genomic research – but emphasise that this opportunity should be embedded within agroecological and other sustainable agricultural approaches to transformative, sustainable, food systems (Canales and Fears 2021; Fears and Canales 2021; UN Secretary-General 2021). A report on the broad topic of regenerative agriculture was published by EASAC in April 2022.

One important priority, capitalising on advances in the biosciences, is to improve the conservation of indigenous crops, wild relatives (e.g. Pironon *et al.* (2019) for sub-Saharan crops) and livestock breeds as a global genetic resource. And, also of very great potential, advances in genome editing and other genomic research now bring within reach prospects to modify traits, for ruminant microbial fermentation to abate GHG emissions (both by breeding more digestible forage species and by changing the rumen microbiome), to improve livestock productivity, resilience to stress, feed conversion efficiency and energy utilisation. There are also major opportunities for improved breeding of crops with traits for resistance to abiotic and abiotic stress, improved nutrient composition and improved use of soil nutrients. Among recent examples discussed (Canales and Fears 2021) are high protein wheat, low-gluten wheat, more nutritious potatoes, tomatoes with multiple resistances to biotic and biotic stress, and rice resistant to bacterial blight. Looking ahead, research priorities include the (re-) domestication of high nutrient, stress-tolerant crops by targeting known domestication genes (Osterberg *et al.* 2017), and the development of perennial grain crops to maximise sustainable crop yields.

However, capitalising on these opportunities to help to adapt agriculture to the adverse consequences of climate change requires not only excellent science but also a flexible and proportionate, science-based regulatory system that encourages innovation. Crops produced by genome editing techniques, including those that contain no foreign DNA, are regulated differently in different countries. Figure 28 illustrates the resulting incoherence that acts to deter science, innovation and competitiveness, creates non-tariff barriers to trade and undermines collective action to enhance food and nutrition security.

5.9 Collective action on solutions

In concluding this chapter on the multiple options for adaptation, we re-emphasise the point that, in addition to requisite national actions, health policy objectives have regional connotations when there are cross-border threats such as those resulting from air pollution and infectious diseases. Regional implications are already recognised in some international agreements, for example the UN Convention on Long-Range Transboundary air Pollution (https://unece.org/environment-policy/air). Regional policy for transboundary cooperation may also

[51] There are, of course, significant opportunities to use research and development (R&D) and innovation from other disciplines, and these are discussed in all the regional reports. For example, applications of microsatellite data can be used as a scalable approach to detect the impact of sustainable agricultural intensification interventions at large scale and to target the fields that would benefit the most from precision application of fertilisers or other interventions (Jain *et al.* 2019). More generally, big data/mobile technologies can be a transformative force in agriculture worldwide with great potential to benefit small-scale farmers in adapting to climate change and other environmental pressures, for example by providing weather forecasts and market prices for crops. Yet access for small-scale farms to information technology (3G or 4G sources) may be poor in some LMICs and merits a digital inclusion agenda for governments and the private sector to increase access to data-driven agriculture (Mehrabi *et al.* 2021; UN Secretary-General 2021).

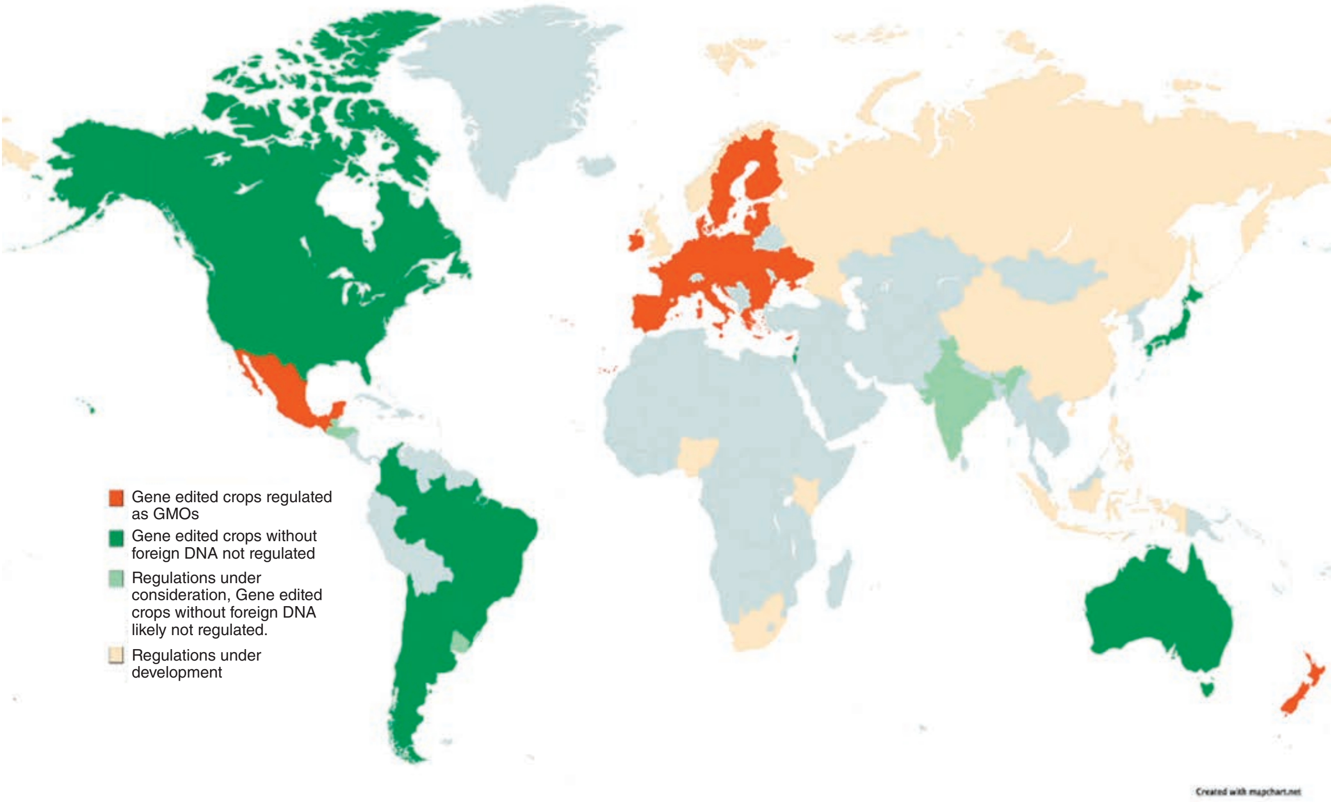


Figure 28 Variation in the regulation of genome editing for plant breeding. See Fears and Canales (2021) for further discussion of genome editing and IAP (2018) for broader discussion of benefit–risk issues of the use of molecular biology-based technologies in agriculture.

be important to make best use of shared resources, for example the potential for Indus River Basin cooperation for cost-effective sustainable development of water resources, electricity generation and food production (AASSA 2021; Vinca *et al*. 2021). Moreover, there may also be inter-regional implications (spill-over effects) if national or regional policy action in one area leads, inadvertently or not, to adverse consequences elsewhere. For example, many nations are currently exporting their lack of environmental sustainability by importing food or biomass generated unsustainably elsewhere. Competition between food, feed and fuel priorities for the effective use of natural resources demands consideration of multiple factors to understand trade-offs and set priorities (Muscat *et al*. 2020; Haines 2021), and requires coherence in integrating adaptation and mitigation actions in order to achieve the triple wins for health, equity and the environment (see chapter 7).

Another example of the importance of understanding inadvertent consequences and trade-offs is the mining of cobalt for batteries in countries such as the Democratic Republic of the Congo, which is often unregulated, sometimes involving child labour and without occupational safety standards (Nkulu *et al*. 2018), resulting in high exposure to cobalt. This exemplifies the bigger research gap currently that is in the health risk assessment of new energy technology.

In addition to their regional collaborations on research, innovation, policy and practice, countries can also participate in wider collective action on solutions, such as these examples:

- Global Race to Zero and Race to Resilience Campaigns (https://unfccc.int/sites/default/files/resource/MP_achievements_progress_April2021.pdf).

- Adaptation Action Coalition (https://www.gov.uk/government/publications/adaptation-action-coalition-an-overview), where one principal action 'Building climate resilient work streams' has been launched as part of the 2021 UK COP26 Presidency.

Potential policy solutions to scale up action on adaptation and mitigation for health are discussed in the next chapters.

6 Systems-based approaches to developing a transformative strategy for solutions

Summary of emerging points in chapter 6

Success of climate mitigation and adaptation interventions depends on achieving broader policy objectives to tackle socio-economic inequality, because of the increasingly systemic nature of risks which share common drivers. A systems-based approach is required to encompass the complex interaction between natural and social systems and for the integration of research outputs from across many disciplines throughout the processes for developing and implementing policy.

Climate change and COVID-19 are converging crises which particularly affect vulnerable groups, with high public health and economic consequences that may be unaffordable for low-to-middle-income countries (LMICs). The pandemic is estimated to have claimed 6 million lives at the time of writing this report. In 2020 it pushed between 119 million and 124 million people into extreme poverty, reversing decades of progress in health and nutrition for children and women. A research priority is to improve data collection of impacts, particularly in poorer countries.

The pandemic and climate change interact in several ways. The increased incidences of extreme weather events (e.g. floods) driven by climate change undermine the public health responses to COVID-19 because of the disruption of basic services and supply chains, the displacement of populations and difficulties in keeping good hygiene. These events further exacerbate underlying factors associated with socio-economic inequalities. The risk of death due to COVID-19 is increased by pre-existing health conditions, including those related to air pollution and poor nutrition.

It is critical to promote a sustainable post-pandemic recovery which requires coordinated policies aiming at both reducing the incidence of climate change-related health risks and increasing socio-economic and intergenerational justice. The current pandemic has brought into focus the need for coordination between different responses to manage disasters; providing support to improve the quality and resilience of health systems in LMICs; and for integrating climate action in multi-sectoral development policies. Global solidarity and international crisis coordination are essential to build collective resilience.

The climate change crisis is also a biodiversity crisis requiring an integration of policies and interventions, further highlighting the need for taking a systems-based approach.

Cost-effectiveness considerations which rely on assumptions of high costs of action often hinder the integration of health issues in the development of mitigation policies. However, available evidence suggests that including health in the economic analysis of mitigation measures strengthens the case for setting and meeting ambitious policy targets and is likely to boost public support for climate action. Further research on the cost-effectiveness of tackling health impacts of climate action is needed.

Climate-related effects are unevenly distributed both within and between populations, and climate injustice also rests on the fact that a small number of countries are responsible for the bulk of emissions and are better prepared and resourced to respond to the risks than poorer

countries. The Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts established by COP19 was introduced to cover climate-related risks that will be addressed neither by mitigation nor by adaptation. High-income countries have a dual obligation, to decrease domestic emissions as fast as technologically and economically possible, and to commit to substantial international cooperation to support LMICs; however, progress has been slow.

The importance of integrating mitigation and adaptation interventions to climate change with the SDGs is highlighted. Since climate change will have even greater impact on the achievement of sustainable development in the years beyond 2030, a strategy should be put in place to follow on from the SDGs in 2030 that prioritises climate mitigation and adaptation.

6.1 Introduction to scope and scale for further strengthening of the evidence base

The success of specific interventions described in chapters 4 and 5 also depends on progress in achieving broader policy objectives for social resilience, including addressing socio-economic and gender disparities and improving adult literacy (see, for example, the Egypt country study in EASAC *et al.* (2021)). There are new opportunities for integrating multiple objectives in development policy. As NASAC (2022) pointed out, over the past decade countries across Africa have adopted increasingly comprehensive development plans with ambitious social and economic objectives. They have attempted to move beyond the narrow objective of poverty reduction to encompass wider objectives of accelerated growth, employment creation, and provision of water, sanitation, health and education needs within the framework of sustainable development.

We have used the terms 'transformative' and 'transformational' several times already in this report, for example in the context of transforming cities for sustainability (Crane *et al.* 2021) and transforming food systems. Transformative change implies a complete system shift across technological, economic and social domains to prioritise people, planet and prosperity equally (EASAC 2021b). Incremental change is not sufficient but there is potential for social tipping dynamics to activate contagious and fast-spreading processes of social and technological change (Otto *et al.* 2020). We recognise that the use of the term 'transformative' may unsettle some policy-makers and citizens. Of course, incremental change can also be of value but, in the context of the urgency of the climate crisis, it is insufficient. Unless major change – rapid overhaul of present systems – is undertaken, rapid transformation will be forced upon us by the accelerating impacts of climate change if societal collapse is to be avoided.

As observed in previous chapters, understanding and integrating adaptation and mitigation solutions within the broader policy context of transformative change requires a systems-based approach to encompass the complex interaction between natural and social systems (Pongsiri and Bassi 2021). This necessitates the transdisciplinary integration of research outputs from across many disciplines throughout the processes for developing and implementing policy. A report from the UN Office for Disaster Risk Reduction (UNDRR 2020) elaborated on the increasingly systemic nature of risk where events overlap and interplay with other risk drivers including poverty and climate change. And as observed by Pongsiri *et al.* (2019), '*Planetary health sets the ambitious task of understanding the dynamic and systemic relationships between global environmental changes, their effects in natural systems, and how changes to natural systems affect human health and wellbeing at multiple scales ...* ' The term 'planetary health', elucidated extensively elsewhere (e.g.

Whitmee *et al*. 2015; Haines and Frumkin 2021), is consistent with and extends other, more focused terms such as One Health[15] and EcoHealth (covering the relationships between health and ecosystems (Lerner and Berg 2017)) and we have taken the planetary health perspective throughout this report.

In this chapter we discuss some additional thematic aspects that must be taken into consideration in devising and implementing the systems-based transformative approach to sustainable development, linking climate and health.

6.2 COVID-19

Climate change and COVID-19 are converging crises (Anon. 2021b). Both have very high public health and economic consequences, exerting disproportionate effects on vulnerable groups (Wyns and van Daalen 2021). At the time of writing this report, the global death toll is 6 million people and the COVID-19 pandemic is still causing enormous impacts for individuals, families, communities and society. NASAC (2022) discussed estimates that, so far, the pandemic has resulted in contraction of Africa's economy by approximately 2.6%, with GDP losses of US$20 billion, and up to 50 million more Africans will fall back into extreme poverty, with 30 million job losses anticipated. The pandemic is estimated to have pushed between 119 million and 124 million people into extreme poverty in 2020 and to have reversed decades of progress in health and nutrition for children. Most countries experienced drops in coverage of life-saving health and nutrition services in 2020, putting millions of pregnant women, children and adolescents at risk of death and other poor health outcomes (NASAC 2022).

The Benin case study (NASAC 2022) warned how the costs of climate change together with costs of new pandemics could produce consequences unaffordable for some African countries and will undermine sustainable development programmes. These many concerns are compounded by difficulties in collecting reliable statistics worldwide. Although the work of the WHO and others has been of very great value in producing and monitoring the global picture, AASSA (2021) pointed out that significant information gaps were identified by local practitioners and scientists in Asian countries, as a result of insufficient financial and other resources.

The effects of climate change and COVID-19 may interact in various ways:

- Although there is theoretical potential for factors such as temperature and humidity to affect the survival and transmission of coronaviruses, in practice non-weather factors are typically more important in transmission. However, climate-induced flooding has undermined the public health responses to COVID-19. Heatwaves could make advice on COVID-19 social distancing and sheltering of vulnerable groups more dangerous (Golechha and Panigrahy 2020; McPhearson *et al*. 2020). However, empirical evidence suggests that severe outcomes such as admission to intensive care units and deaths may be lower in hot periods. One study showed that a 1 °C increase in ambient temperature was associated with 6% lower COVID-19 mortality at 30 days (Christophi *et al*. 2021). Compound risks may, however, arise from interaction of various other climate hazards or their consequences (e.g. migration) with COVID-19 (Phillips *et al*. 2020). IANAS discussed some of the mechanisms that may underlie the contribution by climate in modifying disease exposure pathways, for example extreme weather events resulting in mass displacement, difficulties in maintaining hygiene, reducing access to health services and disrupting supply chains.
- The impact of COVID-19 on food systems may compound vulnerabilities in low-income groups (Ali *et al*. 2020). Evidence discussed by IANAS (2022) suggests that climate change exacerbates underlying factors associated with structural inequalities, for example in Indigenous Peoples in the Peruvian

Amazon. A recent UN human rights report[52] notes additionally that among the severe challenges Indigenous Peoples face with COVID-19 is the prioritisation of economic recovery measures post-pandemic to support the expansion of business operations at the expense of Indigenous Peoples and without adequately consulting them. Further discussion of IAP work on the interaction between COVID-19 and food systems is presented by Canales and Fears (2021) and Fears and Canales (2021) (see also Swinnen and McDermott 2020).

- The risk of death due to COVID-19 is increased by pre-existing cardiovascular and pulmonary diseases. Estimates of the fraction of COVID-19 mortality that is attributable to long-term exposure to ambient air pollution increasing those diseases range from 17% n North America, 19% n Europe to 27% n East Asia (Pozzer *et al*. 2020). In the literature review by IANAS (2022), a strong correlation appears between exposure to particulate matter from fossil fuel combustion and high COVID-19 cases and mortality. There is also the possibility that smoke from wildfires increases risk of severe illness. In a recent review of the global literature (Walton *et al*. 2021), it was confirmed that long-term exposure to air pollution before the pandemic increased the risk of hospitalisation in people infected with COVID-19 and increased susceptibility to worse outcomes. There is limited evidence that exposure to air pollution might increase the likelihood of contracting COVID-19. A review of the evidence from *in vitro*, animal and human studies (Bourdrel *et al*. 2021) highlights that both short- and long-term exposure to air pollution may be important aggravating factors for transmission and severity and lethality through multiple mechanisms. IANAS discussed case studies on climate change-COVID-19 interactions in Mexico City (compounding the consequences of socio-economic inequalities arising from urban planning) and in Iquitos in Peruvian Amazon (already experiencing increased incidence of dengue fever).

In policy terms, these and other mutually reinforcing adverse consequences of climate change and COVID-19 crises underpin the importance of progressing coordinated actions for sustainable recovery after the pandemic (Belesova *et al*. 2020b; Guerriero *et al*. 2020). Systems-based coordinated recovery policies must embed the objective to reduce anthropogenic climate change-induced health problems together with objectives for equity (and intergenerational justice) and resilience as part of economic rescue packages (Fears *et al*. 2020b; IAP 2020a,b). Concern has been expressed that some 'green growth' scenarios may achieve reduction in greenhouse gas (GHG) emissions but at the cost of worsening income inequality and unemployment (D'Alessandro *et al*. 2020). However, an analysis of fiscal recovery archetypes in the context of COVID-19 and climate change (Hepburn *et al*. 2020) concluded that well-designed green projects could create more jobs, deliver higher short-term returns on investment and lead to increased long-term cost savings compared with traditional fiscal stimuli.

Use of the systems-based approach can help to obtain the multiple benefits for equity, biodiversity and climate change. For example, as Africa looks to recover from COVID-19, NASAC (2022) recommended that the time is right to set the priority for green transformation, for example via carefully designed carbon pricing mechanisms that reduce rather than increase inequity (Buchs *et al*. 2021): the Green African Transformation (GREAT) Pathways – building Africa–EU partnership on low-carbon development is a

[52] UN Human Rights Office of the High Commissioner 'Indigenous Peoples still face severe challenges due to COVID-19', released on International Day of the World's Indigenous Peoples, 9 August 2021.

good example of inter-regional collaboration. The AASSA (2021) discussion of the various barriers facing national attempts at sustainable recovery, included the examples of India, aiming to use post-pandemic recovery to invest in technology and self-sufficiency, and China, facing a difficult choice in deciding whether to maintain its pandemic-induced transient reduction in fossil fuel consumption. Many countries have indicated their desire to steer at least some of their post-pandemic stimulus spending to green ends, but only Canada and parts of Europe have oriented their stimulus in a way that significantly shifted their trajectory[53]. Other large economies such as the USA, China and India have not to date (vivideconomics assessment of June 2021) managed to fundamentally reorient their trajectory. In many other emerging markets such as Indonesia, the Philippines, Mexico and Russia, the stimulus has not taken on a significant green orientation. So far (UNEP 2021a), the post-COVID-19 opportunity for a low-carbon transformation has been missed and LMICs are being left behind.

In considering lessons learned, IANAS (2022) observed how the pandemic has revealed inherent vulnerabilities in social structures. Lessons learned from the responses to COVID-19 are applicable to the priorities for tackling climate change health effects and updating NDCs (OECD 2020; Chan *et al*. 2021; Marmot *et al*. 2021; Wyns and van Daalen 2021). They include the following:

- Acknowledging the value of reinforcing global solidarity and acting to build collective resilience (see also IAP 2020a).
- Integrating climate action in multi-sectoral development policies, including One Health. As mentioned by AASSA (2021), the COVID-19 pandemic provided a stark (and previously inadequately recognised) example of the need for integration and coordination between multiple arms of government in managing disasters.
- Providing long-term support for country health systems in LMICs and stepping up collective action to provide and protect global public goods.
- Developing strategies and contingencies for international crisis coordination.
- Building back fairer to achieve health equity.
- Promoting bottom-up citizen engagement for health emergency and disaster risk management as part of the objective for creating and using evidence-based systems that are inclusive.

All of these actions must be supported by transformative objectives for cost-effective public health interventions, health and environmental monitoring and the support of international collaborative research efforts (Guerriero *et al*. 2020). As has been summarised for the converging crises (Watts *et al*. 2021), '*At every step and in both cases, acting with a level of urgency proportionate to the scale of the threat, adhering to the best available science, and practising clear and consistent communications, are paramount.*'. It has also been proposed that '*The COVID-19 health security threat offers the opportunity to overcome the predicaments of traditional public health by leapfrogging to lateral public health*' (Semenza 2021), taking a systemic view to involve multiple stakeholders and develop community capacity for climate change risk reduction by connecting party's unequal in power and access.

6.3 Interactions between climate change and biodiversity policy initiatives to support the development of net-zero solutions

The climate change crisis is also a biodiversity crisis;both ar e predominantly caused by human activities, with consequences for human health as well as ecosystems (see

[53] 'Greenness of Stimulus Index', July 2021, https://vivideconomics.com/wp-content/uploads/2021/07/Green-Stimulus-Index-6th-Edition_final-report.pdf.

Dasgupta (2021) for comprehensive discussion on how to value ecosystems). The realisation that factors impacting on human health also drive biodiversity loss and climate change, as well as threatening to breach other planetary boundaries, has led to formulation of the concept of planetary health which emphasises the interdependence of human health on the integrity of natural systems (see above), further reinforcing the necessity of taking a systems-based approach. Climate change and biodiversity influence each other. Rising temperatures, changing precipitation and extreme weather events affect biodiversity in terrestrial, freshwater and marine environments whereas biodiversity secures climate-regulating functions, and ecosystems are major reservoirs of carbon.

Current work by academy networks (IAP 2021; EASAC 2021b) is helping to identify the importance of biodiversity considerations in climate change mitigation and adaptation measures and to make the case for closer integration of policy actions. The concomitant UN 2022 focus on biodiversity (COP15 of the Convention on Biological Diversity, CBD) and climate change (COP27 of the UNFCCC) provides an opportunity to explore interconnectedness and interdependence and the shared evidence base on biodiversity and climate change is now receiving increasing attention jointly by IPCC and IPBES. Portner *et al*. 2021 observed that '… *functional separation creates a risk of incompletely identifying, understanding and dealing with the connections between the two. In the worst case it may lead to taking actions that inadvertently prevent the solution of one or the other, or both issues. It is the nature of complex systems that they have unexpected outcomes and thresholds, but also that the individual parts cannot be managed from one another*' (see EASAC (2021b) for further discussion). Closer coordination between the UNFCCC and CBD might be attained as part of the recently launched UN Decade of Ecosystems Restoration. Some countries are already making progress on shared issues; for example, in South Africa design principles for climate change have been incorporated into existing biodiversity planning to guide land use (NASAC 2022).

Promoting biodiversity and the ecosystem functions associated with it can support climate action in many ways, particularly through well-designed nature-based[54] and community-based solutions, which often encompass both mitigation and adaptation (Royal Society and Academy of Medical Sciences 2021). Specific examples such as in flood protection and forest conservation have been mentioned in previous chapters and there is now a significant evidence base from solution-oriented research on natural options with potential, but as yet mostly unquantified, benefits for health (see Griscom *et al*. (2017), and UNEP and IUCN (2021) for scope and definitions). However, the potential of such solutions to provide the intended benefits has not always been rigorously assessed and there are concerns over their reliability and cost-effectiveness compared with engineered alternatives, and their resilience to continuing climate change (Seddon *et al*. 2020). For example, climate mitigation policy might unhelpfully encourage land use with low biodiversity value, such as afforestation with non-native monoculture or widespread planting of unsuitable bioenergy crops. Particular concerns have been raised in Africa about plans for afforestation of traditional grasslands and savannas (Bond *et al*. 2019) because these biomes already conserve substantial carbon, absorb less solar radiation than forests and represent major areas of biodiversity. Externally funded initiatives to replace traditional African landscapes with plantations need reconsideration and must ensure that local voices are heeded in mitigation and adaptation

[54] Nature-based solutions are defined by the International Union for Conservation of Nature (IUCN) as 'actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits';s ee https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions.

Box 11 Developing principles for the assessment and implementation of nature-based solutions

Transformation: in the way societies consume and produce resources.

Collaboration: governments working with multiple stakeholders including the private sector and civil society. Particular attention should be paid to supporting the customary rights of indigenous communities who are often custodians of biodiverse territories—'territories of life'[56](and see discussion in preceding paragraphs in section 6.3).

Integration: reversing the current separation between policy action on climate change and biodiversity decline in national and international frameworks.

Additionality: when nature-based solutions are implemented to help mitigate climate change, they should not delay or lower ambition to reduce GHG emissions from fossil fuels and other anthropogenic sources or reduce energy use through more energy-efficient technologies.

Best practice: nature-based solutions (and other interventions) should be evidence-based and tailored to the location.

Equity: all climate and environmental policies should acknowledge the goal of a sustainable and equitable future.

Source: adapted from IAP (2021).

decisions[55]. Moreover, worldwide, Indigenous Peoples are often the custodians of the most biodiverse areas (see, for example, Schuster *et al*. (2019) for assessment in Australia, Brazil and Canada;and Fa *et al.* (2020) for analysis worldwide on intact forest landscapes) and may have concerns about the imposition of nature-based solutions that undermine their customary rights (Reyes-García *et al*. 2022).

The recent IAP Statement (2021) reviewed key principles that should underpin the design and use of nature-based solutions for climate action and biodiversity. Box 11 lists these, together with recognition of the rights of Indigenous Peoples.

Further discussion and exemplification of these principles and of specific policy measures that should be encouraged in consequence are provided by IAP (2021), EASAC (2021b) and in the IAP Communiqués (2009, 2019a) on tropical forests.

The IAP assessments show that, although mechanisms to manage and restore ecosystems and address climate change, alongside supporting human health and well-being, are beginning to be understood and available for deployment in terrestrial systems, they are less advanced for marine systems. The previous relative lack of attention to priorities for sustainable oceans is now being redressed (Lubchenko *et al*. 2020), with delineation of the opportunities for a systems-based approach to integrating management of oceans for climate change mitigation, sustainable seafood production and contributions to economic recovery. This extended scope and scale requires coordination of national, regional and global policy actions.

[55] See also the example from Niger of the value of promoting farmer-managed natural regeneration as an alternative to new tree planting (Haglund *et al*. 2011).
[56] See https://report.territoriesoflife.org.

6.4 Cost-effectiveness considerations in implementing policy

One current barrier to implementation of transformative policy rests on assumptions about the high economic costs of change. But does the perception of economic costs inhibit the influence of health co-benefits on the development of mitigation policies (Workman *et al*. 2019) or the implementation of adaptation policies? On the contrary, there is evidence to suggest that including health in the economic analysis of mitigation measures strengthens the case for setting and meeting ambitious policy targets and is likely to boost public support for climate action (Smith *et al*. (2016) and other literature discussed in EASAC (2019a)).

Regional perspectives on economic issues for the health costs of climate change and the cost of solutions are presented by all the regional reports and discussed elsewhere in the literature, for example in terms of offsetting costs of mitigation actions by alleviating the adverse effects of heat on labour productivity (Orlov *et al*. 2020). Modelling demonstrates that the economic value of health co-benefits using the value of a statistical life approach substantially outweighs the policy cost of achieving mitigation targets (1.5 and 2 °C) in all regions and with particularly favourable effects in some, for example in India and China (Markandya *et al*. 2018). According to the IPCC (discussed by Royal Society and Academy of Medical Sciences (2021)), keeping the global temperature rise to 1.5 °C compared with 2 °C would avert many premature deaths (Vicedo-Cabrera *et al*. 2018) and the estimated benefits of these avoided deaths in monetary terms could offset either a large portion, or all, of the initial mitigation costs, depending on context. Examples are also provided in the other literature discussed in the regional reports (especially EASAC and IANAS). A recent review of the evidence for the USA (The Medical Society Consortium on Climate and Health, and others 2021) concluded that the health costs of air pollution and climate change (to health-care systems and the economy) far exceed US$800 billion per year, this estimate probably vastly underestimating true total costs because of limited available health data. The cost is expected to increase considerably in the absence of stronger societal responses.

Differences in health economics methodologies can complicate generalisations about health impacts (EASAC 2019a; Pongsiri and Bassi 2021) and further studies on cost-effectiveness of health effects are warranted, to challenge and clarify the perception that change necessarily entails high costs and to contribute to the broader, transdisciplinary, multi-sectoral evidence base on the relative costs of climate change action and inaction (OECD 2009; Sanderson and O'Neill 2020)[57].

6.5 Climate justice

There are many inequities in the global response to climate change (e.g. Levy and Patz 2015; Romanello *et al*. 2021). The present report has extensively discussed the concern that climate-related effects are unevenly distributed both within and between populations. Examples are also presented in detail in all the regional reports, and IANAS (2022) provided a comprehensive account of climate justice challenges and options. Among the challenges noted in the present report that need to be tackled in pursuit of climate justice are resolving urban socio-economic disparities in identifying climate impacts on health and implementing solutions; addressing the needs of Indigenous Peoples and other vulnerable people; and responding to climate-induced displacement and migration. The topic of climate justice is a large one. The following quote encapsulates the core issue: '*An explicitly equity-focused approach that protects human rights and supports the social fabric necessary for a functioning global*

[57] See also Swiss Re Institute, April 2021 'The economics of climate change: no action is not an option', https://www.swissre.com, concluding that the world stands to lose close to 10% of total economic value by mid-century if climate change stays on the currently anticipated trajectory and the Paris Agreement and 2050 net-zero emissions targets are not met.

society is required to enhance the health of all in an increasingly warm world' (Howard *et al*. 2020).

The Paris Agreement includes the concept of a global stocktake, a process by which progress on climate action is assessed and this includes efforts related to averting, minimising and addressing loss and damage (L&D) (Thomas *et al*. 2020). The Warsaw Warsaw International Mechanism for Loss and Damage (established by COP19) was introduced to cover climate-related risks that will be addressed neither by mitigation nor by adaptation (see Schinko *et al*. (2019) for exposition on linking L&D with notions of distributive and compensatory justice)[58]. Because developed countries have larger financial and technical resources to respond to climate change (their capacity) and have produced most of the emissions to date (their responsibility), they must do more to ameliorate climate-induced L&D in the LMICs. Therefore, high-income countries have a dual obligation: to decrease domestic emissions as fast as technologically and economically possible, and to commit to substantial international cooperation to support LMICs. The health sector – and academies – can serve as a voice for equity worldwide and to articulate to decision-makers the human cost of failing to meet ambitious and equity-related goals (Howard *et al*. 2020). Actions associated with nationally determined contributions (NDCs) are leading to decreases in GHG emissions inequality, but the rate of this decrease in inequality from 2016 to 2030 is projected to slow down compared with 1990–2015;thi s highlights the tension between the pursuit of decreasing GHG emissions inequality and the ambition to lower overall global GHG emissions (Zimm and Nakicenovic 2020).

Unfortunately, social impacts and inequality outcomes of climate change policies received rather little attention in the past, with any detailed discussion narrowly focused or scattered across disciplines in specific contexts (Markkanen and Anger-Kraavi 2019). Now, however, rights-based litigation is increasingly used as a channel to clarify the obligation of conduct that countries have in order to avoid dangerous climate change for themselves, and for others because of their extraterritorial emissions, for the present and for future generations (see discussion in Pihl *et al*. (2021)). Recent updates on the status of global climate change litigation (UNEP 2021c; Setzer and Higham 2021) emphasise the increasing momentum in initiatives compelling governments and companies to pursue more ambitious climate change mitigation and adaptation goals. There is a particular increase in the number of strategic cases: those that aim to bring about some broader societal shift. One relevant field of advancing science making an increasing contribution to climate lawsuits (Schiermeier 2021) is source attribution, which seeks to identify the relative contributions that different economic sectors and activities have made to climate change. It is also now important to bring in other scientific evidence relevant to climate lawsuits (Schiermeier 2021), in particular to clarify the linkage to adverse health effects.

With regard to the particular consideration of L&D, despite its inclusion in IPCC reports and processes, there remain significant research gaps that need to be filled to enable the desired, robust global stocktake (Thomas *et al*. 2020). L&D research needs include a higher proportion of work originating in LMICs and reflecting their experience and perspectives. Unfortunately, synthesis of the evidence base to clarify risks and limits and to initiate transformative approaches is complicated because many relevant research strands may not use the 'L&D' terminology. Moreover, there must be a new emphasis on losses other than economic losses: most damage functions used to monetise the impacts of carbon emissions

[58] At the World Science Forum in 2019, IAP, EASAC and IIASA organised a session on 'Climate justice for managing climate change risks in health'. Among the presentations was a review of opportunities for the climate adaptation community to support insurance and other forms of pro-active disaster assistance;s ee www.interacademies.org/news/iap-world-science-forum-2019.

have been developed largely by economists without participation by health researchers. This, too, is an opportunity for health professionals to inform climate policy directly (Scovronick *et al*. 2019).

Academies and their regional networks are well placed to support LMICs in making their voices heard about transdisciplinary research priorities and the use of research outputs to inform climate justice.

6.6 Sustainable Development Goals

Many of the issues discussed in this report are relevant to multiple SDGs (Figure 29).

The many linkages are reviewed in detail in the regional reports. Understanding and tackling climate change is critically important to addressing the SDGs. Climate change threatens progress on the SDGs and will have even greater impact on achievement of sustainable development in the decades

Figure 29 SDG interrelationships for climate change and health. Key points for the most relevant SDGs are identified on the basis of the assessments in the regional reports.

beyond 2020. It is vital to take the opportunity to monitor indicators relevant to planetary health as part of the SDG agenda (EASAC 2019a) and to report on this progress nationally, regionally and globally. AASSA (2021) discussed that, whereas countries have flexibility to incorporate multiple benefits and address trade-offs and unintended consequences of decisions made in other sectors on health, there is a common problem of lack of integration at the local level. IANAS (2022) noted the importance of equity considerations for SDGs. As described by NASAC (2022), monitoring of SDG performance shows that many countries are falling behind, and climate change will further threaten progress towards the SDGs. Climate change will have even greater impact on the achievement of sustainable development in the years beyond 2030 so that the issues for climate change are central to discussions on what strategy should be put in place to come after the SDGs in 2030 (EASAC 2019a).

There has been a surge of international agendas to address a range of shared challenges, including Climate Change (Paris Agreement), sustainable development (Agenda 2030), disaster risk reduction (Sendai Framework), biodiversity (Convention on Biological Diversity) and sustainable food systems (UN Food Systems Summit). Health is relevant to all of these agendas (Bowen *et al*. 2021). Objectives to combat the fragmentation of the policy landscape, achieve better coherence between agendas and maximise national-level implementation provide further support for the conclusion that health must be considered in interlinked, multi-sectoral and transdisciplinary terms. '*Identifying and implementing interventions to protect planetary health requires a systems-based understanding of their interconnections and feedbacks …Pl anetary health can be operationalised by the explicit identification of multiple benefits and trade-offs for human health and natural systems of decisions affecting environmental change, consistent with the SDGs*' (Pongsiri *et al*. 2019).

To reiterate a point made earlier, well-designed mitigation and adaptation strategies can support progress towards multiple SDGs (Figure 29) whereas poorly designed interventions may have adverse effects on SDGs. The comparative study of the SDGs and NDCs (Cohen *et al*. 2021a) emphasises the relevance of employing the mitigation co-benefits approach more generally in assessing SDG benefits and trade-offs. For example, many strategies to mitigate emissions of short-lived climate pollutants, such as clean household energy or healthier low GHG diets, can also advance progress towards the SDGs (Haines *et al*. 2017). The UNDRR report (2020) on systemic risk emphasises that inability to understand and manage systemic risk jeopardises the SDGs. The IAP (2019) report on SDGs provides a range of interconnected recommendations on how academies and the wider science community can help to improve scientific input in supporting SDGs, including imparting greater rigour in clarifying, refining, analysing and monitoring targets and their indicators (see also EASAC 2019a). The scientific community has also worked closely with the United Nations Department of Economic and Social Affairs in reviewing the science for achieving progress towards all the SDGs (UNDESA 2019).

7 Conclusions and recommendations

7.1 Key messages: what do we know and why are we concerned?

At the COP26 meeting in November 2021, there were multiple side-events discussing climate and health. Notwithstanding this interest, health issues were not prominent in the political discussions and health was mentioned only once in the Glasgow Climate Pact[1]: '*Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of Indigenous Peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity*'.

This relative lack of political focus on health must change. As emphasised in the previous chapters, adverse health consequences of climate change can arise from diverse direct and indirect pathways, necessitating action coordinated for scope and scale. In the view of IAP, the vital importance of climate and health issues will require higher visibility in COP27 and other international discussions. The impacts are here and now, are a clear and present danger, and must be regarded as a global health emergency.

On the basis of the evidence reviewed in previous chapters about the scientific opportunities and challenges for tackling climate effects on health, we also reaffirm our starting premise that potential solutions must integrate mitigation and adaptation although the balance of these and the specific policies required will vary according to context. There is sufficient evidence available to act now. The EASAC (2019a) report listed seven key messages: these have been reinforced by the large volume of research findings appearing since 2019 and by the comprehensive IAP assessments in Africa, Asia and the Americas.

These key messages are as follows:

- **Climate change is happening and is attributable to human activity**. The global IAP project has proved valuable in encompassing spatial-temporal, socio-economic and political variation within and between regions, to articulate the shared threats. Climate change is posing urgent challenges to development plans, growth and equity, and with risks also to cultures as well as to health – the main subject of this report – and the environment.

- **Climate change poses serious threats to human physical and mental health and health eqit y that are already apparent.** Climate change is already impacting on everyone, everywhere, but certain population groups are increasingly vulnerable and experience a disproportionate burden of health effects. Equity is at the core of an effective response; solutions must be distributed fairly and barriers to participation by those most affected must be collectively dismantled.

- **There is a need for better monitoring and surveillance of potential health impacts due to climate change across all countries**, including assessment of the effects of other environmental changes (e.g. deforestation, pollution, freshwater depletion) that may interact with climate change to influence health. The concept of Planetary Health Watch (Haines *et al*. 2018; Belesova *et al*. 2020a) can help to drive improved coordination and monitoring worldwide.

- **Rapid and decisive climate action could greatly reduce the long-term risks to health from climate change** and bring near-term benefits for health, including through reduced air pollution. Every increment of heat matters: health risks are substantially lower at 1.5 than 2 °C.

- **Actions to tackle climate change and health impacts are urgent.** In addition to the health, equity and environmental gains, low-carbon development options can offer new economic opportunities subject to resources, capacities and governance.

- **Health within a region is also affected by activities that contribute to climate changes outside that region**, for example air pollution that is co-emitted when fossil fuels are burnt. International cooperation on solutions is essential.

- **Solutions are within reach** using present knowledge; mitigation and adaptation experience is growing, but action requires political will.

- **The scientific community has important roles also in generating new knowledge on cost-effective technologies, policies and implementation strategies and in countering misinformation and addressing equity in climate–health responses.** This requires international partnership and correction to the current bias in designing, conducting and reporting research studies.

- **While modelling studies can provide useful insights into the magnitude of benefits from adaptation and mitigation actions there is a pressing need for better evaluation** of implemented actions to quantify benefits, trade-offs and costs and to document facilitators and barriers to change, in conjunction with the better monitoring and surveillance recommended in the concept of Planetary Health Watch.

Following the inception of the COVID-19 pandemic, there is an additional key message:

- **Climate change intersects with and exacerbates other global health challenges including COVID-19.** The COVID-19 pandemic also provides important lessons about responding to global challenges through cooperation, rapid mobilisation at large scale and investment in evidence-based solutions.

These key messages are reinforced by the most recent *Lancet* Countdown and IPCC assessments (Romanello *et al*. 2021; Boxes 1 and 2) reporting alarming trends in many health-related exposures associated with climate change. COP26 climate negotiations unfolded in the context of the COVID-19 pandemic '*a global health crisis that has claimed millions of lives, affected livelihoods and communities around the globe, and exposed deep fissures and inequities in the world's capacity to cope with, and respond to, health emergencies. Yet, in its response to both crises, the world is faced with an unprecedented opportunity to ensure a healthy future for all*' (Romanello *et al*. 2021).

All of the IAP's project's regional outputs have emphasised the importance of taking a transdisciplinary, systems-based approach to transformative change, integrating mitigation and adaptation policies to benefit health, based on shared approaches to measure climate impacts and quantify solutions, to support prioritisation of action in vulnerable groups and in pursuit of equity.

Our global report appears during a period when other international bodies are reaching related conclusions. In its COP26 Special Report, WHO (2021d) lists key entry points to mainstream health in the international climate regime and SDG agenda (Box 12).

The Science Academies of the Group of Seven (G7) (2021), in their focus on a net-zero climate-resilient future, also acknowledged that climate adaptation and mitigation systems must be developed to go beyond climate action, for example to improve human health, ensure food and water security and reduce poverty and inequality. Health statements

Box 12 Recommendations from WHO COP26 Special Report on climate change and health

1. Commit to a healthy recovery from COVID-19.
2. Place health and social justice at the heart of the UN climate talks.
3. Prioritise those climate interventions with the largest health, social and economic gains.
4. Build climate-resilient health systems and support health adaptation and resilience across sectors.
5. Guide a rapid transition to renewable energy systems that protect climate and health.
6. Promote sustainable, healthy urban design and transport systems.
7. Protect and restore nature and ecosystems.
8. Promote healthy, sustainable and resilient food systems.
9. Finance a healthier, greener future to save lives.
10. Mobilise and support the health community on climate change.

Text adapted from WHO 2021d

by governments of the G7 (2021[59]) and G20 (2021[60]) were inevitably dominated by COVID-19 but also emphasised wider ranging points:

- Implementing global health solutions, strengthening global health and health security architecture; investing in human, animal and environmental health systems; domestic preparedness to foster resilient populations and supporting vulnerable countries to do the same (G7)[61].
- Health-in-all-policies; strengthening health systems for transformative resilience approach; recognising importance of climate change and ecosystem degradation in health (G20)[62].

7.2 Barriers to implementation

The evidence discussed in our report also helps to understand the barriers to implementation of solutions, providing guidance to academies and others in the scientific community on how to dismantle these barriers. Many of the impediments have been noted in previous chapters and in the work of the regional groups; they are summarised in Table 5 and will be addressed further in our recommendations.

7.3 What is distinctive about this IAP report?

How can the present report and other continuing scientific inquiry best add value to the many other voices calling for transformative change? There is a large literature on how to maximise the impact of science on informing and delivering health outcomes. For example, Ari *et al*. (2020) developed a science impact framework that recognises five domains of influence on health: disseminating science, creating awareness, catalysing action, effecting change, and shaping the future. As the global network of academies, IAP has the potential to be active in each of these domains.

Based on our experience in conducting this project, we suggest that the distinctive project design has been of value in pursuing the objective we noted in chapters 1 and 2. That is, generating and using research

[59] https://www.g7uk.org/g7-health-ministers-meeting-communique-oxford-4-june-2021/.
[60] https://ec.europa.eu/commission/presscorner/detail/pt/statement_21_2622.
[61] G7 Carbis Bay Health Declaration, https://www.g7uk.org/wp-content/uploads/2021/07/G7-Carbis-Bay-Health-Declaration-PDF-389KB-4-pages.pdf.
[62] Declaration of the G20 Health Ministers, Rome, September 2021.

Table 5 Tackling barriers to implementing solutions

Obstacle to implementing solutions	Clarifying and resolving obstacles: sources of further information
1. Lack of resources and lack of appropriate prioritisation of available resources	Discussed in all regional reports for example with regard to resources for R&D, investment in infrastructure and new technologies, support for accessible, resilient and affordable health systems, local and national government adoption of adaptation measures, and implementation of science-based mechanisms to inform policy options. Whereas about two-thirds of the NDCs cite the importance of health most of them lack detailed consideration of health benefits of adaptation and mitigation. Less than 0.5% of multilateral climate finance is allocated to health projects (WHO 2021d): this proportion must be increased.
2. Insufficient focus on vulnerable groups and structures for their effective participation in planning, policy and practice	All regional reports highlight the need to focus on vulnerable groups, including the elderly, children, women, Indigenous Peoples, and those regions where there is increased exposure to climate hazards. Specific vulnerabilities are compounded by poverty and inequity. Prioritisation of limited resources is discussed in all regional reports and in the global report in terms of climate justice. Vulnerable groups must also be much more involved in the local-global processes to effect change.
3. Limited access to data	Particular issues for LMICs where access to external data is expensive for bodies outside government. Moreover, there may be only limited opportunities for collaboration to produce own data. There is general need for better monitoring and surveillance and better evidence about effective actions (Planetary Health Watch).
4. 'Lock-in' to old technologies	Problems reside in many sectors (e.g. energy, construction, transportation, agriculture). Innovative technologies can be applied by LMICs to 'leapfrog' old technologies that depend on use of fossil fuels or unsustainable patterns of production and consumption.
5. Lack of public engagement and awareness	A challenge for all countries (especially regarding awareness of indirect pathways for impact). Health is of particular interest to the public when appraising the benefits of acting on climate change (e.g. EASAC 2019a; Jennings *et al.* 2020) and there is the opportunity for the health sector to lead in advocating transformative change. Increasing public interest also spurs increasing political interest at national and local governmental levels.
6. Opposition from vested interests	Vested commercial and political interests often oppose rapid phase-out of fossil fuels, withdrawal of subsidies and effective carbon pricing (Whitmee *et al.* 2021). See EASAC (2019a, 2021b) and chapter 6 for a discussion of mostly unsubstantiated assumptions about cost of action and lack of political awareness of costs of inaction. Regional reports noted various other examples of barriers imposed by vested interests such as in local planning policy.
7. Misaligned economic costs and financing—existing subsidies to fossil fuels and inadequate carbon pricing	See Appendix 4 of present report and chapter 4, and the following sections in chapter 7, making the case for removal of such subsidies and other financing, and introduction of equitable pricing mechanisms.

in supporting, monitoring and evaluating innovation, public policy and practice, by the following means:

- Taking an inclusive and transdisciplinary perspective.
- Documenting and communicating the scientific evidence base in support of mitigation and adaptation solutions and sharing examples of good practice between regions.
- Identifying policy options, based on objective and evidence-based inputs, even if challenging and controversial, by comparison with the work of others (such as the IPCC) that is required to be neutral with respect to policy. Clarifying what can be tackled at national and regional (continental) policy levels, what requires collaboration worldwide, and how science-based policy action can be integrated both between different levels of governance and different sectors.

7.4 Framework for developing recommendations for building and using the evidence base

Some messages demand repetition. Climate change is an emergency and IAP reaffirms that the top priority must be urgently to stabilise climate and accelerate efforts to limit GHG emissions to achieve zero-GHG emission economies as soon as possible. The need for concerted and radical action has been promised at COP26. There is hope, despite the obstacles and obfuscation: for example, the proportion of renewable energy is increasing and employment in low-carbon industries is rising (Romanello *et al*. 2021).

Our health-focused, recommendations are as follows:

Recommendation 1:U sing the evidence already available to inform policy with greater urgency and ambition

Although there are many research gaps still to fill, this should not be used as an excuse to delay acting on the best evidence currently available for health-in-all-policies. The previous chapters show where and how there is enough evidence available now to act. The scientific community has a vital role to develop and communicate the science relevant for policy-making (and for guiding practice and driving innovation) as well as in filling research gaps. This role is applicable at national, regional and global levels.

National level

Many policy solutions are advanced at a national level, including mitigation and adaptation in target sectors. Now it is increasingly important to take account of the health implications for climate change policy integration in all sectors and to bring the interventions to scale. We emphasise that there must be more commitment from policy-makers to integrate health effectively into NDCs and NAPs. For example, NDCs must contain sufficient detail on health objectives, aligned with emission targets and must represent increased ambition. The health-care sector itself is an important location for mitigation action and its support by multiple public policies. Similarly, NAPs must contain sufficient detail on health and on the resources required to enable decision-making. There must also be better integration of individual mitigation and adaptation measures, hitherto often applied in a fragmented way, accompanied by increased political commitment to implement policies that already exist and to use the available evidence to change policies (Beggs *et al*. 2021).

A core theme, pervasive throughout this report, has been the importance of taking account of health effects in all policies for climate action. There is much still to be done in this regard. For example, a systematic review of the UK literature (Brimicombe *et al*. 2021) found that extreme heat exposure is often an invisible risk whose impacts on health are not always recognised and, in consequence, there is insufficient policy action to prepare for direct or indirect effects of heat on health. Moreover, national strategies must also be well-connected with more local policies (Oktari *et al*. 2022), for example in cities and other local authorities, for adaptation and mitigation and it has been proposed that these interconnections could be facilitated by local scientific platforms to encourage cooperation with scientists in local decision-making[63].

Regional level

In addition to required national actions, health policy objectives have regional considerations (Figure 30) when there are cross-border threats: for example, emerging from infectious diseases or air pollution; and when action is enhanced by the critical mass afforded by multiple countries in a region, for example to support research infrastructure and research priorities (see section 5.9).

Current models of regional policy development in the EU (EASAC 2019a) and African

[63] See, for example in the EU, work by the European Committee of the Regions, 'Opportunities and synergies of a precautionary adaptation to climate change to promote sustainability and quality of life in regions and municipalities: which framework conditions are required for this?' ENVE-VII/010 2020. See also the proposed European Commission's Adaptation Mission Implementation Plan, as a stimulus for local action.

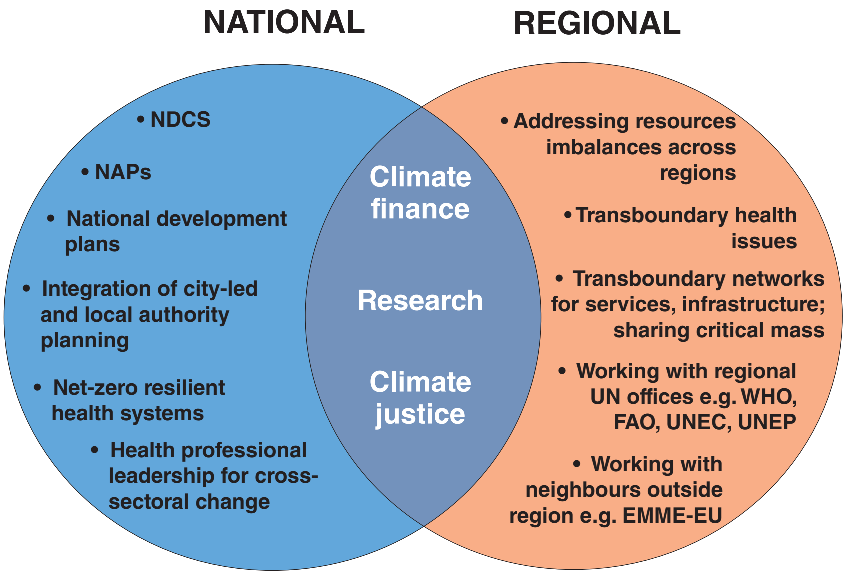


Figure 30 Navigating the policy matrix: roles and responsibilities for tackling health effects of climate change. Although some roles are dominant at different levels, there are also major shared responsibilities.

Union (NASAC 2022) and their attendant science–policy interfaces exemplify particular opportunities for engagement within continents. Continental-level interfaces also provide the opportunity for equitable inter-continental partnership, for example the EU–Africa strategy based on converging interests in areas including tackling climate change[64], and a basis for partnership with neighbouring countries. There are other models for regional partnership, for example via the regional office activities of the UN system (Figure 30): academies with their established convening and advisory roles at national, regional–continental and global levels can help to support integrating these frameworks. Other regional models are under development, for example arising from the work of the EMME-CCI (see footnote 8) that has brought scientists and policy-makers together with the objective to tackle shared problems with feasible, affordable solutions embedded in a broader policy framework.

Global level

In addition to national and regional policy action based on shared goals for supporting climate research, climate action and climate justice, there is considerable scope for integration at the global level to underpin the objectives for an inclusive transition for health, social justice, intergenerational equity, sustainability and survivability. Some of the practical challenges for embedding adaptation and mitigation solutions worldwide include the following:

- *The need for coherence in intergovernmental policy.* There are significant opportunities as part of collective action on the SDGs, One Health, disaster risk reduction, and the current discussions within the UN FCCC, UN FSS and UN CBD. Coordinated action does need to acknowledge that there may be necessary differences in timescales, for example between the immediate response in a disaster reduction strategy and long-term action on resilience in indirect climate–health pathways. As emphasised frequently in all of the IAP project reports, it is essential to take account of the health implications of policy in other sectors in addition to the health sector, including

[64] See European Parliamentary Research Service 'A new EU-Africa strategy – a partnership for sustainable and inclusive development' PE 690-515, March 2021; and the European Commission joint Communication 'Towards a comprehensive strategy for Africa' JOIN (2020) 4 final, March 2020.

energy, agriculture, transportation, urban design and construction.

- *Financing agreed changes.* While much action on climate change will be cost-effective, there are implications for the financial status quo, including the potential for stranded assets such as coal and oil to damage some economies. As emphasised recently (WHO 2021a), the Paris Agreement rulebook is essential to ensure ambitious actions to deliver the agreed goals, which include ensuring that a portion of the proceeds from carbon markets are allocated to adaptation finance, aligned with the emphasis on health and social justice and action on L&D. And as discussed in previous chapters and Appendix 4, financial reform must include cessation of subsidies and other public financing for fossil fuels and other polluting activities, and the removal of harmful agricultural subsidies (e.g. on intensively produced meat, palm oil and sugar). Recent examination of country case studies at COP26 suggests that most food system subsidies create perverse incentives to destroy natural ecosystems and increase GHG emissions while failing to promote food security[65]. Redirecting harmful subsidies to support universal health coverage, public transport, affordable healthy food choices and other policies that improve health, reduce GHG emissions and promote equity could be key to achieving public and political support (see also Buchs *et al*. 2021).

- *Identifying and financing transformative change.* There are major related challenges to be tackled (Whitmee *et al*. 2021). Policy-making is typically focused on maximising GDP growth but this does not account for the costs of damaging externalities such as air pollution and climate change. Further consideration must be given to developing alternatives to GDP in order to monitor societal well-being (Stiglitz *et al*. 2009; EASAC 2019a). And other major action is essential in tackling climate change and its consequences if the objectives of near-term equity and longer-term intergenerational fairness are to be realistic: for example, reviving policy interest in personal carbon allowances (Nerini *et al*. (2021), discussed further in Appendix 4), to deliver health and other societal benefits, could be an important national–regional–global objective.

- *Convergence of policy action on climate change, biodiversity and food systems.* As noted previously (chapter 6), IAP has recommended greater convergence between policy action for climate change and for biodiversity and the prospect of convergence is facilitated by the commitment of science-based intergovernmental advisory panels (IPCC and IPBES; Portner *et al*. (2021)). A case can also be made for further convergence, between policy action for both climate change and biodiversity with action for food systems, in which case an equivalent science-based intergovernmental advisory panel for food systems might be desirable (IAP 2018; von Braun *et al*. 2021; Fears and Canales 2021).

- *Other intergovernmental initiatives.* Action is also possible as part of G7 and G20 Presidency's initiatives, and when linked to other strategic initiatives worldwide in pursuit of the circular economy and bioeconomy to integrate supply-side and demand-side considerations. In the past decade, there has been a surge of international agendas to address global challenges. A focus on human health helps to catalyse the strengthening and linkage of these agendas (Bowen *et al*. 2021; Willetts *et al*. 2022) and helps to inform the design of cross-sectoral action to be context-specific and culturally sensitive.

[65] SDG Knowledge Hub, November 2021 'COP26 events show climate ties to locust upsurge, adaptation in agriculture'.

- *Addressing synergies, conflicts and trade-offs.* Integration of mitigation and adaptation policy approaches depends on better quantification of policy actions. Currently there is often a lack of information on best practice in policy implementation or mechanisms to provide feedback on current initiatives to improve future policy development, while also taking account of new evidence or changing circumstances. Of course, the need for policy coherence is not unique to climate change: for example linkages must be made with food systems policy where there is also a need to correct misalignment between support for agricultural production through harmful subsidies and recommendations on sustainable dietary guidelines.

- *Responding to concurrent crises such as climate change and COVID-19*. There are multiple implications for the health sector as previously described. We emphasise here the significance of the potential for delivery of sustainable recovery post-COVID-19 with the opportunity to pursue a low-carbon trajectory and benefits to health, equity and the environment as well as to economic growth. This potential opportunity must not be wasted.

Recommendation 2:Filling know ledge gaps by research

Attending to evidence gaps requires sustained commitment both to basic research[66], the fundamental resource for all discovery and innovation, and support for the transdisciplinary health research agenda, based on a systems approach with cross-sectoral integration.

It is not the purpose of the present report to be comprehensive in identifying individual research priorities for resolving current uncertainties, but many transdisciplinary needs have been mentioned in previous chapters and in all the regional reports (e.g. mental health and nutrition outcomes have been relatively understudied). Certain types of research to produce actionable knowledge (e.g. long-term observation of cohorts, critically relevant to the point made previously about better monitoring; analysis of exposure–response functions; characterisation of tipping points) must be augmented everywhere, as must the evaluation of adaptation and mitigation actions including health risk assessment of new technology development and implementation.

The current research enterprise worldwide is skewed and there is insufficient representation by LMICs (and highly exposed regions such as the Arctic and SIDS) in the design, conduct and use of research. The regional reports describe opportunities for international collaborative research, strengthening systems for R&D and for education and training. Research partnerships between regions must be based on agenda setting for mutual interests and with equality in decision-making between partners. There are instances of good practice even in regions beset by political differences. For example, the SESAME project for scientific cooperation developed by UNESCO (United Nations Educational, Scientific and Cultural Organization), focusing on countries in the Middle East region[67] exchanging data and supporting scientific infrastructure, where a key factor in success has been scientific willingness in the participating countries.

The design of research must also take more account of the issues for systematically and transparently assessing how much confidence to place in different types of research evidence when informing judgements about policy options to

[66] It is timely to emphasise the global importance of basic research as the UN International Year of Basic Science for Sustainable Development will start in mid-2022: https://www.iybssd2022.org/en/home.
[67] https://en.unesco.org/sesame-history, an initiative on synchrotron light for experimental science and applications. While this project has some specific relevance for tackling climate change, for example in its research on soil health, groundwater pollution and development of novel materials for carbon capture and storage, it also may represent a general model for use on other themes for scientific cooperation and linkage with innovation and policy development.

address health and health system problems (Lewin *et al*. 2012). This requires, among other things, consistent use of standardised procedures for health impact assessment. The rapidly increasing number of publications on climate and health research also means that policy-makers and others must assess large amounts of information, and this, too, can present a barrier to effective action. As noted several times previously, there is a core role for evidence synthesis including the use of machine learning approaches to enhance efficiency of undertaking systematic reviews (Berrang-Ford *et al*. 2021b) and research mapping exercises.

Data integration is an essential part of evidence synthesis but the traditions for using evidence to inform policy have been rather different in the health and environmental change communities (Minx *et al*. 2019). Both approaches have been highly important in evidence synthesis in their own fields but there are weaknesses: for example, on the one hand, the narrow, disciplinary-focused approach in health does not readily lend itself to understanding grand challenges for planetary health; on the other, outside the modelling community, there has been a dearth of systematic review methods and their communities of practice in studying global environmental change (Minx *et al*. 2019). It is important to do more to bring these two traditions together.

As also emphasised in all the regional reports, stakeholders, for example farmers, patients and Indigenous Peoples, must be involved in the co-design of research for agreed objectives and endpoints. Co-design and the utilisation of diverse evidence streams necessitates supporting qualitative as well as quantitative research to understand the lived experiences of climate change impacts on health outcomes, as well as the contexts within which adaptation and mitigation efforts unfold. As also discussed in the regional reports, there are emerging opportunities to use citizen science and social media in data collection, if subject to rigorous scientific standards. Furthermore, co-production of knowledge with stakeholders helps build user receptivity at the science–policy interface.

Recommendation 3:St rengthening monitoring and surveillance activities that link health and climate

There is a need to link well characterised population cohorts and data from demographic and health surveillance sites to climate and other environmental data. This will facilitate detection and attribution of health effects to human-induced climate change. New initiatives should additionally encompass data on socio-economic determinants of health because these modulate the effect of climate change on health and are themselves affected by climate change, for example increases in poverty due to declines in labour productivity and crop yields. Data on health impacts can also connect to climate services including early-warning systems. As discussed in the regional reports, there are many data challenges still to resolve including issues for standardisation of data collection (and with real-time, empirical data), interoperability between different systems, data organisation, curation and sharing. The objective must be for development of open access data repositories and use of consolidated, standardised data in applications including delivery of climate services. One other challenge for collecting and using data is the high degree of micro-climate variation within some areas, including cities. This will necessitate increasingly fine-scale climate and health data collection.

The recent inception of the European Climate and Health Observatory[68] provides a useful model which, we suggest, could be replicated in other regions and extended globally; but

[68] https://climate-adapt.eea.europa.eu/observatory.

it requires political will and international collaboration and sustained investment to develop and share good practice.

Recommendation 4: Improving evaluation of impacts of climate mitigation and adaptation actions on GHG emissions and health

All countries must undertake comprehensive health and climate change vulnerability assessments to provide the basis for action. Whereas there is a rapidly accumulating evidence base on climate change effects on health, there is more to be done to clarify the degree to which adverse effects are attributable to climate change, location-specific, population group-specific or disease-specific (Rocklov *et al*. 2021). Furthermore, there is only limited information available to quantify solutions and understand which responses are most cost effective at protecting human health. The potential positive effects of adaptation are less well understood than for mitigation and their frequent exclusion in modelling studies leads to overall uncertainty in predictions (Rocklov *et al*. 2021).

There is relatively little information available on how to scale up solutions, how better to characterise some of the obstacles to implementation, how to resolve unintended adverse effects and how to capture synergies including those between adaptation and mitigation[69]. Nonetheless, data on the health and economic impacts of potential solutions are particularly important in convincing policy-makers and the public, and in motivating their action.

Recommendation 5: Effective health risk communication and countering misinformation

There is now considerable awareness worldwide of the risks of climate change but there is still much more to do to raise awareness of the current and future effects on health and the opportunities for mitigation and adaptation (see Table 5). Scientists have a responsibility to engage widely in developing and evaluating the impacts of adaptation and mitigation options. Examples in this report and the regional reports describe the value of involving marginalised groups and lay communities more generally in research and its implementation in guiding practice, for example early-warning systems, sustainable dietary recommendations and urban management.

There are research gaps to fill in social science in order to understand individual and institutional behaviour, support stakeholder empowerment and influence change. It is imperative to counter misinformation and denial of scientific knowledge by vested interests and so reduce polarisation in public and policy debates. Furthermore, systematic review (Reynolds *et al*. 2020) shows that public support for a policy can be increased by communicating evidence of its effectiveness: this realisation helps to substantiate a role for academies and others in the scientific community to communicate about policy impact as well as policy formulation, to help bridge between policy-makers and the public (Fears *et al*. 2020a). In framing climate change as a human health issue, health professionals have particular roles and responsibility in advising on climate policy (Rossa-Roccor *et al*. 2021) and the health benefits of effective mitigation and adaptation action.

Health professionals can also be champions of change in the community by advising on how climate change risks health, how to equitably support adoption of sustainable, healthy lifestyles and how to elicit transformative action in their own and other sectors (Xie *et al*. 2018; Luong *et al*. 2021; Oktari *et al*. 2022). Health professionals identify climate change as the biggest threat to the future of global health and advise that governments

[69] In addition to examples of potential synergies discussed in previous chapters, for example planting fire-resistant trees and developing alternative dietary protein sources.

and health bodies are not doing enough to prepare for future impacts[70]. A large majority of these health professionals also agree that misinformation and anti-science pose a dangerous threat to the future of health care.

Recommendation 6:Ident ifying and implementing continuing academy roles in support of science as a public goodf— rom ambition to action.

The strong convening powers of academies together with their traditions of scientific excellence enable the gathering of information from across disciplines and from other knowledge sources, sharing perspectives between sectors and countries, and fostering cooperation in setting and monitoring priorities, within the broad context of the SDGs. Academies worldwide are developing considerable experience in bringing together public policy-makers and the scientific community. Academies vary in these capacities, but all share a common goal to do more in strengthening linkages—and one of the internal objectives of the present project was to disseminate good practice and build capacity at the science–policy interface. As described previously, two of the priorities for academies and their networks are (1) to engage actively within the UN system worldwide; and (2) to examine and advise on national commitments and plans relating to health and climate change.

The IAP framework facilitates integration of academy action at multiple scales to communicate the seriousness of the problems, to engage with policy-makers and the scientific community more widely – including younger researchers – and other stakeholder groups. Specific examples of activities have been discussed in the project's regional reports and this global report; we take the opportunity here to emphasise general points, according to level of governance:

- **Country level.** National policy-makers are sometimes hesitant to act if evidence for climate effects on health is not available for their own territory. Academies can help by communicating how the evidence available from elsewhere is relevant to the local setting. In addition, academies can help to advocate and support an increased focus on health in NDCs, coupled with advising on greater representation of science and health expertise in national negotiating teams. Academies could also play a greater role in advocating for, and engaging in, better monitoring, surveillance and assessment of health impacts and their attribution to climate change and the evaluation of policies and interventions. Academies can help by taking account of local health profiles, ecosystems and cultures and by linking local action with regional and global pathways of transformative change as these emerge. Academy reports are regarded as credible sources of information and can be influential in informing a wide range of stakeholder groups and the public-at-large (e.g. as seen by the impact of US National Academies consensus reports Hicks *et al.* (2022)).

- **Regional level.** Policy decisions depend on more than scientific evidence and must also take into account, for example societal attitudes towards risk and other social values as well as political economy. There is significant variation in attitudes and values within and between regions: academies are well placed to help policy-makers understand diversity and the barriers and facilitators of change so that policy can be science-based, economically and socially feasible.

- **Global level.** The very wide geographical coverage of IAP is valuable in representing the voices of those – from LMICs and vulnerable populations – who are not

[70] For example, Royal Society of Tropical Medicine and Hygiene, UK 2019: https://rstmh.org/sites/default/files/files/GlobalHealthReport.pdf.

always heard during the processes whereby evidence informs international policy. In incorporating those voices, IAP can and does play a role in emphasising issues for health equity and climate justice, and in holding policy-makers to account. IAP's role as a voice for global science can help to support the broad science-and-society objective recently articulated (Anon. 2022c): '*Ensuring diversity and inclusion in the scientific community could reduce the elite image of science and change power dynamics in knowledge-generating pathways*'.

There is emerging evidence in several countries that independent expert advisory groups can inform the design and delivery of ambitious climate policy (Dudley *et al*. 2021): helping governments raise ambition, increasing public support for climate action, and enabling a longer-term strategic vision. Academies can play an increasingly important role in these expert advisory activities, and IAP and its member academies are committed to supporting further analysis, engagement and action at all levels on the matters raised in our reports.

In conclusion, we have emphasised in our reports that, despite the considerable diversity in geography, socio-economic status and health systems, as well as in scientific infrastructure, research capabilities and the degree to which research outputs are used to guide policy and practice, there are commonalities and opportunities to foster mutual learning. These include sharing knowledge of the challenges to health posed by climate change, in the need to develop resilient and equitable health systems and to address fragmentation and skewed distribution of research systems and knowledge use. Climate change is a health crisis as well as an environmental and economic one.

Some have suggested that COP26 was the last and best opportunity to set the path for net-zero in 2050. At the time of writing our report, the longer-term impacts of COP26 deliberations are unknown. But what we do know is that there are continuing opportunities – and great urgency – to use the evidence base already available, and to build on scientific advances worldwide, to develop mitigation and adaptation solutions, with cooperative intent, and customised according to context. Building on COP26, COP27 in 2022 provides a major opportunity to generate a higher profile for health in climate change discussions about mitigation and adaptation solutions.

Appendix 1 Summaries of all four regional reports

The imperative of climate action to protect human health in Europe

Summary of EASAC policy report 38

The pace and extent of climate change pose serious challenges to global health gains made over recent decades. In its report on 'The imperative of climate action to protect human health in Europe', the European Academies' Science Advisory Council (EASAC) focuses on the consequences of climate change for human health in the European Union (EU), recognising that climate change effects in other regions have tangible consequences for Europe and that the EU has roles and responsibilities in addressing problems outside its area. Although the EU is very actively engaged in collective efforts to reduce greenhouse gas (GHGS) emissions and to identify suitable adaptation measures, the impacts of climate on health have been relatively neglected in EU policy. This must change. EASAC's concern is motivated by 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 are increasing over time.
- Rapid and decisive action to cut GHGS emissions sufficiently to keep temperature increase below 2 °C above pre-industrial level could greatly reduce risks to health.
- Climate change will have effects on health within the boundaries of the EU, and the EU should also be concerned about the effects of climate change on the health of populations outside the EU.
- Solutions are within reach and much can be done to reduce risks 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.

In this report, EASAC advises on (1) using the available evidence to inform coherent health policy development for climate change mitigation and adaptation strategies, and their connection to other policy initiatives; and (2) the priorities for filling knowledge gaps through transdisciplinary and intersectoral research. The EASAC Working Group provided detailed evaluation of a broad range of scientific evidence, and drew the following **conclusions**:

1. **Climate change poses major risks to health in the EU** via both direct effects (e.g. due to increased exposure to extreme heat and floods) and effects mediated through ecosystems and socio-economic systems. Climate change can increase risks of communicable and non-communicable diseases (including mental illness), and injuries. Among the most vulnerable groups are likely to be the elderly, the sick, children, and migrating and marginalised populations. City dwellers are exposed to higher levels of heat stress than rural populations because of the urban heat island effect. Without prompt and effective action, the problems are forecast to worsen considerably.
2. Despite challenges in attribution**, there is growing evidence that climate change is having effects on health** associated with high temperatures,

wildfires, flooding, changes in infectious disease transmission and in allergens. 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.

3. **The Arctic and the Mediterranean region** are the European territories likely to be **most vulnerable** to the effects of climate change with consequences for the rest of the EU.

4. Projected future effects on health depend on the magnitude of climate change and the adaptive responses made. Despite uncertainty on temporal and spatial scale, robust projections suggest **an increasingly negative balance of effects on health**. Climate change will also affect the ability of health systems to function effectively, particularly when confronted by climate extremes.

5. Responding to climate change **requires integrated strategies for mitigation** (reducing GHGS emissions) **and adaptation**. Certain mitigation actions will also bring ancillary (co)-benefits for health. For example, a zero-carbon economy would potentially avert several hundred thousand deaths annually in the EU from air pollution caused by fossil fuel combustion. Major health benefits are also likely to accrue from policies to mitigate the contribution of agriculture to GHGS emissions and from adaptation to increasing threats from infectious disease, heat, and other direct and indirect effects of climate change.

6. Although many adaptation and mitigation plans have been compiled across the EU, **concrete objectives for health are often weak**. Health impact assessment should be part of all proposed initiatives, and monitoring should link climate and health data to assess the effectiveness of adaptation and mitigation strategies.

7. **Health co-benefits of mitigation can be clearly identified**, but optimisation of individual initiatives requires adoption of systems thinking to identify potential for synergies, inadvertent consequences and trade-offs. Similarly, systems approaches are required to ensure adaptation strategies achieve their intended effects.

8. **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 national level. EU-level action on health should be increased where appropriate, alongside the specific actions at country level that need to be taken by EU Member States.

9. The **economic benefits** of action to address the current and prospective health effects of climate change **are likely to be substantial**. More work is needed on methodologies for economic valuation of costs and benefits, and on identifying alternatives to gross domestic product as a measure of societal progress.

10. **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 of climate change and health. It is vital to counter misperceptions that may be fostered deliberately by those with vested interests.

As an overarching recommendation, EASAC reaffirms the top priority is urgently to stabilise climate and accelerate efforts to limit GHGS emissions, with the aim of achieving a zero-carbon economy before 2050. In addition, collective priorities include building better strategic links between different research and policy communities; resolution of EU-level versus Member State responsibilities and effective integration of roles; and consideration of the effects of decisions by the EU on neighbouring countries and the rest of the world, and the implications of changes elsewhere for the EU.

Priorities for linking research outputs and policy development continue to be the following:

- 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.

EASAC's recommendations pertaining to human health can be summarised as follows:

Health-in-all-policies: Make best use of the current evidence base to develop coherent and coordinated EU policy framework to encompass benefits to health as a major consideration in adaptation and mitigation actions, including the following:

- Reform of the EU Adaptation Strategy to increase focus on health consequences of climate change.
- Health impact assessment in all climate change adaptation and mitigation strategies.
- Development of healthy, climate-smart food systems, with corresponding modifications of the Common Agricultural Policy.
- Development and promotion of dietary guidelines for sustainable healthy diets, including consideration of when and, if so, how the EU and Member States should use health and/or environmental criteria to influence food system policies.
- Linkage of climate change and health objectives into all key EU domestic policies, for example for reducing air pollution, and neighbouring country and international development policy initiatives.
- Continue to build links between EU climate and health policies with global organisations such as the World Health Organization, Group of Seven (G7) and Group of Twenty (G20), and with collective action on the United Nations Sustainable Development Goals (SDGs) and the United Nations Framework Convention on Climate Change (UNFCCC). Health considerations should be integrated into the implementation of nationally determined contributions (NDCs) under the Paris Climate Agreement.

Fill knowledge gaps through research and integration of data sets: Alongside continued commitment to basic research, further research is needed to characterise alternative scenarios, tipping points, effective adaptation and mitigation strategies, as is improved surveillance and linkage between environmental, socio-economic and health data.

Health risk communication: 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.

The full report was published in June 2019. It is available at https://easac.eu/publications/details/the-imperative-of-climate-action-to-protect-human-health-in-europe/.

The imperative of climate action to promote and protect health in Asia

Executive summary

Climate change poses a significant threat on human health, especially with the progression of global warming, hazards due to severe heat spells, and heavy rainfall predicted to increase further. Asia and Oceania, which experiences the full range of global climate variations, has been identified as one of the most vulnerable regions in the world to the effects of climate change. A range of environmental factors have direct and indirect effects on human health: the availability of clean air, potable water, safe food, exposure to hazards, pathogens, and toxins, as well as several social, behavioural, and genetic factors determine the health and well-being of individuals and communities. Scientific and governmental organisations in this region have continued to explore the current and potential threats of climate change to human health. On the basis of the evidence that has been gathered, there is a need for further exploration of the topic, to ensure that adequate and timely strategies are used to prevent and mitigate the effects of climate change on human health. In its report on 'The imperative of climate action to promote and protect health in Asia', The Association of Academies and Societies of Sciences in Asia (AASSA) addresses how climate change has affected the spatio-temporal, socio-economic, and political variations within Asia and Oceania. AASSA recognises that areas lacking technological advancement and development require a different set of criteria and approaches to assess the health and well-being of their citizens. The COVID-19 pandemic has exposed the underlying vulnerability of this region to common diseases and their subsequent dire effects including deaths. There is a need for real-time and accurate data across Asia and Oceania, which requires the collection of both primary and secondary data and models with an appropriate feedback system. AASSA recommends a multi-sectorial framework to embrace a coherent approach. The health sector should be an active participant in discussions, action planning, and implementation on climate change issues in collaboration with other economic areas and activities.

The main objectives of this report are the following.

- To emphasise that climate change is happening on a wide regional scale and escalating.
- To emphasise the significance of climate change effects on health through multiple pathways. To identify regional variations on impacts, solutions, science-based evidence, avenues for regional cooperation for mitigation, etc.
- To fill knowledge gaps by suggested new research, increased transdisciplinary and intersectoral information sharing on the overlooked public health issues associated with climate change.
- To accumulate and use the evidence on the health impacts of climate change from the reports to emphasise the basis for coherent health policy development for climate change mitigation and adaptation strategies.
- To increase responsiveness to the health impacts of climate change as well as promoting actions that improve health while reducing greenhouse gas emissions.
- To clarify the public health issues associated with climate change that should be addressed through multilateral collaboration.
- To highlight the common needs for national planning, for example public awareness, development of health-care facilities, education and training, research and knowledge implementation, financial resources, and government support in policy development.

Impact and challenges

The relationship between climate change and health is complex, and it is imperative to understand these complexities to formulate policies that can mitigate the direct and indirect effects of climate change. The impacts of climate change on health will need to be better documented, especially in developing nations where the effects on health will be felt the most owing to the vulnerable population groups in these countries. Quantification of the magnitude and severity of these health impacts is greatly needed. Reducing poverty is a key step to be taken by policy-makers to promote the health of future generations in these countries. In certain areas, we have experienced some **health impacts of climate change**:

- excess mortality due to heat has increased, especially among the elderly;
- heat stress from rising temperatures will increase heat-related excess mortality and morbidity; an increase in the frequency of extremely hot days, leading to a higher risk of outdoor heatstroke;
- exposure to night-time heat disrupts sleep, which results in mental and physical stress;
- a rise in temperature and an increase in precipitation during the monsoon;
- changes in the risks and the epidemic patterns of gastroenteritis, water-/foodborne diseases, and certain viral infections;
- shifts and expansion in the geographical distribution of vectors (e.g. mosquitoes) due to higher ambient temperatures have resulted in the widespread incidence of VBDs (e.g. dengue and malaria) and increased mobility;
- increasing risk of simultaneous disasters, for example sediment disasters, flooding, and storm surges, which have more pronounced impacts than a single event;
- an increasing concentration of ozone, which will increase ozone-related mortality; and
- increasing unreported mental health status among youth and certain groups of people who are seriously affected by climate change.

These impacts are a few among many of the effects of climate change on human health. As millions of people's livelihoods across Asia and Oceania depend on natural resources, the damage caused is enormous. A higher temperature jeopardises human health. At the same time, there are several **challenges in climate change** that are shared among countries in Asia and Oceania, but which vary in their intensity and frequency, as described below.

1. There is insufficient awareness that climate change affects human health through various pathways. While direct health impacts, such as mortality from heat and flood, are well recognised, there is a lack of comprehensive understanding about direct and indirect health impacts because of their complex causal pathways.
2. Although there has been an increased awareness of the health impacts of climate change, mitigation and adaptation of health systems are planned and executed in a fragmented manner.
3. Unlike most fields of study and areas of influence within a country, the medical community seems to be largely detached from the imminent threat of climate-related health effects. The medical community must emerge as the leaders in the study, thought, innovation, and influence in decision-making of climate-related health effects and its mitigation as well as in adaptation initiatives and policies.
4. It is difficult to develop reliable models of the impacts of climate change because of insufficient retrospective climate and health data. This is further complicated by very high microclimatic variations including geographical variations within short distances.
5. The costs of buying climate and other meteorological data are very high for researchers and governmental bodies. It is, therefore, necessary for international governments to agree to free access of such data for research and surveillance purposes.

6. There is a shortage of appropriate personnel and human resources for disease surveillance, including environmental scientists, entomologists, environmental health experts, and climate modelling experts. Governments should encourage students to study these fields and show potential for growth, by offering scholarships, learning opportunities, and fellowships.
7. Some regulations and a lack of clear institutional strategies and mandates make it difficult to establish an integrated disease surveillance and early-warning system. It is important to assess the internal and external environments of health systems, focusing on policy implementation and making sure that adequate resources are available.
8. The difficulty in developing a coherent strategy across multiple sectors.
9. A clear gap is noted in the integration of common goals of climate change health policies at national and state levels. Most health policies at the state level are found to be flawed with vested development interests rather than improving health qualities. There is a need for better integration of policies and planning across different scales and levels.
10. Compared with the direct impacts, studies of the indirect impacts on health, especially quantitative assessments, have been very limited.
11. Policy-making should account for vulnerability in the health impacts of climate change. It is well recognised that the elderly is vulnerable to heat stress. Fewer studies have examined the influence of socio-economic status on health effects of climate change even though many are aware of health disparity.
12. Lack of implementation of the policies that are already in place to mitigate effects as well as amend and add policies periodically that consider the unpredictable nature of climate change.
13. Life-threatening changes are expected to occur such as changes in the hydrological cycle, melting of land and sea glaciers, narrowing in glacial areas, rising sea levels, sliding of climate zones, and frequent extreme weather events.
14. Climate change also adversely affects health needs such as fresh air, clean water, adequate nutrition, and healthy shelter requirements. Climate change will negatively affect water quality and accessibility. In some regions, in countries where food is cooked with biomass, nutritional deficiencies can be seen more because of famine and lack of access to clean water as a result of desertification.
15. The rising air temperature will directly affect socio-economic (industry and agriculture), ecosystem, and ecological systems as well as human life, particularly in developing countries.
16. The decrease or disappearance of transportation potential directly and indirectly affects human health.
17. The impact of climate change on the human immune system has been well documented (undernutrition, psychological stress, and exposure to ultraviolet light). These pathways are likely to weaken the immune system and make populations, especially children, more susceptible to recurring infections, allergies, and development of autoimmune diseases as well as cancer.

Recommendations according to evidence-based data

Scientific evidence is essential for policy-making to prevent the health impacts of climate change. AASSA's report summarises the policy suggestions and directions for adaptation and mitigation and clarifies the current research gaps. These actions should also accompany social transformation towards sustainable development. AASSA's recommendations pertaining to human health can be summarised as follows.

1. **Education and training**
    - Awareness-raising activities should be implemented at the social and individual levels as well as in various interest groups (non-governmental organisations and non-profit organisations) to prevent and minimise the negative effects of climate change on health.
    - Training of human resources for climate change actions should be accelerated. Trained workforce capacity in the field of climate change and health should be increased and a common language should be established on health impacts.

2. **Research and knowledge implementations**
    - Currently, there are several platforms across multiple sectors. However, there is always room for improvement in terms of comprehensive health impact assessment spanning different sectors, with the theme of health as a common denominator. Improving the multi-sectorial framework is warranted in every country and regional grouping to prepare a coherent strategy across multiple sectors.
    - Effective health risk communication is also an important part of adaptation for climate change.
    - Studies should be made on how to reduce the susceptibility of vulnerable groups.
    - Databases should be developed to reveal the relationship between climate change and health.
    - Continuous data collection and monitoring of infrastructure should be strengthened to examine the climate change process more actively and to develop action plans. As there are various health effects of climate change, developing specific and systematic surveys and monitoring programmes for heat-related health outcomes are required.
    - Meteorological information, warnings and alerts, and information on prevention and adaptations should be provided through cooperation with relevant ministries and agencies in the nations and regions.
    - Geographical heterogeneity in health effects should be considered. A country is vulnerable to natural disasters because of its climate and topography. As such, policies for climate change adaptation in that country should consider natural disasters.
    - Conduct mapping of vulnerability and health impacts to understand which populations are under the risk of what threat and implement interventions to safeguard against the acute and chronic effects of climate change on human health. Pay more attention to translating the health impacts to economic costs in the policy-making process.
    - Ministries and government departments that are entrusted with the health of their people should mobilise existing infrastructure to identify and implement early-warning components of the effects of climate change on health.
    - Technological innovations to counter climate change, alleviate its health risks, and aid in adaptation should be explored. This is best done nationally and regionally by focus group discussions of concerned experts. Cooperation between all parties should be developed and capacity should be increased. Interdisciplinary and cross-sectoral studies should accelerate.

3. **Integrated health-care facilities, services, and implementation**
    - The health sector should be an active participant in discussions, action planning, and implementation of all actions on climate change issues led by other sectors (e.g. food systems, air pollution, etc.).

- It is crucial to ensure health is integrated across the climate change spectrum of initiatives and interventions, and to mobilise existing infrastructure to identify and implement early-warning components of the effects of climate change on health.
- Immigrants and asylum-seekers as well as other vulnerable groups, such as the young, women, and the elderly, should be followed up with a good monitoring programme.
- Stress the immediacy of policy implementation by creating a rapid response team that can effectively implement disease monitoring and surveillance, disaster evaluation, response and adaptation, and proper communication of risks and measures to vulnerable populations.

4. **Government support in policy development**
   - Although individual action plays a crucial role for adaptation to climate change, political will by governments is demanded to transform societies. Decision-makers should focus their attention on protecting human health against the high-level impacts of climate change.
   - While providing solutions to the negative effects of climate change on health, solutions covering global health risks and all segments of society should also be produced.
5. **Financial aid and adequate resources**
   - Almost all adaptation and mitigation initiatives and policies have emphasised climate change as a major threat to public health, but very few and limited budgets have been allocated for health sectors.
   - Ensure a sustainable and healthy recovery from COVID-19 that reduces carbon emissions and protects human health.
   - Investment decisions made after COVID-19 stimulus plans will shape energy systems and the public's health for years to come. Thus, post-pandemic economic recovery plans should prioritise renewable energy expansion and improvements in energy efficiency.

The full report was published in November 2021.It is available at http://www.aassa.asia/achievements/achievements.php?bbs_data=aWR4PTE4MyZzdGFydFBhZ2U9MCZsaXN0Tm89JnRhYmxlPWNzX2Jic19kYXRhJmNvZGU9YWNoaWV2ZW1lbnQmc2VhcmNoX2l0ZW09JnNlYXJjaF9vcmRlcj0=||&bgu=view

Taking action against climate change will benefit health and advance health equity in the Americas

Summary

Climate change is impacting health now

Climate change is affecting the Americas. We have already experienced record-breaking increases in mean and extreme temperatures, lengthened wildfire seasons, increased intensity and frequency of extreme precipitation and floods, ocean warming, permafrost thaw, increased drought, increased aridity, sea level rise, and coastal flooding and erosion. The impacts of these events have widespread and sweeping implications for the entire planet, presenting an urgent global public health challenge.

This report focuses on the ways in which climate change is affecting human health throughout the Americas. The report documents how climate change is increasing heat-related morbidity and mortality, increasing air pollution-related disease and death, threatening nutrition and food security, challenging mental health and wellbeing, damaging respiratory health, and increasing the incidence and prevalence of waterborne, foodborne, and vector-borne illnesses throughout the Americas (Figure 1 below).

The report assesses options for reducing the impacts of climate change on human health. It offers recommendations for climate-resilient pathways forward that are transdisciplinary in structure and underpinned

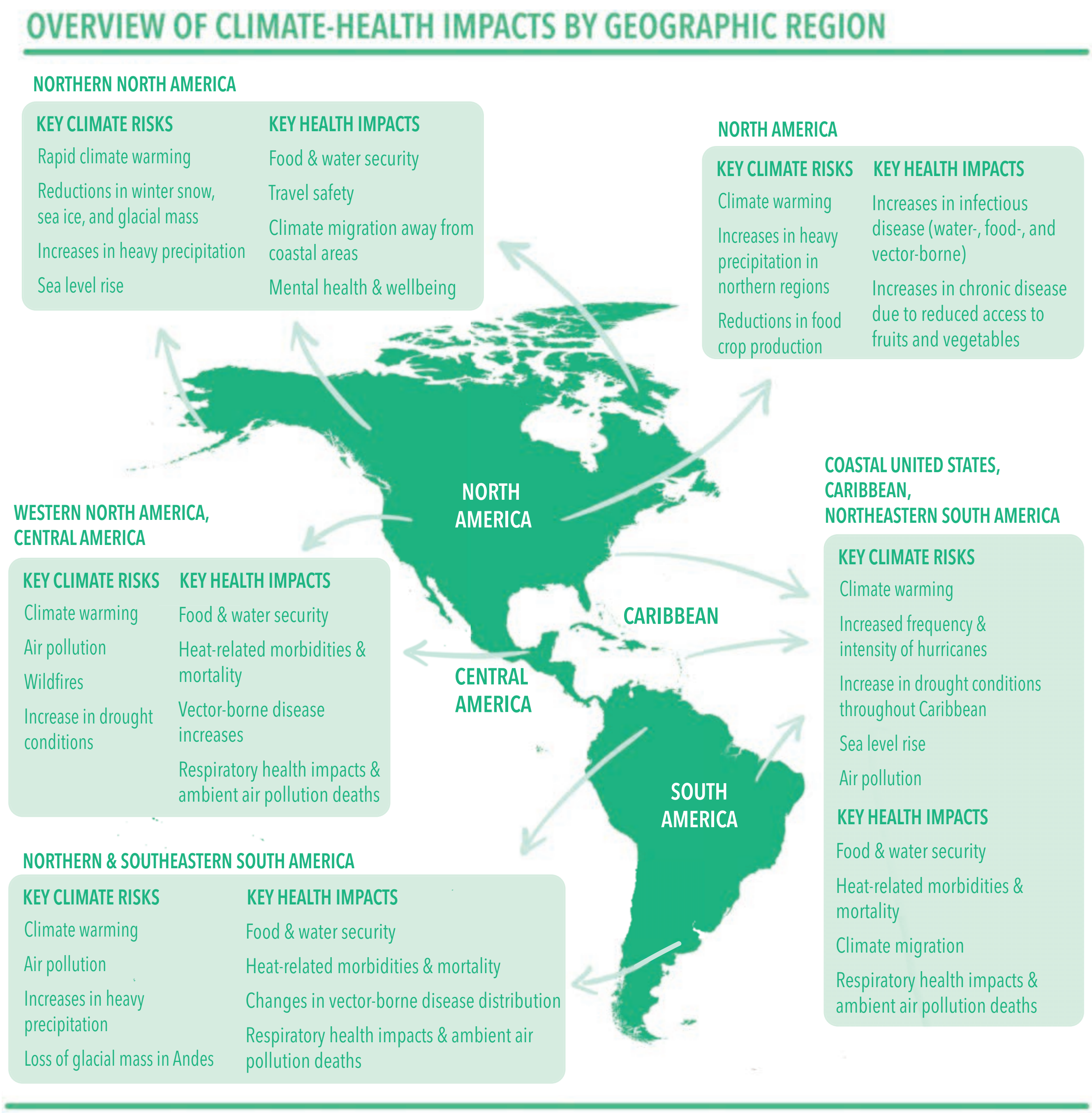


Figure 1 Summary of the climate change hazards and key health impacts by location in the Americas.

by principles of equity, human rights, and social justice.

Climate change converges with and compounds other health crises

This report comes at a time when the effects of the climate crisis on human health have converged with the effects of the COVID-19 pandemic. Over the past two years, health systems have had to respond to COVID-19 as well as the impacts of record-breaking heatwaves, intense storms and disasters, and wildfires. For example, in July 2020 Hurricane Hanna made landfall in southern Texas at a time when the state was experiencing the highest COVID-19 hospitalization incidence in the United States. Efforts to evacuate and provide shelter for people while simultaneously limiting viral transmission presented difficult logistical challenges, and residents who chose not to evacuate due to fear of COVID-19 increased their risk of injury and drowning.

Both crises are pertinent reminders of how the interconnectedness of social, environmental, and climatic factors have exacerbated existing social and health inequities. Many factors that increase vulnerability to climate change impacts, such as age, sex and gender, socio-economic status, and environmental degradation, also increase vulnerability to COVID-19. Thus, it is essential that we move forward with preparedness and robust response planning that consider and incorporate issues of equity and social justice.

Climate change action will improve human health in the Americas

Health systems must coordinate with other sectors to adapt to climate change

Climate change has already negatively impacted health in the Americas. In this report, we address how our health systems can adapt to cope with current and expected climate change and simultaneously reduce harmful health impacts through both adaptation and mitigation efforts. Examples of climate change adaptations include the following: (i) raising public awareness of climate–health risks including improved climate–health education in schools; (ii) developing heat action plans; (iii) modifying the built environment to cope with higher temperatures; (iv) explicitly incorporating health provisions into disaster risk management plans; (v) establishing and frequently testing early warning and response systems; (vi) incorporating mental health impacts into disaster risk management; (vii) developing integrated environment and health surveillance and response systems; and (viii) improving access to key services, including improved water, sanitation, and hygiene systems. Importantly, when developing adaptation strategies to reduce the health impacts of climate change, it is essential that the health sector coordinates its efforts with other sectors, including water and sanitation, energy, food production, transportation, housing, education, and land use planning.

The Americas need adaptation strategies, policies, programs, and the finances to build climate-resilient and environmentally sustainable health and healthcare systems. This report outlines how assessments of the vulnerability of regions, populations, and individuals, as well as evaluations of the capacity of governments, organizations, and individuals to prepare for and manage changes in the magnitude and pattern of risks, have been used to establish a knowledge base of current and projected climate–health risks in the Americas. These assessments are important for informing the health components of national adaptation plans (HNAPs), nationally determined contributions, and other key climate change planning, programming, and response policies.

But there are limits to our ability to adapt to future climate change, as currently effective adaptations may become inadequate over the medium- to longer-term. Furthermore, it is critical to understand that adaptations designed without sufficient attention to equity, and the needs of the most vulnerable, may increase risks or shift risks across groups. Therefore, this report identifies situations where health systems might face intolerable risks due to the extent of climate change alone or in combination with physiological, institutional, technological, social, behavioral, or economic factors. For example, climatic conditions could significantly change the geographic range of vectors carrying climate-sensitive infectious diseases, thereby placing stress on health systems already facing capacity constraints or on those not yet equipped to manage those diseases. Similarly, if average global temperature increases exceed 2°C, outdoor workers in several Latin American countries could experience extreme heat conditions that exceed the threshold for safe moderate physical labor during the hottest months of the year. These impacts are likely to increase poverty and inequities, with the potential to undermine or reverse previous gains made towards the United Nations Sustainable Development Goals.

Ambitious climate change mitigation can produce both immediate and long-term health benefits

There are clear benefits to drastically reducing greenhouse gas (GHG) emissions to meet the Paris Agreement targets, including reduced health risks in the coming decades; however, there are also immediate and nearer-term benefits of mitigation against climate change. This report provides examples of how climate change mitigation can improve human health and reduce health-care costs here and now, providing decision-makers with an important rationale to take more aggressive action now.

- Phasing out the use of coal will produce major benefits for the environment and human health in the Americas. In addition to reducing global GHG) emissions, coal phase-out will immediately reduce the burden of disease, disability, and premature death from air pollution-related cardiovascular disease, respiratory disease, lung cancer, premature birth, and neurodevelopmental disorders in infants and children.

- Road traffic currently accounts for nearly three-quarters of transport-related emissions, which, based on current trends, will only increase. Modifying transportation systems to reduce emissions can provide both environmental and health benefits. For example, the construction of safe, affordable, and reliable public transport systems and the use of active transport methods (e.g. cycling, walking, and running) reduce emissions while providing important health benefits, including significant reductions in ischaemic heart disease, cerebrovascular disease, depression, and diabetes.

- The food production system contributes an estimated 20–30% of global GHGS emissions. Because livestock production contributes substantially more to GHGS emissions than plant-based products, this represents a critical area of focus for mitigation. Reducing the consumption of animal-based food products would also have health co-benefits. Diets low in red and processed meats and high in fruit, vegetables, and legumes are associated with reduced mortality and lower risk of cardiovascular disease, coronary heart disease, and colorectal cancer. However, equity and justice must be carefully considered in these mitigation efforts. Indeed, dietary transitions may not have the same impact, or be appropriate, in all settings.

Addressing equity and justice underpins effective climate change actions that improve health

Climate change affects the health of all people, but the burden is not distributed evenly or fairly. Instead, it falls most heavily on minorities, those in low socio-economic conditions, and the marginalized, and is influenced by intersecting factors such as health status, social, economic, and environmental conditions, and governance structures. Climate change impacts exacerbate insecurities and injustices currently experienced by vulnerable populations, many of which are founded in injustices such as colonialism, racisms, discrimination, oppression, and development challenges. This report examines climate change health risks for various vulnerable groups, and emphasizes that health-related adaptation and mitigation efforts must prioritize Indigenous Peoples, aging populations, children, women and girls, those living in challenging socioeconomic settings, and geographically vulnerable populations.

This report also highlights how the integrity and legitimacy of decisions made by governing bodies in response to climate change rely on the extent to which equity and justice are incorporated in decision-making processes and their respective outcomes. It presents equity and justice considerations for decision-makers, including distributional, procedural, capability, and recognition considerations in all climate–health actions.

Evidence-based recommendations support an emergency response to climate change

Based on the assessment and knowledge synthesis provided in this report, we have arrived at the following key conclusions:

- Climate change is already impacting everyone, everywhere – but the magnitude and distribution of those impacts vary.
- Every degree (Celsius) of climate warming matters in the Americas, emphasizing the importance of taking all possible actions to limit warming to well below 2°C.
- Climate change intersects with, and exacerbates, other global challenges such as COVID-19. The current pandemic has highlighted the intersections between climate, environment, and society, and has demonstrated how these factors can exacerbate existing health and social inequities in the Americas. COVID-19 also provides us with important lessons about responding to grand global challenges through cooperation and rapid mobilization at large scale.
- Equity is at the core of effective responses. Globally, groups that are socially, politically, and geographically excluded are at the highest risk of health impacts from climate change, yet they are not adequately represented in the evidence base. Therefore, equity at the local, regional, and international scale must be at the forefront of research and policy responses moving forward.
- Actions taken now to build climate–health resilience will reduce future risks. Investing in climate-resilient infrastructure, programming, and healthcare systems will support adaptation and decrease future health risks from climate change.
- A "health-in-all-policies" response will support climate change adaptation and mitigation actions to help meet the goals of the Paris Agreement, will have co-benefits for health, and will support the achievement of key international initiatives such as the Sustainable Development Goals and Sendai Framework for Disaster Risk Reduction targets and priorities.
- A focus on building climate–health research momentum in the Americas is needed. The body of literature is growing, and yet climate–health interactions are still understudied compared with other areas of climate research. Continuing efforts to build the evidence base are needed, particularly for regions of the Americas that are currently underrepresented in the literature, such as the Caribbean, Central America, and South America.
- Cross-sectoral and global collaboration is crucial. Addressing research gaps and acting on the current evidence base will require intersectional, intersectoral, and interdisciplinary approaches that bring decision-makers together with microbiologists, epidemiologists, social scientists, environmental scientists, engineers, economists, demographers, and climatologists.

The full report was published in March 2022.

Protecting human health against climate change in Africa

Summary

The synthesis report of COP26 illustrates the compelling evidence linking climate change and health supported by leading climate scientists from around the world (IPCC, 2020). Considering the gravity posed by Africa being the most vulnerable continent for adverse effects on health, leading scientists from Africa, under the aegis of the Network of African Science Academies (NASAC), critically reviewed the evidence linking climate change to health in Africa and formulated evidence-based recommendations to mitigate and adapt to the threats of climate change that can be viewed as a health disaster in the making. If these threats are not addressed now, climate change will destroy the lives and livelihoods of millions of Africans and impede future development on the continent.

NASAC's objectives in this project are to advise on the following aspects:

1. To assess the status of climate change and its adverse health consequences in order to make policy-level recommendations that African governments should consider when dealing with climate change and resilience in Africa.

2. To advocate evidence-based policy and practical solutions for climate change mitigation and adaptation strategies.

3. To identify and prioritise existing knowledge gaps with respect to the risks to health and to promote research to fill the knowledge gaps and find solutions for the following questions:
   (a) What are the levels of risks?
   (b) What are the major associated health risks?
   (c) Who are the vulnerable populations?
   (d) Under what conditions are vulnerable communities exposed to climate change?

4. What are the tipping points beyond which irreversible changes will occur?

5. How can we balance economic development with health protection in all sectors so that there is synchrony in building a resilient health system?

Previous work by NASAC has highlighted climate change adaptations and resilience in Africa, and a separate publication has characterised the changing disease patterns ('Climate Change Adaptation and Resilience in Africa: Recommendations to Policymakers'; http://nasaconline.org/wp-content/uploads/2016/09/Climate-Change-Adaptation-and-Resilience-Recommendations-to-Policymakers-WEBi.pdf). In the present report we extend our work into a single compilation on climate change and health, and update the most recent developments in the field. The information contained in this report provides African governments with an important knowledge base for formulating their national policies and stating their positions in international climate change negotiations. Climate change is being addressed in Africa by various organisation including the World Health Organization (WHO), United Nations Framework Convention on Climate Change (UNFCCC), African Union (AU) and others. Ours is a synthesis report specifically focusing on climate change and health in Africa. NASAC's main messages, based on our assessment, are as follows.

Main findings of the NASAC report

- *The African continent is the most vulnerable to the adverse health effects of climate change*
  The vulnerability of the African continent to the adverse effects of climate change stems from four fronts: (1) physical factors imparting its unique topology and climate; (2) the high prevalence of climatic hazards; (3) pre-existing disease that could potentially be amplified by climate change; (4) its health systems are not resilient enough to cope with the accrued burden of climate-sensitive diseases; and (5) poverty levels and other social determinants of vulnerable groups that confer on them inadequate adaptive and coping mechanisms. In combination, these factors confer a high vulnerability to adverse effects of climate change.
- ○ Physically, Africa consists of 60% of dry land mass; 38% of which is desert and crossed by the Equator and both Tropics, conferring a variety of climates and topologies with varying vulnerability to adverse effects of climate change.
  - ○ The continent has a high prevalence of climatic hazards marked by rising temperature and sea levels and extreme weather conditions increasing the risk of hydrological disasters, forest fires, and air and water pollutants.
  - ○ The disease burden due to climate change is the highest in the world, with roughly 120 deaths per 1 million inhabitants annually. This burden

comprises heat-related complications, drought, floods, famine, malnutrition, non-communicable diseases (especially stroke) and mental health issues such as being demoralised as a result of climate change. The projections for these conditions and other climate-sensitive adverse effects such as vector-borne diseases and air pollution are dire.
  - The health system is not resilient enough to cope with any surge in the burden of diseases, as amply illustrated during the continuing outbreaks of Ebola virus, influenza and the ongoing COVID-19 pandemic.
  - Poverty, lack of infrastructure and other social determinants undermine the coping capacities of vulnerable populations.

- *Climate change is happening now in Africa, and its impacts are already being felt*
  There is strong evidence that warming over land across Africa has increased over the past 50–100 years and climate change has already altered the magnitude and frequency of some extreme weather events in Africa. This is amply illustrated by temperature rise melting the icecap of the Kilimanjaro mountains; the increased droughts recorded in countries of Western Africa; periodic flash floods observed in Central Africa; and sea-level rise leading to coastal erosion in Northern and West Africa.

- *Further climate change is inevitable in the coming decades*
  Modelling shows that the temperatures on the African continent are likely to rise more quickly than in other land areas, particularly in the more arid regions of central and Southern Africa, leading to desertification. Extreme weather is projected to lead to more frequent cyclones in Eastern and Southern Africa, as has already been observed in the past decade.

- *The health, livelihoods and food security of people in Africa have been affected by climate change*
  Climate change will invariably result in an increase in climate-sensitive diseases, leading to deaths in many cases or severe disability and mental health. The climatic hazards may act singly or in various combinations to have a cascading effect from one sector to another. Climate change will alter the incidence and geographic range of vectors and concomitantly vector-borne diseases. In addition, climate change will create pressure on water resources; consequently, reduced crop productivity, leading to food insecurity may be further aggravated by crop failure due to drought, floods and pest infestation.

- *Climate change also challenges growth and development in Africa*
  The United Nations Sustainable Development Goals (SDGs) are linked and inherently affected by climate change. The COVID-19 pandemic has already adversely affected the health and economies of Africa. The convergence of adverse effects of climate change and the COVID-19 pandemic will affect fundamental social and economic policy goals such as growth, equity and sustainable development.

- *Data on climate change in Africa are dispersed and scanty*
  Although the evidence for climate change and its adverse effects is compelling, precise information on the prevalence of climatic hazards and diseases over extended periods and regions is scanty and dispersed and the most poorly characterised of all continents. Although most African countries have instituted integrated disease surveillance with help of the WHO, event-based surveillance using the EWARS[71] method is virtually non-existent for climatic hazards and climate-sensitive diseases There is

[71] EWARS, early-warning system, a tool for surveillance.

limited information on data gathered from national government sources. In synthesising our evidence, we used various sources ranging from case studies, anecdotal data, research to projections; all are in urgent need of being updated.

- *Statistical modelling supports the role of adaptation and mitigation in reducing the impacts of climate change in Africa.* The impacts of adaptation and mitigation measures for selected climatic hazards such as heat, diarrhoea and malnutrition, vector-borne diseases and non-communicable diseases have been characterised specifically for the African continent to the year 2030 and beyond. All the evidence points to the fact that timely implementation of adaptation and mitigation measures will considerably save lives and livelihood.

- *Health adaptation and mitigation are not adequately planned in Africa* Over the past decade, many countries across Africa have adopted increasingly comprehensive development plans with ambitious social and economic development objectives. Several African governments, such as Ethiopia and Rwanda, have adopted national climate-resilience strategies with a view to applying them across economic sectors. Although most African countries mention health in their Nationally Determined Contributions (NDCs), in practice very few have included a strategic plan for the health component in their National Adaptation Plan (NAP), resulting in insufficient climatic actions for health protection.

- *International cooperation to avert adverse climate change is limited in Africa.* Several UN agencies including the UNFCCC, United Nations Environment Programme (UNEP) and WHO are involved in climate actions in Africa. However, there is a dearth of international non-governmental organisations, international research institutes and academia supporting the fight against climate change in Africa.

Key cross-cutting recommendations of the NASAC report[72]

On the basis of the evidence reviewed in this report, including that from the case studies, and considering previous work in this field, the working group formulated the following recommendations.

1. *Policy*. Climate policy is central to guiding programmatic actions and ensuring consistency and continuity. Although many international and regional policies are available to planners, to ensure inclusion of the health component in climate change, a national policy is of paramount importance.
   - Update policy to reflect emerging and current issues or expected pathways on national climate change and health.
   - Incorporate health in the Nationally Determined Contribution (NDC) during formulation of the national health adaptation plan as proposed by the Libreville Declaration. This will ensure inclusion of the health ministry in planning, monitoring and accessing available climate funds.
   - Conduct/complete the Situation Analysis and Needs Assessment (SANA) process to integrate health National Health Adaptation Plans (NHAPs) of all African countries, as recommended during the Paris Agreement.

2. *Intersectoral collaboration*. Since the NDC is usually undertaken by the Ministry of Environment, while the National Adaptation Plan (NAP) is usually undertaken by the Ministry of Health, the health component of climate change is either missing or incomplete.
   - Promote intersectoral collaboration across sectors at all stages from planning

[72] These recommendations are further elaborated in the appropriate sections of the report.

and implementation to monitoring and evaluation.

- Mainstream the WHO Health in All Policies (HiAP) tool.
- Promote the joint WHO–FAO, one-health approach to avert risk in agriculture and manage climate-sensitive zoonotic diseases.

3. *Data for policy and programmes*. Policy-makers, scientists and all relevant stakeholders need information for designing policy, implementing and monitoring programmes and setting priorities.

- Roll out a robust database for collecting and analysing information on the prevalence of climatic hazards, their exposure pathways and related health conditions.
    - The climatic hazards of concerns for Africa include air and water quality, temperature and ocean rise, and extreme weather in the form of droughts, floods and storms.
    - Monitor ecological contamination of air and water media to detect toxic levels of air pollutants responsible for respiratory health conditions and water-borne diseases causing diarrhoea and infant mortality after flooding.
    - Institute the early-warning system of surveillance (EWARS) on vectors that may be amplified by climate change to avert outbreaks of climate-sensitive diseases such as malaria and other vector-borne and zoonotic diseases.
    - In countries where a systematic database cannot be implemented immediately, an early-warning system aiming at a climate-related event base surveillance system may be explored.

4. *Capacity building*. Africa needs a critical mass of climate scientists who are well versed in policy, programmes and research and who can play important roles in the field and lead climate science in the region. To reach these goals, we make the following recommendations.

- Train policy-makers and government officials in the basics of climate change, policy-making, implementation, climate activity financing and emerging issues such as NetZero carbon policy to be able to negotiate at national, regional, and global levels and access various funding sources including the Green Climate funds and Africa–European Union collaboration.
- Produce graduate-level scientists qualified in climate change to manage the imminent crisis in Africa.
- Train climate scientists, health-care workers including practitioners to monitor epidemiological trends in climate-sensitive diseases, as well to detect, monitor and manage such diseases.

5. *Research*. Policy-makers need basic information generated within the African continent to make important decisions on choosing the best control strategies. Much international research on climate change in Africa is constrained by the lack of mutual agenda setting and benefits, and equality in decision-making between partners. This disequilibrium must shift to build research capacity.

- Foster formal arrangements with various partners such as the WHO Regional Office for Africa and the African Union. The Network of African Science Academies with its all its member academies should be supported to promote research.
- Research should, *inter alia*, be directed to fill the gaps in the dearth of information on the prevalence of climatic hazards in time and space; link disease mortality with exposure; elucidate the complex causal exposure pathways; and demonstrate the economic and health co-benefits of various adaptation and mitigation strategies.

6. *Health adaptation*. To avert and minimise the immediate adverse effects of climate change, protective actions must be implemented by communities, some of which are evident from the case studies in this report.

- Incorporate adaptative measures including EWARS in the national climate policy to

detect warning signals due to climate change and adverse effects.
  - Develop EWARS for heatwaves, hydrological disasters, vector controls and climate-sensitive diseases.
  - Develop strategies for coping with surges in adverse health impacts.
  - Anticipate and support vulnerable communities.
- Empower indigenous communities with the basic science of climate change to enable them to incorporate their knowledge into agricultural and cropping practices, including exploiting the planting of fire-resistant trees to limit forest fires, and drought- and pest-resistant crops to increase yields.
- Promote switching traditional cooking practices from biofuel to cooking stoves to reduce indoor air pollution.
- Encourage all communities to adapt their diets from high animal-based protein to plant- and insect-based protein.

7. *Mitigation*. While adaptation measures provide immediate relief from the adverse effects of climate change, eventually these adverse effects overcome the adaptation measures and necessitate mitigation measures to reduce the carbon sink.

- Formulate and mitigate national mitigation strategies to reduce the carbon sink by incorporating it into NDCs.
- Reduce greenhouse gas (GHG) emissions across sectors that are big polluters, for example in urban transport, agriculture and forestry.
- Promote urban green spaces for planting trees to mitigate the effects of urban heat islands.
- Incorporate and sustain green technologies in post-COVID-19 recovery innovative technologies.
- Africa stands to benefit from integrated climate adaptation, mitigation and development approaches.
- In expanding economically and meeting their development needs, African countries have abundant opportunities to adopt clean, efficient low-carbon technologies and practices.
- Some low-carbon development options may be less costly in the long term and could offer new economic opportunities for Africa.
- Many of the measures to avoid GHG emissions provide generous gains in economic productivity, human development and quality of life. The adoption of a low-carbon pathway needs to fit into countries' specific national circumstances.
- Integrate adaptation and mitigation strategies into short- and long-term development planning. Short-term measures include integrating climate adaptation and disaster risk reduction, while long-term mitigation measures require, governments, businesses and communities to prepare for climate impacts by reducing the carbon sink.

8. *Advocacy*. Awareness about climate change and health must be raised to set the public agenda and bring the issue to the attention of policy-makers and implementers.

- Simplify climate change science including adaptation and mitigation measures to influence the social behaviour and practices of institutions and individuals.
  - Promote system dynamics and a participatory approach by engaging lay citizens, school children and youth to capture their innovative approach and guarantee the future of Africa.
- Target health risk communications to counter misinformation on climate change and health.
- Educate primary health care and community-level doctors in climate change, to make significant strides in advocating citizens to adopt lifestyle changes that limit carbon emissions and achieve better health.

9. *Partnership*. The agenda to avert the adverse health effects of climate change in Africa calls for substantial investment

in knowledge, infrastructure, and human and financial resources. Climate change is a shared global problem that lies outside the political reach of any one nation state and requires a collective, global response. Therefore, international cooperation is vital to avert dangerous climate change.
- Forge multidisciplinary and transdisciplinary engagement at national, regional, and global levels.
- There is an urgent need to support Africa in dealing with its disproportionately high disease burden in relation to the low amount of GHGs. The European Union–Africa Green Climate cooperation is an exemplary initiative and may be replicated with developed countries, where most of the GHGs are produced.
- Link climate action with specific provisions of SDGs, the New Urban Agenda, WHO Urban Health Research Agenda, AU Agenda 2063 and other regional networks such as the Southern African Development Community (SADC) and the African Continental Free Trade Area (AfCFTA).

The full report will be published in April 2022.

Appendix 2 Follow-up to EASAC 2019 report

1 Introduction

In addition to the 2019 report, EASAC key messages from the project were published in:

- Hobbhahn *et al*. 2019
- Fears *et al*. 2019
- Fears *et al*. 2021

With the report, EASAC also catalysed further discussion by academies at the country level in Europe for example the Netherlands, Estonia and Ireland. The EASAC work was discussed in a workshop hosted by the US Academies of Science, Engineering and Medicine in 2019 to help scope work in the USA.

The EASAC work has also been used to begin to catalyse IAP engagement with international bodies for example at a WHO-UNEP Asia-Pacific regional event in Manila in 2019.

2 Engagement with policy-makers

Examples of EASAC follow-up work with European policy-makers are listed in Table 6.

3 Informing the wider scientific community

In addition to EASAC's scientific outreach efforts through its peer-reviewed publications and follow-up with individual academies, key messages have been reinforced at conferences attracting a broad range of scientific disciplines

Table 6 EASAC discussion with EU Institutions and European regional activities of UN bodies

Policy-making audience	Activity
Finnish Presidency of EU Council Helsinki, 2019	EASAC organised a public event to present work on climate change, including health, to Presidency policy leads and others.
European Parliament Brussels, 2019 European Parliament Brussels, 2020	EASAC co-organised event with European Parliamentary Research Service to present and discuss climate change and health report to MEPs/researchers and others. Invited presentation to ENVI Committee Health Working Group on climate change-health-food -nutrition issues.
European Commission	Prior to, and during project, EASAC maintained contact, for example with Directorate-General Santé and members of the EU Scientific Advice Mechanism (SAM), to discuss project objectives and scope. In 2019, SAM organised a workshop with EASAC Working Group members to inform future European Commission work. Other Commission participants included the European Centre for Disease Prevention and Control, EEA, European Food Safety Authority, JRC, Directorates-General Santé, Clima, Environment, GROW, Research and Innovation. These discussions and the EASAC report helped to inform the work of the Group of Chief Scientific Advisors (GCSA) in producing an Opinion on climate change and health in 2020. EASAC contributed to a follow-up SAM–GCSA seminar in January 2021.
FAO Europe Budapest, 2019	Invited contribution to FAO-organised workshop on partnerships and climate–food–nutrition–health SDG 2–3–13 interlinkages.
UNDESA and other UN departments Vienna, 2020	UN organised workshop on 'Science, Technology and Innovation for the SDGs', EASAC lead contributor on climate–food–nutrition–health SDG 2–3–13 interlinkages.
UNECE, Online, 2021	Invited contributions on climate change-food-COVID-19 interactions.
UN Food Systems Summit Scientific Group	Invited Brief covering climate change-food systems plus online discussion at UN FSS Science Days, July 2021.

Table 7 Engagement with the broader scientific and health communities

Scientific event	Activity
European Commission's Scientific Panel for Health annual conference Brussels, 2019	Invited contribution on climate change and health with regard to EU health research and health equity issues.
World Health Summit Berlin, 2019	EASAC–IAP organised session on climate change and health issues.
World Science Forum Budapest, 2019	EASAC–IIASA organised session on climate change and health issues for ethics and equity.
UN Office at Geneva and World Academy of Art and Science 'Global leadership in the 21st Century', Online, 2020	EASAC presentation on climate change and health recommendations.
World Health Summit, Online, 2020	EASAC–IAP organised session on climate change and health regional issues.
Consortium of Universities of Global Health, Online, 2021	IAP organised session on climate change and health regional–global issues.

and younger scientists. Examples are listed in Table 7.

4 Relevant new EASAC work

Since the completion of the EASAC Working Group discussions on climate change and health, several other relevant pieces of EASAC work have been initiated or completed:

- Energy Programme report on decarbonisation of transport, 2019.
- NASEM-EASAC-IAP workshop on microbial threats, 2019.
- Biosciences Programme commentary on regulation of genome-edited plants, 2020.
- Cross-Programme commentary on green recovery after COVID-19, 2020.
- Energy Programme report on decarbonisation of buildings, 2021.
- EASAC-FEAM commentary on decarbonisation of health sector, 2021.
- EASAC-IAP-Cyprus Institute workshop on climate change and health in the Mediterranean region, 2021.
- Cross-Programme commentary on relevant issues for both biodiversity and climate change policies, 2021.

Appendix 3 Procedures for preparing the global report

The scoping of the global report was discussed at an initial meeting with experts from all four IAP regions held in Germany in 2019 and draws on the published outputs of the four regional reports, other academy and academy network work and other literature cited in the text. Actions were modified as a result of the COVID-19 pandemic, primarily moving all activities online after March 2020.

A first draft of the text was prepared by the scientific secretariat Robin Fears and Claudia Canales Holzeis with the assistance of Johanna Mogwitz and Shayda Mollazadeh. It was reviewed and revised together with an editorial group comprising the core project team:

- Volker ter Meulen (Germany) and Andy Haines (UK), co-chairs
- Khairul Annuar B Abdullah (Malaysia, chair of AASSA working group) and Victor Hoe Chee Wai (Malaysia, chair of AASSA working group from January 2022)
- Jeremy McNeil (Canada, chair of IANAS working group)
- Deoraj Caussy (Mauritius), chair of NASAC working group, and Jackie Kado (Kenya), Executive Director of NASAC

Support was provided by:

- AASSA working group experts Tony Capon (Australia), Shabana Khan (India), Ho Kim (Korea)
- NASAC working group experts Michel Boko (Benin), Ama Essel (Ghana)
- IANAS working group experts Sherilee Harper (co-chair, Canada), Phil Landrigan (USA), Noel Solomons (Guatemala)
- EASAC working group experts George Christophides (Cyprus), Maria Nilsson (Sweden), Filip Duarte Santos (Portugal)

The draft text was peer-reviewed in February 2022. IAP thanks:

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- Kristie L. Ebi, University of Washington, USA
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- Sotiris Vardoulakis, Australian National University, Australia

The final draft of this report was approved by the IAP Steering Committee in March 2022.

Appendix 4 Policy instruments

The importance of considering diverse policy options in the systems-based approach to mitigation, adaptation and cooperation has been discussed throughout the report. This Appendix briefly discusses some of the array of policy instruments available, drawing on the work of the IPCC 5th Assessment Report (Somanathan *et al*. 2014). By the time of the 5th Assessment Report there had been a marked increase in national mitigation policies and legislation on climate change. However, taken together, these policies had not yet achieved a substantial deviation in emissions from the past trend. The *Lancet* Countdown assessment (Watts *et al*. 2021) concluded that progress towards zero-carbon energy has stalled;i nvestments in zero-carbon energy and energy efficiency have not increased since 2016 and are a long way from doubling by 2030, which is required to be consistent with the Paris Agreement.

Table 8 Characteristics of policy instruments for mitigation of climate change. Categories adapted from Somanathan *et al*. (2014)

Policy option	Examples
Economic instruments to internalise external costs	Sector-specific fuel taxes; reduction of subsidies to fossil energy; carbon taxes; emissions trading systems
Regulatory approaches	Energy and other performance efficiency standards; support for green technologies
Information policies	Labelling programmes for consumers
Other government initiatives	Monitoring, provision of public goods and services, procurement; integrating at different governance levels and linkages across jurisdictions; collective action; capacity building
Voluntary actions	Role of stakeholders in advocacy and accountability, research design, policy design and implementation

Mitigation

Examples have been discussed in chapter 4 and in the regional reports: in this Appendix we confine our additional examples of the primary categories of policy instruments (Table 8) to recent EU developments and assessments in order to update the discussion in EASAC (2019a).

'*Simple economic solutions for addressing both climate change and biodiversity loss are well known but poorly applied; for example governments continue to subsidise fossil fuels … New environmentally and socially sustainable economic models are required, together with replacing gross domestic product with measures that include socio-ecological, human health and well-being factors. Well-being indicators should guide economic instruments such as subsidies, payments, taxation, pricing and discounting for internalising environmental costs, in order to steer production and consumption behaviour to a sustainable form.*' (EASAC 2021b).

The social cost for carbon is still not applied comprehensively and at levels sufficient to reduce emissions to rates compatible with Paris Agreement targets. Including the costs of climate change-related adverse effects on health increases the social cost of carbon drastically (Bressler 2021; EASAC 2021b). Composite indicators of net carbon pricing reveal that government policies are often miscoordinated, resulting in inefficiencies and disrupted price signals (Watts *et al*. 2021). Although economic theory suggests that economy-wide, market-based policies would generally be more cost-effective than sector-specific policies, political economy considerations often make those economy-wide policies harder to design and implement than sector-specific policies and the latter can also incorporate specific design elements to overcome sectoral market failures (Somanathan *et al*. 2014).

The focus on impact of a specific instrument can assess whether it is effective but not whether it is better than others to meet a set goal (Anon. 2021d). A structured synthesis comparing policy instruments, to advise practitioners on what to select, can help to build a bridge between science and policy. Penasco *et al.* (2021) conducted a systematic review of the outcomes and trade-offs of decarbonisation policy instruments; it showed that some instruments were often associated with short-term negative impacts on competitiveness and distributional or other outcomes. However, trade-offs can be reduced or transformed into co-benefits by appropriately designing R&D and government procurement, deployment policies, carbon pricing and trading. The structured synthesis should, of course, include assessment criteria in addition to monetary valuations but there is a challenge to ensure that the criteria are commensurate.

An example from Sweden, where the first carbon tax worldwide was introduced in 1991, illustrates unforeseen consequences. The experience during the 1990s reveals that although it reduced emissions, it encouraged demand for biomass (Johansson 2000). Further work is still required to ensure that use of forest biomass meets climate and biodiversity objectives (EASAC 2021b). Moreover, action to increase carbon prices could increase poverty if issues around equity and re-distribution are not addressed (Whitmee *et al.* 2021). As discussed in chapter 4, the work of Buchs *et al.* (2021) on European countries is useful in highlighting the value of compensation actions provided through universal green vouchers, together with expanded green infrastructures, in leading to greater reductions in home energy emissions and motor fuel emissions than would be achieved by provision of equal per capita rebates.

International carbon markets (Table 8) are an appealing and popular tool to regulate carbon emissions, making pollution less attractive for regulated firms. However, cap and trade mechanisms often appear to be a trade-off between political feasibility, distributional equity and environmental effectiveness. That is, carbon markets produce prices that are deemed too low relative to the social cost of carbon. The European Union Emissions Trading Scheme (EU ETS), which regulated about 50% of EU carbon emissions, saved more than one billion tonnes of CO_2 during the period 2008–2016, which is 3.8% of total EU-wide emissions compared with a world without EU ETS (Bayer and Akin 2020). Revision of the ETS is currently underway.

Adding one mitigation policy to another may not necessarily enhance mitigation (Somanathan *et al.* 2014). For example, if cap and trade systems have a sufficiently stringent cap, then other policies such as renewable subsidies may have no further impact on total emissions. There is still optimism that carbon markets can deliver real emissions abatement and drive ambitions, if rules are clearly defined, designed to reflect actual reductions in emissions, and if progress is transparently tracked (UNEP 2021a).

The concept of a personal carbon allowance whereby everyone has an equal allowance to spend on their consumption-related emissions (heating, transport, food etc) is radical but technically increasingly possible. Credits would be tradable so that those using least could sell some of their allowance to a central carbon bank where heavy users could buy additional credits. Allowances could be adjusted each year so as progressively to cut emissions. While this notion has been controversial previously, it has been proposed as worth reconsidering (Nerini *et al.* 2021) as an approach to enabling equity and justice and promoting healthier lifestyles.

Technology policies (Table 8), properly implemented, can reduce the cost of achieving a given environmental or health goal. They are most effective when technology-push policies, for example publicly funded R&D, and demand-pull policies, for example government procurement, are used in a complementary fashion. But there is need also to manage concomitant social challenges of technology policy change.

Policy monitoring should be treated as a governance activity in its own right (Table 8) and this has implications for policy design. The EU Monitoring Mechanism Regulation allows EU Member States to report as a single entity to the UNFCCC on climate progress (Schoenefeld *et al*. 2019), exemplifying the importance of regional-level integration. Policy monitoring also entails auditing of performance standards and targets set, for example for energy efficiency. A comprehensive review of mitigation policies in the EU and other major economies (Fekete *et al*. 2021) concluded that effective policies are available for renewable energy, passenger vehicles and forestry but that other sectors are lagging behind in mitigation targets. Success in the EU, at least in part, is related to setting increasingly ambitious benchmarks for sector-specific actions, for example to increase energy efficiency (recognising also, however, that higher efficiency can lead to lower energy prices and greater consumption).

Adaptation

As discussed in chapter 5, widely applicable adaptation measures are less easily definable and quantifiable in terms of specific instruments although guidance is available. For example, Environment Agency Austria (2014) comprehensively reviewed the strategic basis[73] for the adaptation process and applied this to integrated planning to protect from climate change-induced flooding in Upper Austria. The adaptation policy instruments exemplified in chapter 5 and the regional reports can be categorised in terms of the following:

- *National and delegated legislation, for example* health adaptation plans and health impact assessment of other sectoral legislation (agriculture, urban planning etc).
- *Economic instruments, for example* financing resilience building through tax incentives, subsidies, grants, including support for R&D and payment for ecosystem services. The EU provides an example of regional-level financing both for R&D and for adaptation projects, including the Green Climate Fund and LIFE Climate Action.
- *Integrated local planning and strategies, for example* across sectors for land use change to tackle climate impacts such as flooding. Strategic land use in spatial planning, such as new building on flood plains, has to recognise that planning is a result of a political process and needs a vision-oriented integrative framework (Thaler *et al*. 2020).

When evaluating all policy instruments, we reiterate that it is vitally important to take health impacts into account and, when considering how best to reallocate funding, to make health equity a priority (Gupta *et al*. 2015; Cuevas and Haines 2016; Guerriero *et al*. 2020).

[73] This strategy comprised (1) creating a foundation for adaptation;(2) i dentifying risks and finding solutions;and (3) i mplementing and monitoring actions. See also the IIASA PACINAS project.

Abbreviations

AASSA	The Association of Academies and Societies of Sciences in Asia
ALLEA	All European Academies
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
COVID-19	Coronavirus disease 2019
DPSEEA	Driving Force, Pressure, State, Exposure, Effect, and Action
EASAC	European Academies' Science Advisory Council
EEA	European Environment Agency
EM-DAT	International Disaster - Emergency Events Database
EMME	Eastern Mediterranean and Middle East
EMME-CCI	Eastern Mediterranean & Middle East Climate Change Initiative
ETS	Emissions Trading Scheme
EU	European Union
FAO	Food and Agriculture Organization
FEAM	Federation of European Academies of Medicine
GDP	Gross domestic product
GHG	Greenhouse gas
HNAP	Health national adaptation plan
IANAS	InterAmerican Network of Academies of Sciences
IAP	The InterAcademy Partnership
IIASA	International Institute for Applied Systems Analysis
IOM	International Organization for Migration
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre of the European Commission
LMIC	Low-to-middle-income country
N_2O	Nitrous oxide
NAP	National Adaptation Plan
NASA	National Aeronautics and Space Administration
NASAC	Network of African Science Academies
NASEM	National Academies of Sciences, Engineering, and Medicine
NDC	Nationally determined contribution
NHS	National Health Service
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRWR	Natural renewable water resources
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter
RCP	Representative Concentration Pathways
SAM	EU Scientific Advice Mechanism
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SSP	Shared socio-economic pathway
UN	United Nations

UN CBD	United Nations Convention on Biological Diversity
UN FSS	United Nations Food Systems Summit
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VBD	Vector-borne disease
WHO	World Health Organization
WMO	World Meteorological Organization

Glossary

Term	Explanation	Source
Adaptation/ maladaptation to climate change	Adaptation (to climate change): the process of adjustment to actual or expected climate and its effects. In human systems the process may moderate harm or exploit beneficial opportunities. Multiple outcomes may result from climate adaptation processes, including unintended consequences. (New proposed definition, adapted from the Intergovernmental Panel on Climate Change (IPCC)'s definition.) Maladaptation (to climate change): actions to adapt to climate change that may lead to increased risk of adverse outcomes. These could include increased vulnerability to climate change, further negative environmental impacts or diminished well-being, now or in the future. Maladaptation is usually an unintended consequence. (New proposed definition, adapted from the IPCC's definition.)	An Australian Glossary on Health and Climate Change[74]
Air pollution	Air pollution: degradation of air quality with negative effects on human health or the natural or built environment due to the introduction, by natural processes or human activity, into the atmosphere of substances (gases, aerosols) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect. (IPCC) Pollutant: a substance that contaminates the air or water. Pollutants can cause problems in ecosystems as well as health problems in humans. (Minnesota Climate & Health Program, Minnesota Department Of Health.)	An Australian Glossary on Health and Climate Change[72]
Climate change	A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.	IPCC Glossary[75]
Early-warning systems	The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.	IPCC Glossary[73]
Extreme weather event	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th centile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g. drought, megablaze or heavy rainfall over a season). (Slightly adapted definition from IPCC.)	An Australian Glossary on Health and Climate Change
Food and nutrition security	A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.	World Food Summit, 1996[76]

[74] Zhang Y, Barratt A, Rychetnik L and Breth-Petersen M (2021). An Australian Glossary on Health and Climate Change. Prepared for The Human Health and Social Impacts (HHSI) Node, The NSW Adaptation Hub.
[75] IPCC (2012). Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (Field CB, Barros V, Stocker TF *et al.* (eds.)), pp. 555–564. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[76] World Food Summit 1996, Rome. Declaration on World Food Security.

Term	Explanation	Source
Greenhouse gases (GHGs)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are several entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Besides CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).	IPCC Glossary
Health co-benefits	The positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefits. (IPCC)	An Australian Glossary on Health and Climate Change
Intergovernmental Panel on Climate Change (IPCC)	A group of experts established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Its role is to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change, based mainly on peer-reviewed and published scientific/technical literature. The IPCC has three Working Groups and a Task Force.	WHO Climate Change and Human Health Glossary
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.	IPCC Glossary
National adaptation plan	The national adaptation plan process under the UN Framework Convention on Climate Change is a strategic process that enables countries to identify and address their medium- and long-term priorities for adapting to climate change.	NAP Global Network[77]
Nationally determined contributions (NDCs)	Nationally determined contributions embody efforts by each country under the Paris Agreement to reduce national emissions and adapt to the impacts of climate change.	UNFCCC
Nature-based solutions	Nature-based solutions are actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.	IUCN
Particulate matter	Particulate matter (also called particle pollution) is the term used to describe a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope.	US Environmental Protection Agency
Planetary health	Planetary health is the health of human civilisation and the state of the natural systems on which it depends. The achievement of the highest attainable standard of health, well-being, and equity worldwide through judicious attention to the human systems — political, economic, and social — that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity and other species can flourish. (New proposed definition, adapted from Rockefeller–*Lancet* Commission.)	An Australian Glossary on Health and Climate Change

[77] https://napglobalnetwork.org/2019/12/the-national-adaptation-plan-nap-process-frequently-asked-questions/#:~:text=In%20simple%20terms%2C%20the%20NAP,assessing%20vulnerability%20to%20its%20impacts.

Term	Explanation	Source
Public health	Public health is defined as 'the art and science of preventing disease, prolonging life and promoting health through the organized efforts of society'[78]. Activities to strengthen public health capacities and service aim to provide conditions under which people can maintain to be healthy, improve their health and well-being, or prevent the deterioration of their health. Public health focuses on the entire spectrum of health and well-being, not only the eradication of particular diseases. Many activities are targeted at populations such as health campaigns. Public health services also include the provision of personal services to individual persons, such as vaccinations, behavioural counselling, or health advice.	WHO
Sustainable development goals (SDGs)	The Sustainable Development Goals, also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. The 17 SDGs are integrated: they recognise that action in one area will affect outcomes in others, and that development must balance social, economic and environmental sustainability.	UNDP
Sustainable food systems	A sustainable food system is one that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generation is not compromised. This means that it is profitable throughout, ensuring economic sustainability, it has broad-based benefits for society, securing social sustainability, and that it has a positive or neutral impact on the natural resource environment, safeguarding the sustainability of the environment.	FAO
Transdisciplinary research	Transdisciplinary research is defined as research efforts conducted by investigators from different disciplines working jointly to create new conceptual, theoretical, methodological and translational innovations that integrate and move beyond discipline-specific approaches to address a common problem.	Harvard definition[79]

[78] The WHO definition of public health. See: https://www.euro.who.int/en/health-topics/Health-systems/public-health-services#:~:text=Public%20Health%20is%20defined%20as,Acheson%2C%201988%3B%20WHO.

[79] Harvard School of Public Health https://www.hsph.harvard.edu.

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