THE ROYAL SOCIETY

Healthy planet, healthy people: climate change and health

In brief

Climate change affects people's health directly and indirectly. The magnitude of these impacts will increase over time and their severity will depend on the actions that are taken to mitigate and adapt to climate change.

Drivers of climate change, such as fossil fuel combustion, also have negative impacts on human health, for example because air pollutants are co-emitted with greenhouse gases. Well-targeted actions can therefore simultaneously benefit human health and accelerate progress towards the target of net zero greenhouse gas (GHG) emissions by 2050 and to the goal of the Paris Climate Agreement. Replacing fossil fuels with clean renewable energy has health benefits such as reduced air pollution, while increasing consumption of healthy, predominantly plant-based diets can reduce GHG emissions from the global food system.

Effective adaptation and resilience strategies are also needed to protect health as far as possible in the face of climate change. These include the development of health systems better able to cope with extreme events and disease outbreaks.

Beyond the near-term health benefits of climate adaptation and mitigation actions, the benefits of a net zero transition will accrue over decades by reducing the risks from climate change.

INSIGHTS

- Actions taken to mitigate and adapt to climate change will benefit health in the near and longer term through multiple pathways.
- Promoting wider uptake of more sustainable and affordable dietary choices and reducing food waste can improve human health and protect the natural environment.
- Specific actions to reduce GHG emissions by using renewable energy, zero-emission vehicles, and well-designed interventions to promote more efficient energy use will also support health co-benefits from reduction of air pollutants. Walking and cycling also yield health benefits from increased physical activity.
- 'Nature-based solutions' that support mitigation of, and adaptation to, climate change can also have multiple benefits on physical and mental health.
- Transdisciplinary research into the health benefits and trade-offs of climate mitigation and adaptation strategies can identify opportunities to save lives, reduce inequities and GHG emissions, while supporting aspirations for development.
- Adaptation strategies include monitoring and early warning systems to protect communities from extreme weather and infectious diseases.
- The healthcare system can play important roles in adaptation and mitigation actions.

1. Health and climate change

"Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income as compared to a baseline without climate change."[1]

IPCC Global Warming of 1.5°C, 2018.

1.1 Impacts of climate change on health

The impacts of climate change on health fall into three broad categories:

i. Direct impacts eg heat and extreme events

ii. Indirect impacts via eco-systems eg undernutrition and changes in vector-borne disease transmission.

iii. Indirect impacts via socio-economic systems eg increased poverty and migration[2].

The World Health Organization (WHO) has estimated that climate change is expected to cause approximately 250,000 additional deaths per year between 2030 – 2050 from four health impact categories: undernutrition, malaria, diarrhoea, and heat stress[3]. However, this is probably a major underestimate as climate change has other health-related impacts, ranging from physical injuries sustained in climate-related disasters to mental health outcomes.

i. Direct impacts

These include increasing heat exposure and injury, death and disease resulting from extreme weather events, such as droughts, floods, fires, and intense storms. Increasingly, techniques that detect and attribute climate change-related factors are being applied to health outcomes. For example, recent research using empirical data from 732 locations in 43 countries estimated that over a third of heat-related deaths were attributed to anthropogenic (human-caused) climate change[4]. Increased mortality was evident on every continent, with the elderly being at particular risk[5]. Increasing temperatures were responsible for an additional 100 billion potential work hours or more lost globally in 2019 compared to in 2000, with India's agricultural sector among the worst affected and Cambodia having the largest per capita losses[6].

A systematic review showed that the risk of premature birth and stillbirth generally increased with temperature, particularly in heatwaves, and the impacts were higher in low income populations[7].

As another example, the incidence and severity of wildfires has increased in some regions due to climate change related factors such as increases in temperature and wind speed, and rainfall anomalies. Health impacts include burns, consequences of air pollution exposure, and long-term effects on mental health. Wildfire smoke contains a range of pollutants, including particulate matter (PM); carbon monoxide; nitrogen oxides (NO_x); and volatile organic compounds (VOCs)[8]. It may be more harmful than urban PM, for example with a larger effect on exacerbations of asthma. The higher average temperatures also narrow the opportunity for deliberate burning which must take place during cooler temperatures to reduce the risk of wildfires.

ii. Indirect impacts that are mediated through eco-systems

These include vector-borne diseases, such as malaria and dengue fever that are transmitted by mosquitoes.

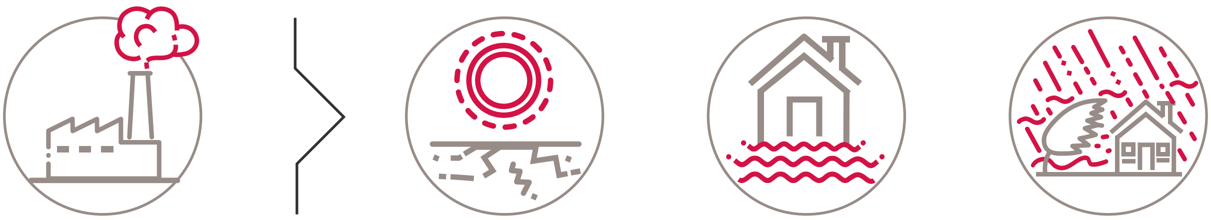
The climate's suitability for transmission of vector-borne diseases has increased due to shifts in temperature and rainfall, for example, in between 1950 and 2018, the global climate suitability for dengue transmission by *Aedes aegypti* and *Aedes albopictus* increased by about 9 – 15% respectively[5].

Other indirect impacts include climate-mediated declines in agricultural productivity and the nutritional quality of crops. For example, yields of African maize fall 1% for each degree above 30°C under optimal rainfall conditions and even more (1.7%) under drought conditions[9]. Increasing childhood stunting, particularly severe stunting in Sub-Saharan Africa and South Asia, is likely[10], with long term impacts on cognitive function and life prospects. Climate change, in conjunction with declines in freshwater and other environmental changes, will reduce yields of vegetables, legumes, fruit, nuts and seeds[11, 12].

FIGURE 1

Impacts of climate change on health[2].

Increasing levels of carbon dioxide and short-lived climate pollutants	RISING TEMPERATURE	RISING SEA LEVELS	INCREASING EXTREME WEATHER EVENTS



Demographic, socioeconomic, environmental, and other factors that influence the magnitude and pattern of risks

Geography
Ecosystem change
Baseline air and water quality
Agricultural and livestock practices and policies
Warning systems
Socioeconomic status
Health and nutritional status
Access to effective health care

EXPOSURE PATHWAYS

Extreme weather events	Heat stress	Air quality	Water quality and quantity	Food supply and safety	Vector distribution and ecology	Socioeconomic factors

EXAMPLES OF HEALTH OUTCOMES

Extreme weather events	Heat stress	Air quality	Water quality and quantity	Food supply and safety	Vector distribution and ecology	Socioeconomic factors
• Injuries • Fatalities • Mental health effects	• Heat-related illness and death	• Exacerbations of asthma and other respiratory diseases • Respiratory allergies • Cardiovascular disease	• Campylobacter infection • Cholera • Cryptosporidiosis • Harmful algal blooms • Leptospirosis	• Undernutrition • Salmonella food poisoning and other foodborne diseases • Mycotoxin effects	• Chikungunya • Dengue • Encephalitis (various forms) • Hantavirus infection • Lyme disease • Malaria • Rift Valley fever • West Nile virus infection • Zika virus infection	• Physical and mental health effects of increased poverty, violent conflict and forced migration (complex and context-specific risks)

WHO estimates that ambient (outdoor) air pollution is responsible for about 4.2 million deaths annually.

iii. Indirect impacts mediated via socio-economic systems

These include those resulting from increased poverty, population displacement, and conflict. The World Bank has estimated that, in the absence of effective action, between 30 and 130 million people could be forced into extreme poverty by 2030 as a result of climate change[13]. These impacts are particularly marked in Sub-Saharan Africa and South Asia.

Migration is a complex phenomenon with multiple drivers. Sudden-onset hazards such as floods and droughts or slow-onset hazards such as sea level rise, declines in agricultural yields, or extreme heat exposure preventing labour outdoors may contribute to population displacement. The health impacts of migration are likely to vary depending on whether the movement is a planned adaptive strategy, which could improve health prospects, or whether it is due to forced displacement, where negative health impacts may predominate[14]. A study of EU asylum applications found applications increased when average temperatures in the source country's growing season deviated from an agricultural optimum of around 20°C. It projected asylum applications would rise by between 28% and 188% this century as a consequence of climate change[15].

Long-term impacts on mental health of exposure to floods, droughts, and wildfires, have been documented, with evidence that children and adolescents are particularly vulnerable[16, 17, 18, 19].

1.2 Impacts of climate change drivers on health

Human health is also affected by many of the same activities that drive climate change, particularly within the world's energy and food systems.

Energy use and air pollution

WHO estimates that ambient (outdoor) air pollution is responsible for about 4.2 million deaths annually[20, 21, 22]. The burning of fossil fuels, including in power plants, vehicles, and heating systems, is the main human-related source of ambient air pollution. One estimate suggests it accounts for around 3.6 million premature deaths per year, with more recent research suggesting much higher estimates however with wide uncertainty ranges[21, 23]. Besides generating GHGs, coal, oil and gas also emit pollutants which affect air quality, including varying amounts of particulates (particularly $PM_{2.5}$ including black carbon) and nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide and sulphur dioxide (SO_2). A recent estimate suggests that around 3.5 million incident asthma cases in children and adolescents globally (~14% of the total age specific incidence) can be attributed to nitrogen dioxide exposure annually. Land transport is the leading global contributor to nitrogen dioxide emissions (~44%)[24]. Methane, NOx and VOCs react in sunlight to produce ozone which is also a GHG and has been associated with increased premature mortality through effects on the respiratory system. One estimate suggested over a million premature deaths annually can be attributed to tropospheric ozone exposure[25].

Household air pollution, generated largely by burning of solid fuels such as wood, crop waste, dung, or coal, causes around an estimated 1.5 – 3 million premature deaths annually, mainly in low- and middle-income countries, and more than half of them children under five[26]. However, since 2010, there has been an 11% overall reduction in proportion of the global population relying on solid fuels for cooking and around a 15 – 30% decrease in deaths attributed to household air pollution[27, 28].

Impacts of the food system

The world's eating habits, particularly those of high- and middle-income countries, are another driver of both climate change and adverse health outcomes. The IPCC has estimated that the global food system accounts for 21 – 37% of global GHG emissions or 11 – 19 billion tonnes of carbon dioxide equivalent per year ($GtCO_2e$), mainly from agricultural production. These include methane from ruminants, rice paddies and wetlands, carbon dioxide from land-use change, and nitrous oxide largely from fertilisers.

This environmental burden is being generated to serve a food system that is creating health risks of its own. Nearly one billion people lack sufficient food, while in 2016, more than 1.9 billion adults were overweight, of whom over 650 million were obese[29]. Unhealthy diets pose a greater risk to morbidity and premature mortality than alcohol, drug and tobacco use combined[30].

Agricultural activity also contributes to air pollution, largely as a result of ammonia leakage from fertilisers and livestock waste and contributes to the formation of secondary particles, constituting a substantial proportion of $PM_{2.5}$ in some regions[31]. Methane, a highly potent GHG, is also key precursor of tropospheric ozone (see page 4).

Other health impacts of climate change drivers

Other human actions driving climate change also have health impacts. For example, deforestation, which releases GHGs and removes carbon sinks, affects health through raised local temperatures that affect workers' productivity and may contribute to increases in vector-borne diseases such as malaria in some regions.

Fossil fuel production and use can also have some direct impacts on health, in addition to those resulting from climate change or air pollution. For example, people living close to coal plants can suffer exposures to a range of heavy metals and radioactive isotopes in coal ash with consequent increases in adult and infant mortality[32].

The IPCC has estimated that the global food system accounts for 21 – 37% of global GHG emissions.

2. Climate action for health

Research shows that there are many actions that have benefits both for the global and local environment and for human health. These range from effective adaptation strategies and the phasing out of fossil fuels, to specific sectoral policies such as for food systems, transport, urban development, and healthcare systems.

These actions can be operationalised through a wide range of policies and incentives, many of which may command greater public support by being seen as joint solutions for heath and the climate.

2.1 Adaptation to climate change

Actions to promote adaptation and resilience to climate change can reduce health impacts[33]. Such strategies include the use of early warning systems for extreme weather and infectious disease outbreaks. The WHO proposes that climate resilient health systems should address 10 key areas (Figure 2). However, of 101 countries surveyed in 2020, only 48 had assessed national vulnerability and adaptation for health; and while 51 had developed national health and climate change strategies or plans, only four reported adequate funding for implementation[5]. Effective adaptation strategies need to avoid unintended adverse consequences such as increasing disease risks, as in the case of malaria associated with irrigation and dams[34, 35].

Adaptation to climate driven extreme weather can be modelled on learning from past disasters. For example, Bangladesh has improved cyclone management through a range of measures, including: greater public understanding assisted by rising literacy, especially among women; early warning systems; community engagement; and a network of shelters[8]. Consequently, death tolls have reduced dramatically[36]. The evidence base for good adaptation practice is still emerging, and well-targeted research is important and urgent. Existing studies highlight steps such as helping farmers minimise time spent in the fields, for example through better crop storage facilities or use of early warning systems and preparation plans, as used in the Indian city of Ahmedabad in Gujarat[37, 38]. (See briefing 8: *Weathering the storm: how science can contribute to improving global climate resilience through adaptation*.)

Climate services for health are increasingly used to predict and prevent infectious disease outbreaks. One example is the development and use of a dengue early warning system in Ecuador[39]. Researchers have set out ways in which such monitoring could be accelerated and enhanced by integrating remote sensing, satellite imaging, crowdsourcing, cloud computing, smartphones, networks, robotics, artificial intelligence, and social media[40]. (See briefing 8: *Weathering the storm: how science can contribute to improving global climate resilience through adaptation*.)

Nature-based solutions (NBS) are "actions that involve working with nature to address societal goals" from creating green areas in cities to forest and landscape restoration[41, 42]. Potential health benefits include the reduction in all-cause mortality associated with living in proximity (500 metres) to green space[43]. Residential green space exposure can also improve mental health and is associated with reduced risk of psychiatric disorders from adolescence into adulthood[44, 45, 46]. (See briefing 9: *Climate change and land*; and 8: *Weathering the storm: how science can contribute to improving global climate resilience through adaptation*.)

FIGURE 2

WHO operational framework for building climate resilient health systems[47].

2.2 Phasing out fossil fuels

Well-designed actions to reduce emissions from fossil fuel sources have multiple benefits including improved air quality, better housing, healthier diets, and more physical exercise[48].

Reducing fossil-fuel use to a level that would keep the global temperature rise to 1.5°C rather than 2°C, could also lead to more than 100 million avoided premature deaths over the 21st century due improvements in air quality, with around 40% of the benefit occurring during the next 40 years[49]. The estimated benefits of these avoided deaths could in monetary terms offset either a large portion or all of the initial mitigation costs depending on assumptions[50].

Use of transitional fuels, such as liquified petroleum gas (LPG) replacing firewood for cooking, could prevent additional deaths from household air pollution and deliver modest climate benefits, such as from reduced firewood harvesting, although there are uncertainties around the extent of such benefits[51].

Research has calculated the potential effect of pricing fossil fuels to reflect the costs of air pollution as well as climate impacts. According to an International Monetary Fund estimate, efficient fossil fuel pricing in 2015 would have reduced global carbon emissions by 28% and fossil fuel air pollution deaths by 46%, while increasing government revenue by 3.8% of GDP[52]. Well-designed carbon taxes can be redistributive mechanisms, improving health, reducing inequity, and contributing to mitigation of climate change[53].

BOX 1

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Co-governance – tackling climate change and air quality together

Several countries are addressing climate change and air quality through 'co-governance' approaches that treat them as closely linked challenges with common solutions. A 2019 UN report showed how China had made co-governance of the issues a key part of its climate and clean air strategy with comparable approaches being taken in Chile, Finland, Ghana, Mexico, Norway, and the UK[54].

The Chinese government has designed policies to limit the use of fossil fuel through an optimised energy structure, clean energy, and energy efficiency. The amount of electric power generated from renewable sources tripled as wind and solar power capacity grew 25 times in the 2008 – 2018 decade. More than 30% of all electricity in China now comes from non-fossil fuels. Between 2013 and 2017, concentrations of $PM_{2.5}$ in the Beijing-Tianjin-Hebei region were cut by 40%. China has also launched a coal-cap policy, setting limits on coal use, starting in the most polluted regions.

In the UK, one aspect of the co-governance approach has been expert assessment of the air quality impacts of policies to achieve net zero emissions by 2050 by an Air Quality Expert Group of the Department for the Environment, Food and Rural Affairs.

2.3 Food system-driven emissions reductions

Changes in food production and consumption can both improve health and mitigate climate change. Science has demonstrated that there would be major benefits in both areas if humans shifted to diets containing plentiful fruit, nuts, seeds, vegetables, and legumes, which tend to have relatively low GHG footprints, along with, in high consuming countries, more modest intakes of red meat and dairy, which have high GHG emissions[29]. Diets of this nature, plus changes in food production to increase yields of foods with lower footprints and reducing waste, have been estimated to have potential to reduce agricultural GHG emissions by up to 90% by 2050[29]. However, research has noted that such diets, with high levels of fruit and vegetables, may be currently unaffordable or impractical for many and individual requirements may differ[59]. Uptake requires policy action in fields such as social protection, infrastructure, and public procurement. (See briefing 10: *Nourishing ten billion sustainably*.)

BOX 2

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Heath impacts of non-fossil fuels

Non-fossil fuels are not without health risks. For example, accidents at nuclear power stations, such as those at Chernobyl in 1986 have led to high levels of exposure to radioactive material, fatalities, and illness[55]. Following the tsunami at Fukushima in 2011 the levels of radiation were 100 times lower than at Chernobyl but increases in obesity and related non-communicable diseases from reduced outdoor exercise were described and impacts of displacement on mental health were observed[56].

Manufacturing of photovoltaics can give rise to some toxic occupational exposure, for example from emissions from copper processing and silicon refinement but these can be reduced by regulation and are minor compared with those arising from fossil fuels[57].

Extensive biofuel use could lead to increase food prices if this involves competition for land between food (including animal feed) and fuel. Safeguarding food production should be the first priority[58].

Improved home energy efficiency could lead to 2,200 quality adjusted life years (QALYs) gained per 10,000 people over 50 years.

2.4 Healthy 'green' buildings

About 40% of primary energy is used for buildings. Certification schemes that reduce energy use and improve the indoor environment can yield a range of health improvements. A study of LEED (Leadership in Energy and Environmental Design) certified buildings in six countries estimated energy cost savings of $7.5bn, together with substantial reductions in air pollution and GHG emissions. The economic value of the health benefits arising from these emission reductions were almost equal to the value of the energy savings in the USA and much higher in low- and middle-income countries[60].

A major strategy for reducing GHGs from homes in temperate regions is to reduce demand for heating through improved energy efficiency by improving insulation, preventing air leaks, replacing windows, and improving heating systems. However, modifications should be accompanied by efficient ventilation systems to prevent increased household air pollution exposure such as radon and $PM_{2.5}$ from cooking, fires, or smoking. In England, modelling suggests improved home energy efficiency could lead to 2,200 quality adjusted life years (QALYs) gained per 10,000 people over 50 years; but if ventilation was reduced beyond regulations, around a third of those QALYs could be lost due to increased levels of indoor generated pollutants[47].

Approaches such as reflective roofs, external shutters and passive ventilation can reduce indoor exposure to extreme heat without increasing energy demands. A modelling study in the UK showed that external window shutters could reduce heat-related mortality by 37 – 43%[61].

2.5 Sustainable healthy cities

Cities are responsible for about 70 – 75% of GHG emissions and much of the world's economic activity. Integrated action across sectors can help cities to reduce emissions and adapt to climate change as well as improving health and equity[62].

The transport sector for example offers major potential opportunities for progress, including transition to low emission vehicles, greater use of public transport, and walking and cycling. A study of England and Wales suggested there could be substantial reductions in the burden of ischaemic heart disease, stroke, dementia, diabetes, depression, and some cancers, as well as healthcare savings, if urban-dwellers adopted European best practice for walking, cycling, and reduced car use[47, 63]. Research has estimated the annual cost of adverse health impacts associated with transport emissions at around $1 trillion globally[64].

Cities tend to be hotter than surrounding regions – the 'urban heat island effect', partly due to the lack of tree canopy and green space, and the presence of large roadways and buildings. One example of climate change adaptation is the use of 'green infrastructure' such as parks and trees[65]. This can also lessen energy requirements for cooling and thus contribute to mitigation.

2.6 Supporting development policies

Decarbonising the global economy can help advance human development, particularly in low- and middle-income countries, in line with the UN Sustainable Development Goals[69, 70]. For example, the achievement of SDG2 (Zero Hunger) and SDG3 (Health) will be helped by adaptation and mitigation measures. SDG7 addresses access to clean renewable energy and SDG11 envisages sustainable cities. A more comprehensive mapping is needed to demonstrate the full extent of synergies between health and climate action.

BOX 3

Decarbonising healthcare – the case of the UK's NHS

Healthcare systems are themselves responsible for about 4 – 5% of global GHG emissions and providers worldwide are committing to targets for reductions[66, 67]. As one example, the UK's National Health Service (NHS) was the first national healthcare system to make a net zero commitment, pledging in 2020 to achieve net zero emissions from all sources by 2045[68]. It has already reduced direct emissions by more than 60% since 1990. A new baseline of NHS England's carbon footprint has now been quantified by combining bottom-up measurements such as on-site fossil fuel use, transport, and anaesthetic gases with top-down modelled estimates for indirect emissions such as those from the upstream energy system and pharmaceutical procurement.

3. Conclusion

The COVID-19 pandemic has provided a graphic demonstration of the costs of a global health emergency. Research reinforces the fact that climate change and its drivers, such as fossil fuel use and the global food system, also have severe long-term impacts on human health. On the positive side, well designed actions taken to mitigate and adapt to climate change will reduce multiple associated adverse impacts on people's health, particularly if they address inequities. Science can help policy-makers and individuals identify beneficial actions, trade-offs and priorities, from measures to improve air quality to more climate-friendly behaviours such as healthy and more sustainable dietary choices.

This briefing is one of a series looking at how science and technology can support the global effort to achieve net zero emissions and adapt to climate change. The series aims to inform policymakers around the world on 12 issues where science can inform understanding and action as each country creates its own road map to net zero by 2050.

To view the whole series, visit **royalsociety.org/climate-science-solutions**
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