A healthy future – tackling climate change mitigation and human health together

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Executive summary

Climate change poses serious, and potentially catastrophic, threats to human health and to the natural systems that underpin civilisation, with increasing impacts witnessed on a global scale in recent years. Major efforts are needed both to mitigate and adapt to climate change in the near term, without which consequences could increasingly be dangerous for the UK and globally. However, if the drivers and impacts of climate change are effectively addressed, there are substantial opportunities for climate action to benefit human health, via evidenced, coordinated, and equitable strategies across multiple sectors. This report addresses the co-benefits from action on climate change and makes four headline recommendations.

Climate change has complex impacts on people's health. The impacts of climate change on health fall into three broad categories: i) direct impacts such as heat and extreme events; ii) indirect impacts via eco-systems which include impacts on global food supplies and changes in vector-borne disease transmission; and iii) indirect impacts via socio-economic systems exemplified by increased poverty and intensification of existing inequalities and migration.[1,2]

The magnitude of these impacts will increase at least until the climate is stabilised, and their severity will depend on the effectiveness of climate mitigation and adaptation actions. Drivers of climate change, particularly the air pollutants that are co-emitted with greenhouse gases (GHGs) from fossil fuel combustion, have negative impacts on human health. Well-targeted actions could simultaneously benefit human health and accelerate progress towards the UK target of net-zero GHG emissions by 2050 and to the global goal of the Paris Climate Agreement to keep the mean temperature increase to well under 2°C.

This report summarises the evidence of how climate change mitigation actions could promote human health in the near term, through 'co-benefits'. It also highlights where there may be trade-offs and potential unintended consequences of climate action on human health. Such unintended consequences include exporting negative health impacts to other countries and exacerbating inequalities but can be addressed by well-designed policies. We also highlight current gaps in knowledge and associated research priorities which will be important in addressing these challenges.

The main health co-benefits of climate mitigation policies stem from actions to phase out fossil fuels, develop more energy-efficient housing, promote healthier dietary choices, and encourage more active travel (walking and cycling). There are also indirect co-benefits including those that can accrue from providing healthy and productive employment opportunities and greater access to nature. Evidence suggests that the value of the health benefits of climate change mitigation has the potential to offset most of the initial mitigation costs.

While the UK has scaled up its efforts to reduce emissions, including through the *Delivering a Net Zero NHS* strategy, the pace of global climate change will mean that climate mitigation and adaption will be an increasingly important focus for policy and practice across all sectors. Moreover, bringing in the advantages for health in the climate change narrative could further increase public support and policymakers' ambition for climate action.

1. Intergovernmental Panel on Climate Change (2018). *Human health. Impacts, Adaptation and Co-benefits.* https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap11_FINAL.pdf
2. The Royal Society (2021). *Healthy Planet, Healthy People: climate change and health.* https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-health.pdf

The overarching recommendations of this report are both consistent with, and supportive of, the 2020 recommendations of the Prime Minister's Council for Science and Technology on a systems approach for net-zero.[3] They provide an opportunity to capitalise on the growing ambition of the UK Government's impending Net-Zero strategy while demonstrating global leadership.

Recommendation 1: Incorporating health into the climate narrative

The evidence presented throughout this report highlights a clear connection between human health and climate action. This year offers an unprecedented opportunity to improve the health of the planet and its people – and for the UK to take a lead. Following on from its upcoming Presidency of the UNFCCC Conference of Parties (COP26),[4] the UK Government has the opportunity to influence the incorporation of health within the climate narrative in future COP agendas.

The UK Government has a key promote a stronger focus on health within the international climate narrative, and advocate for this to be maintained going forwards. By integrating the protection and promotion of human health in all actions to address climate change in the UK and demonstrating the potential health gains of the net-zero transition, the UK can take a global leadership role.

Recommendation 2. Integrating climate adaptation and mitigation policies to benefit health

Well-designed actions to promote adaptation can also reduce negative health impacts of climate change. Whilst this report focuses on climate mitigation, we recognise that the synergies and trade-offs of climate change mitigation and adaptation strategies should be considered in tandem. Integrated approaches could amplify the co-benefits and manage the trade-offs.

To maximise the potential health benefits of climate action, greater efforts should be made to integrate climate adaptation and mitigation policies at national and local levels, to identify and address the potential trade-offs and potential unintended consequences on human health.

Recommendation 3: Developing metrics to assess health impacts

To fully realise potential health co-benefits, monitoring the health impacts of mitigation policies will be crucial in identifying possible trade-offs between climate action and health and any possible unintended consequences, including spillover effects and impacts on equity. However, systematic mechanisms to monitor these impacts across sectors are not yet in place. It will therefore be vital to ensure a robust set of metrics are both made available and integrated into policies. Improving the granularity of data will improve the value of some of these metrics, particularly at the local level, and among particular groups of people.

To properly harness the benefits of climate mitigation, there is an urgent need to robustly and regularly assess the health impacts of climate action. National and local governments, in collaboration with research teams and appropriate public health bodies, should prioritise the integration and refinement of standardised metrics to assess all mitigation policies. These should aim to capture the broad scope of potential health and societal impacts, including on equity, and work towards their use in the reporting and evaluation of all mitigation policies.

3. Council for Science and Technology (2020). *A Systems Approach to Delivering Net Zero.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910446/cst-net-zero-report-30-january-2020.pdf

4. UKCOP26 (2021). *United Nations Climate Change Conference UK 2021.* https://ukcop26.org/

Recommendation 4: Promoting transdisciplinary systems approaches to address the complex interaction between climate change mitigation and health

Addressing climate and health in tandem is complex and crosses multiple sectors. Activities will require input across disciplines to better understand and address the complex interaction of climate change mitigation policies and health impacts in the context of national and global systems. Efforts currently being made by the UK healthcare systems to reach net-zero emissions across all three pillars of sustainability, via the *Delivering a Net Zero NHS* strategy, could stand as a useful case study for wider sectors, as an exemplar of working towards net-zero within a complex system.

To support such efforts, research design and implementation should reflect the complex nature of these issues. In doing so, it will be important that research looks to target and address areas with evidence and data gaps. These include potential direct and indirect health impacts; inequities in effects of emerging energy and food technologies and of policies that play a role in meeting the net-zero target; factors influencing both incremental and transformational behaviour change; and identifying areas for targeted interventions.

Research funders, led by UK Research and Innovation, should support a transdisciplinary systems approach in research design and implementation, to better understand the complex interaction of climate action and health across sectors.

Introduction

In 2019, the UK set a legally binding target to reach net-zero greenhouse gas (GHG) emissions by 2050. The Climate Change Committee's Sixth Carbon Budget, published in December 2020, recommended a pathway for requiring a 78% reduction in GHG emissions by 2035 on 1990 levels, equivalent to a 63% reduction on 2019 emissions.[5] Many of the actions needed to meet these targets will also have 'co-benefits', for example on human health, which are mostly positive. For instance, reducing fossil fuel use to a level that would keep the global temperature rise to 1.5°C rather than 2°C could help to avert more than 100 million premature deaths over the 21st century globally due improvements in air quality, with around 40% of the benefit occurring during the next 40 years.[6] The estimated benefits of these avoided deaths could, in monetary terms, offset either a large portion or all the initial mitigation costs depending on context.[7] These estimates are dependent on a range of assumptions and extensive use of some energy sources such as wood burning could jeopardise some of these gains.

Types of co-benefits for health

This report focuses on the human health co-benefits and trade-offs of climate change mitigation policies in the UK. Many of these ancillary benefits will be experienced in the relatively near term, for example because of reductions in air pollution from the use of renewable energy. These are distinct from the avoided long-term health impacts of climate change itself over coming decades and centuries. We use the term 'co-benefits' but acknowledge that it can cause confusion. For example, when a policy is designed to yield multiple benefits it can be unclear which is the primary benefit, and which is the co-benefit. For the purpose of this report, we largely assume that the primary purpose of a given policy is climate change mitigation, but we also encourage policymakers to consider the potential climate co-benefits of policies designed to achieve health or other outcomes.

The main health co-benefits of climate mitigation policies stem from actions to phase out fossil fuels, implement more energy-efficient housing, promote healthier dietary choices, and encourage more active travel (walking and cycling). Other benefits can accrue from providing healthy and productive employment opportunities and greater access to nature. This report also looks at the potential for unintended negative health impacts for example of increasing green technologies and jobs, especially highlighting the potential international spill-over impacts. While 'Health in All Policies' (HIAP) is gaining traction with many policymakers in the UK, it is particularly relevant to climate policy where there are numerous potential synergies to achieve and trade-offs to avoid.[8]

5. Climate Change Committee (2020). *Sixth Carbon Budget*. https://www.theccc.org.uk/publication/sixth-carbon-budget/
6. Shindell D, *et al*. (2018). *Quantified, localized health benefits of accelerated carbon dioxide emissions reductions*. Nature Clim Change **8**, 291–295.
7. Intergovernmental Panel on Climate Change (2018). *Special Report: Global Warming of 1.5°C*. https://www.ipcc.ch/sr15/
8. Local Government Association (2016). *Health in all policies: a manual for local government*. https://www.local.gov.uk/sites/default/files/documents/health-all-policies-hiap--8df.pdf

Table 1: UK climate change interventions & health co-benefits.[9]

These modelled estimates are illustrative of the health benefits that could be achieved by climate mitigation policies. The size of the estimates varies depending on the assumptions about the amount of change achieved in key exposures and the exposure–response relationships.

	Intervention	Environmental Benefits	Health Benefits
Diet	Replace half of UK meat/dairy consumption with fruit, vegetables, and cereals.[10]	19% reduction in agricultural GHG emissions.	Avoid or delay 37,000 deaths per year from coronary heart disease, stroke, and diet-related cancer.
	Population adherence to WHO dietary recommendations.[11,12]	17% reduction in food-GHG emissions.	Save more than 6.8 million years of life lost prematurely over 30 years, mainly from improvements in coronary heart disease and stroke incidence.
	Reduce red meat consumption by 92–96% overall, calorie-balanced 'flexitarian' diet.[13]	Dietary changes align with the commitments of Paris Agreement.	Avoid 98,000–100,000 premature deaths attributable to diet in 2040 (when compared to current trajectory).
Housing	Improve insulation and ventilation, and switch from fossil fuel sources.[14]	Reduction of 0.6 megatonnes CO_2 per million population (relative to 2010 baseline).	Potential saving of 850 disability adjusted life years (DALYs) per million population (relative to 2010 baseline).
Transport	Increase daily walking (1 km) and cycling (3 km) in urban England and Wales, similar to the pattern in Copenhagen.[15]	*Not modelled*	Reduction in physical-inactivity-related disease burden (diabetes, ischaemic heart disease, dementia, cancer) £17 billion costs averted for NHS over 20-year period.
	Increase proportion of regular cyclists in England from 4.8% to 25%.[16]	2.2% reduction in passenger-related CO_2 emissions.	2.1% reduction in years of life lost due to premature mortality.
	Partially replace car travel with active travel in London (2-fold increase in distance walked; 8-fold increase in distance cycled) and implement low-carbon-emission cars (95 g/km CO_2 compared to current 177 g/km CO_2).[17]	Compared to 'business as usual' projections, 2.5-fold decrease in per person CO_2 emissions.	Reduction of more than 500 premature deaths per million people through improvements in health outcomes related to physical activity and air pollution, compared to 'business as usual' projections.
Power Generation	Use fuels and energy systems described in International Energy Agency's Sustainable Development Scenario (aligned with Paris Agreement's goal of limiting global warming to below 2˚C).[13,18]	67% reduction in GHG emissions relative to 2015 levels.	Avoid over 3,400 deaths related to air pollution improvements in 2040 (when compared to current trajectory).
	Change systems of power generation to achieve 80% reduction in GHG emissions by 2050 (relative to 1990 levels) in a 'low greenhouse gas' scenario.[19]	60% reduction in NO_2 concentration (compared to 2011 levels).	7 million life-years saved for all-cause mortality from 2011 to 2154 because of reduced long-term NO_2 exposure.

Climate mitigation and adaptation

Mitigation aims to prevent climate change, by reducing the sources or enhancing the sinks of greenhouse gases, while adaptation aims to reduce the impacts of climate change through adjustment to actual and expected climate and its effects. Some adaptation strategies focus directly on reducing the effects of climate change on health, e.g. infectious disease or heatwave early warning systems, whereas others focus on reducing other impacts such as on biodiversity and in these cases improved health would be co-benefit. This report focuses particularly on climate mitigation but also discusses potential synergies and trade-offs between climate change mitigation and adaptation strategies. For example, increased reliance on air conditioning can reduce extreme heat exposures indoors but increase air pollution if fossil fuels are used to generate the required electricity. Air conditioning can also increase the urban heat island effect and exacerbate inequities when it is unaffordable for those on low incomes. It is therefore fundamental that a systems approach is taken to understand the interactions between sectors and to include health metrics in the ongoing monitoring and evaluation of the policies. Integrative methods can capture this complexity and support a dynamic understanding of the effects of policies over time, bringing together different kinds of knowledge in an improved decision-making process. For example, although adaptation measures are often implemented locally and mitigation measures may be implemented at larger scales, there are actions that support both climate adaptation and mitigation, such as nature-based solutions, including equitable access to urban green space.[20] These synergistic relationships between mitigation and adaption can be described as promoting net-zero emission resilient societies.

The role of behaviour

Beyond government policies, it is important to note the impact that individual decisions could have in reducing emissions. More than half of the emission reductions required to meet net-zero will require changes in individuals' behaviour, such as by choosing low-carbon technologies, diets, or travel options. Recent public survey data from Ipsos Mori show climate change/pollution/environment is rated 8th of the perceived major issues facing the UK, below unemployment, the NHS, and the economy. Awareness of the health co-benefits of climate mitigation and adaptation policies may increase public support for climate action compared with focusing on response to climate change in isolation.

9. Milner J, *et al*. (2020). *Health benefits of policies to reduce carbon emissions*. BMJ **368**, l6758.

10. Scarborough P, *et al.* (2012). *Modelling the health impact of environmentally sustainable dietary scenarios in the UK*. European Journal of Clinical Nutrition **66**, 710-715.

11. World Health Organisation (2003). *Diet, Nutrition and the Prevention of Chronic Diseases*. https://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf

12. Milner J, *et al*. (2015). *Health effects of adopting low greenhouse gas emission diets in the UK*. BMJ Open **5**, e007364.

13. Hamilton I, *et al*. (2021). *The public health implications of the Paris Agreement: a modelling study*. Lancet Planetary Health **5**, e74-e83.

14. Wilkinson P, *et al*. (2009). *Public health benefits of strategies to reduce greenhouse-gas emissions: household energy*. Lancet **374**, 1917-1929.

15. Jarrett J, *et al*. (2012). *Effect of increasing active travel in urban England and Wales on costs to the National Health Service*. Lancet **379**, 2198-2205.

16. Woodcock J, *et al*. (2018). *Development of the Impacts of Cycling Tool (ICT): a modelling study and web tool for evaluating health and environmental impacts of cycling uptake*. PLoS Medicine **15**, e1002622.

17. Woodcock J, *et al*. (2009). *Public health benefits of strategies to reduce greenhouse-gas emission: urban land transport*. Lancet *374*, 1930-1943.

18. International Energy Agency (2019). *World Energy Outlook 2019*. https://iea.blob.core.windows.net/assets/98909c1b-aabc-4797-9926-35307b418cdb/WEO2019-free.pdf

19. Williams ML, et al. (2018). *The Lancet Countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain*. Lancet Planetary Health **2**, e202-e213.

20. The Royal Society (2021). *Weathering the storm: how science can contribute to improving global climate resilience through adaptation*. https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-adaptation.pdf

An opportunity for change

The COVID-19 pandemic has caused significant economic damage and uncertainty but has also created an opportunity to put net-zero and equity at the centre of economic stimulus packages to support recovery, investments in research, and infrastructure and behaviour change strategies.[21] The UK Government has announced several green strategies and schemes that can support a post-COVID green recovery, such as the Ten Point Plan for a Green Industrial Revolution, the Green Recovery Challenge Fund, and the Green Jobs Taskforce.[22,23,24] Many of these strategies will have positive impacts on human health, but it is important to ensure they are designed to consider system interactions and avoid potential unintended consequences. There are also opportunities to amplify the health benefits by targeting policy in a way that supports equitable co-benefits: for example, investments in home improvements focused on lower socioeconomic groups lead to greater economic and health benefits than untargeted investments.[25]

In the following chapters we examine key areas being targeted by UK policies on climate change that also should have important near-term implications for health.

Initially, the project also sought to further explore transformational change and the importance of systems approaches in achieving transformational decarbonisation. However, there was little empirical evidence available during the preparation of this report to demonstrate how this type of change can be achieved at scale. Whilst this is an important area to explore, the Working Group felt that addressing this question sat beyond the scope of the project, which could add greatest value in focusing on how to capitalise on the potential of health co-benefits to accelerate uptake of zero-carbon policies.

21. Hepburn C, et al. (2020). *Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?* Oxford Review of Economic Policy **36**, S359-S381.
22. UK Government (2020). *The ten point plan for a green industrial revolution.* https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
23. UK Government (2021). *£40m second round of the Green Recovery Challenge Fund opens for applications.* https://www.gov.uk/government/news/40m-second-round-of-the-green-recovery-challenge-fund-opens-for-applications
24. UK Government (2021). *Green jobs taskforce.* https://www.gov.uk/government/groups/green-jobs-taskforce
25. Thomson H, *et al.* (2013). *Housing improvements for health and associated socio-economic outcomes.* The Cochrane Database of Systematic Reviews **2**, CD008657.

1. Energy use

1.1 Climate, energy, and health

Electricity generation is one of the UK's highest CO_2 emitting sectors, as much electricity is still produced by burning fossil fuels, largely natural gas with small contributions from coal and oil. Between October and December 2020, these sources generated around 40% of the UK's electricity supply with the remainder coming from renewable sources (37%) and from nuclear reactors (15%) that will gradually close over the next decade (Figure 1).[26]

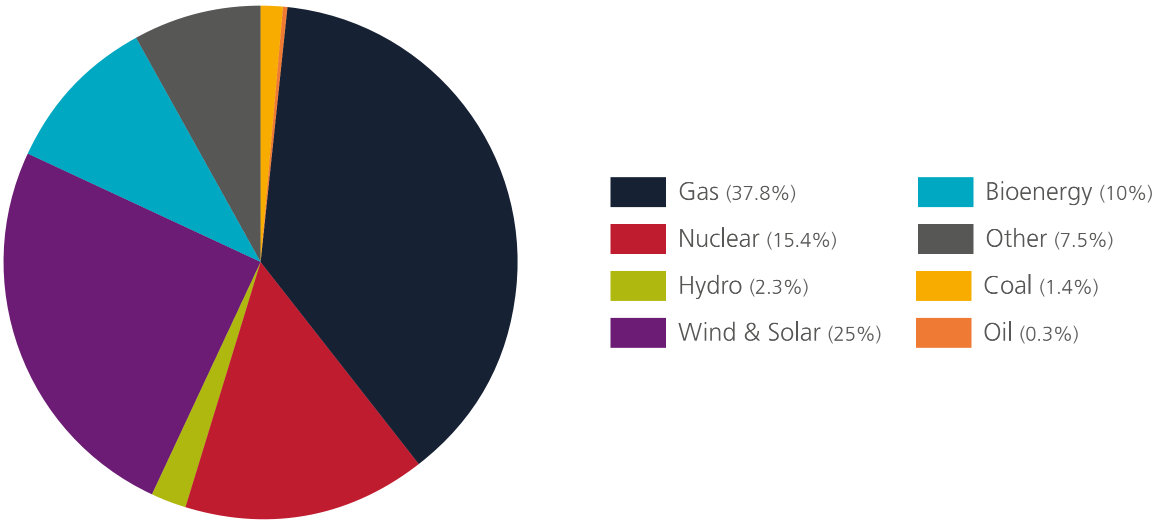

Figure 1: UK electricity generation mix by fuel source for October – December 2020.[26] N.B. 'Other' includes pumped storage, other fuels and net imports.

Besides emitting CO_2, the burning of fossil fuels co-releases other pollutants including nitrogen oxides, carbon monoxide, black carbon, volatile organic compounds (VOCs), and sulphur dioxide, all of which affect air quality and therefore our health.[27,28] Tropospheric ozone is formed from complex interactions between precursors such as methane, NO_x, and VOCs.

Particulate matter (PM) of 2.5 microns or less in diameter is commonly known as $PM_{2.5}$. Primary $PM_{2.5}$ is emitted during the combustion of solid and liquid fuels including for power generation, domestic heating and in vehicle engines. $PM_{2.5}$ particles have a complex composition and are made up of various organic and inorganic chemicals. Secondary particles of $PM_{2.5}$ can also be formed from the chemical reactions of gases such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x: nitric oxide, NO, and nitrogen dioxide, NO_2). Exposure to $PM_{2.5}$ can have short-term health impacts over a single day, and long-term impacts from exposure over the life course, with the latter responsible for the majority of health effects. Fine particulate air pollution can have multiple health effects in part due to being able to travel deep into the lungs and the bloodstream, causing, for example, aggravated asthma, reduced lung function, and premature deaths of

26. Ofgem (2021). *Electricity generation mix by quarter and fuel source (GB).* https://www.ofgem.gov.uk/data-portal/electricity-generation-mix-quarter-and-fuel-source-gb
27. Kim C, *et al.* (2020). *Health effects of power plant emissions through ambient air quality.* J R Statist Soc A **183**, 1677-1703.
28. Thind M, *et al.* (2019). *Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography.* Environ Sci Technol **53**, 14010-14019.

those with lung or heart disease.[29] Health impacts have been observed at very low $PM_{2.5}$ concentrations and the WHO has acknowledged that there is no safe level for $PM_{2.5}$ but has recently set a new guideline limit for the protection of health at an annual average of 5 µg/m^3 where meeting this target would lead to significant reductions in risks for acute and chronic health effects.[30] The UK's objective is an annual average of 25 µg/m^3 (except in Scotland it is 10 µg/m^3); this objective has been criticised as too high to protect human health.[31]

It is difficult to assess the health impacts of a single pollutant as there is significant correlation, especially with $PM_{2.5}$ and NO_2. Given this correlation, the Committee on the Medical Effects of Air Pollutants recently updated their estimates on the link between health and air pollution to include the combined effects of $PM_{2.5}$ and NO_2. The estimates suggest that long-term exposure to air pollution leads to between 28,000 and 36,000 premature deaths in the UK every year.[31a]

Air pollution can disproportionally affect susceptible groups such as those who are already experiencing health problems. Populations living in the most deprived areas are on average more exposed to poor air quality than those in less deprived areas. Although this is mostly due to high traffic levels, power plants also tend to be disproportionally sited in low-income and minority communities.[32,33] Due to the short-lived nature of most air pollutants, the emissions and consequent health impacts tend to be highly localised.

1.2 Climate action for health

1.2.1 Phasing out fossil fuels

The UK has significantly reduced coal use for power generation and the UK Government has committed to phasing out unabated coal (coal power without carbon capture and storage) entirely by 2024. This has contributed to UK territorial GHG emissions decreasing by 44% since 1990.[34] To meet the 2050 net-zero target, the Climate Change Committee's Sixth Carbon Budget has projected a significant increase in the demand of renewable electricity, which has an expected consequent impact on air quality through further phasing out energy generation from unabated fossil fuels.[1]

Studies have shown that GHG mitigation strategies in power generation could simultaneously bring about public health co-benefits by reducing concentrations of the harmful co-emissions that generate ambient air pollution.[35,36] In the UK, scenarios to meet the former target of an 80% reduction in emissions by 2050 have shown that around 500,000 to one million cumulative life years could be saved by the changes in electricity generation, largely due to reductions in $PM_{2.5}$ exposure.[9,37] The estimated benefits of these avoided deaths could in monetary terms offset either a large portion or all of the initial mitigation costs.[7]

29. Royal College of Paediatrics and Child Health (2016). *Every breath we take: the lifelong impact of air pollution*. https://www.rcplondon.ac.uk/file/every-breath-we-take-lifelong-impact-air-pollution-full-report
30. WHO (2021). *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. https://apps.who.int/iris/handle/10665/345329
31. Mayor of London (2019). *$PM_{2.5}$ in London: roadmap to meeting World Health Organization guidelines by 2030*. https://www.london.gov.uk/sites/default/files/pm2.5_in_london_october19.pdf
31a. The Committee on the Medical Effects of Air Pollutants (2018). *Associations of long-term average concentrations of nitrogen dioxide with mortality*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf
32. Unearthed (2020). *UK waste incinerators three times more likely to be in poorer areas*. https://unearthed.greenpeace.org/2020/07/31/waste-incinerators-deprivation-map-recycling/
33. PSE Healthy Energy (2017). *Natural gas power plants in California's disadvantaged communities*. https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_.Gas_.Plants.pdf
34. Department for Business, Energy and Industrial Strategy (2019). *Provisional UK greenhouse gas emissions national statistics 2018*. https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2018
35. Gao J, *et al.* (2018). *Public health co-benefits of greenhouse gas emissions reduction: a systematic review.* Sci Total Environ **627**, 388-402.
36. Department for Environment, Food and Rural Affairs (2020). *Impacts of Net Zero Pathways on Future Air Quality in the UK*. https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2006240802_Impacts_of_Net_Zero_pathways_on_future_air_quality_in_the_UK.pdf
37. Williams ML, *et al.* (2018). *The Lancet countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain*. Lancet Planetary Health **5**, e202–e213.

Ultimately, the extent of the health benefits accrued by the net-zero transition will depend on the future energy mix. For example, the substantial use of biomass to replace fossil fuels will lessen the expected health benefits due to increases in $PM_{2.5}$ exposure.[38] This is particularly a concern for use in residential heating, as for large point sources such as power stations it is easier to manage the particulates using post-combustion technologies.[39] However, for the environment, recent reports have shown that many current practices using woody biomass for energy could have negative implications for biodiversity and for climate change mitigation.[40,41]

1.2.2 Challenges and opportunities

Recent reports have analysed how to achieve a net-zero GHG economy by 2050 and indicated that efforts to phase out fossil fuel combustion and achieve major emissions reductions are feasible and economically viable.[42] However, there remain several critical research and technological priorities to reach net-zero. For example, for health, there are research uncertainties regarding the possible impacts of these low-carbon power technologies (see Box 1). Life-cycle assessments of all power scenarios would be useful to better understand and mitigate adverse human and environmental health impacts.[43]

38. Department for Environment, Food and Rural Affairs – Air Quality Expert Group (2017). *The potential air quality impacts from biomass combustion*. https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf

39. Climate Change Committee (2018). *Biomass in a low-carbon economy*. https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/

40. European Commission (2020). *The use of woody biomass for energy production in the EU*. https://publications.jrc.ec.europa.eu/repository/handle/JRC122719

41. Norton M, et al. (2019). *Serious mismatches continue between science and policy in forest bioenergy*. GCB Bioenergy **11**, 1256– 1263.

42. The Energy Transitions Commission (2021). *Making Clean Electrification Possible – 30 Years to Electrify the Global Economy*. https://www.energy-transitions.org/publications/making-clean-electricity-possible/#download-form

43. European Environment Agency (2020). *Carbon capture and storage could also impact air pollution*. https://www.eea.europa.eu/highlights/carbon-capture-and-storage-could

Box 1: Health impacts of non-fossil fuel technologies

Although it is widely acknowledged that non-fossil fuel power sources have a significantly lower human health impact compared to fossil power, some health risks and uncertainties have been identified.[44]

For example:

1) Exposure to toxic chemicals:

- manufacturing of photovoltaics for solar panels can give rise to some toxic occupational exposure, such as emissions from copper processing and silicon refinement but these can be reduced by regulation and are minor compared with those arising from fossil fuels.[45]

- the extraction of some minerals used in renewable energy technologies, such as the mining of cobalt used in batteries, may have adverse effects on health (see Box 10, Chapter 8 for more details).

2) Air quality uncertainties:

- the potential implications of CCS for health are largely unknown and vary greatly depending on the CCS approach and fuel source. Across difference scenarios, research has shown both benefits and trade-offs on air quality.[45] For example, sulphur dioxide emissions and $PM_{2.5}$ are removed after the fuel combustion stage, but the primary energy demand to build and run the capture unit could increase $PM_{2.5}$ and nitrogen oxide emissions, especially if coal is used. Further, if using an amine-based approach this may result in increases in local fugitive emissions of ammonia and other organic nitrogen species.

- the impacts on air quality from biomass with CCS, whereby biomass that has absorbed carbon during its growth is burned for power with the CO_2 being captured and stored, are currently unknown.[46] Also extensive biofuel use could lead to increases in food prices if this involves competition for land between food (including animal feed) and fuel (see Box 13, Chapter 8 for more details).[47]

- fuel substitutions to achieve GHG reductions such as by the combustion of ammonia or liquefied natural gas have uncertain relative impacts on air pollutants and human health.[48]

3) Noise pollution:

- wind energy has been the source of some public concern, particularly because of the alleged effects of infrasound exposure. However, several studies have not shown any adverse direct health effects.[49]

4) Accidents:

- accidents at nuclear power stations are rare and the UK nuclear power sector has a good safety record, but previous events notably the Chernobyl accident have led to high levels of exposure to radioactive material, fatalities, and illness.[50] New technologies have the potential to address some of the concerns surrounding nuclear energy use such as nuclear waste and nuclear proliferation. An assessment of the safety of different nuclear power technologies however is beyond the scope of this report.

Overall, evidence shows that displacing fossil fuel power sources will have significant human health benefits; however life-cycle assessments would be valuable on all power technologies to understand, and prevent as much as possible, the potential adverse impacts for both human and environmental health thus avoiding any 'lock-in effects' when investing in large-scale infrastructure.[51]

1.3 Conclusions

When monitoring and evaluating GHG emissions reductions from power generation, it will be critical to include health metrics within assessments, as outlined in **Recommendation 3** of this report. This would help to highlight the co-benefits of reducing fossil fuel use whilst also revealing any potential unintended consequences –such as those from burning biomass – and the communities they may disproportionately affect. Moreover, it will be important to improve the spatial granularity of data collection to support these efforts and allow the impacts of such activities to be better understood geographically and demographically, to ensure an equitable response.

Key insights

- If appropriate action is taken at scale and pace, considerable public health benefits could amount from policies to reduce GHG emissions and the accompanying reductions in harmful co-emitted air pollutants. This includes potential to significantly reduce avoidable premature deaths in the coming years.
- Health benefits acquired through reduced GHG emissions and improved air quality could be even greater by avoiding adverse effects of biomass burning increases, e.g. arising from power plants or domestic wood-burners.
- There is a need to increase our understanding around potential direct and indirect health impacts of emerging energy technologies, especially those expected to play a significant role in meeting the net-zero target such as Bioenergy with Carbon Capture and Storage (BECCS) and low-carbon hydrogen. Life-cycle assessments of all power scenarios would be valuable to better understand and mitigate adverse human and environmental health impacts.
- It will be critical that assessments to monitor and evaluate GHG reduction policies include health metrics (see **Recommendation 3**) to highlight the co-benefits of reducing fossil fuel use, along with any potential unintended consequences and define the communities they may disproportionately affect.
- The spatial granularity of data collection should be improved to allow the impacts of climate mitigation policies to be better understood geographically and demographically and ensure an equitable response (see **Recommendation 3**).

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2. Transport

2.1 Climate, transport, and health

Transport is the largest single sectoral source of GHG emissions in the UK, with domestic transport accounting for 27% of the UK's total emissions, mainly from road vehicles, and a further 10% from aviation and shipping.[52] The transport sector also has both direct and indirect impacts on health. Direct effects include impacts on air quality, accidents, and noise pollution. The principal air pollutants from transport are NO_x and PM, and the UK transport sector contributed to 34% and 13% of the UK's total emissions of NO_x and $PM_{2.5}$ respectively.[52] Air pollution from transport has decreased over the last decades but is still a significant contributor to adverse health impacts. For example, land transport is the main sectoral contributor to asthma incidence in children and adolescents from nitrogen dioxide (NO_2) emissions.[53] Indirect effects occur through inequalities of ownership and social exclusion such as lack of access to the services that cars or good public transport provide.

2.2 Key pathways for net-zero transport and potential health co-impacts

Reducing GHG emissions in the transport sector offers major opportunities for both direct and indirect benefits for public health. Direct effects will stem from the transition to low-emission vehicles both public and private, greater use of public transport, and increased walking and cycling. These trends will reduce exposure to harmful air pollutants and provide the mental and physical benefits of increased exercise. Indirectly, improving the quality of the overall transport system will improve access to amenities, healthcare, and social activities – all of these being socio-economic determinants of health.

Research has estimated the annual cost of adverse health impacts associated with transport emissions at around $1 trillion globally.[54] 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.[15,55] The avoided costs to the NHS from these behaviours could amount to around £17 billion over a 20-year period, increasing over time. Much of the projected benefit comes from increased physical activity rather than reduced air pollution.[56]

2.2.1 Low-emission road vehicles

The UK has set out plans for reducing emissions from road vehicles in the 2020 Ten Point Plan for a Green Industrial Revolution and the 2018 Road to Zero Strategy.[22,57] These include increasing the use of low-carbon fuels, retrofitting new technology on existing vehicle, and implementing strategies to influence driver behaviour. These strategies are expected to be accompanied by improvements in health.

The UK Government announced a ban on the sale of new petrol and diesel cars by 2030 and new petrol and diesel heavy-goods vehicles (HGVs) by 2040, which should lead to a reduction in GHG emissions and some pollutants, especially NO_x emissions in urban areas. For cars and light-goods vehicles (LGVs), electric vehicles (EVs) are the likely alternative and adoption will lead to reduced tailpipe emissions, but there are

52. Department for Transport (2021). *Transport and environment Statistics 2021 Annual report*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/984685/transport-and-environment-statistics-2021.pdf

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56. Jarrett J, *et al.* (2012). *Effect of increasing active travel in urban England and Wales on costs to the National Health Service.* Lancet **379**, 2198-2205.

57. UK Government (2018). *The Road to Zero: Next steps towards cleaner road transport and delivering our Industrial Strategy.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf

concerns regarding non-exhaust emissions such as the particulate pollution from tyre and brake wear, which are expected to be higher with heavier cars such as EVs; however regenerative braking may reduce emissions from brake pads.[58] Non-exhaust emissions currently contribute to 7% of UK primary $PM_{2.5}$ emissions.[59]

The transition away from petrol and diesel cars will expose the inequalities in mobility and access especially for those in rural areas where refuelling and charging infrastructure is insufficient and alternatives to private car ownership, such as public transport, are scarce. Low income communities that are poorly served by public transport may struggle to cover the increased cost of low-emission solutions such as EVs.[60] It is important that policies to promote the shift to low-emission vehicles are supported by measures to promote access such as shared use schemes for EVs.[61,62,63]

For HGVs, where the required journeys are longer with heavier loads, a likely low-emission option being considered is hydrogen fuel cells (as opposed to hydrogen combustion which would generate NO_x emissions without exhaust treatment). Non-exhaust emissions from friction and abrasion will also provide a challenge here as vehicle weights are expected to increase with fuel cells or batteries.

2.2.2 Public transport – buses and trains

Similar to LGVs and HGVs, the electrification or use of hydrogen fuel cells are demonstrated options for buses and trains and have the potential for significant improvements in local air quality especially in urban centres. For underground rail lines, such as the London Underground which serves 2.8 million passenger journeys per day, there remains significant $PM_{2.5}$ exposure principally from the wear of the trains and rails which is exacerbated with the depth and limited ventilation.[64] Small-scale studies have not found consistent health impacts of underground $PM_{2.5}$ exposure; however detailed studies on the $PM_{2.5}$ composition have highlighted that larger and better designed studies could expose hypothesised health impacts and encourage action.[64]

The quality of the public transport system has many impacts on health, especially indirectly by providing access to friends and family, amenities, and healthcare services. Recent surveys have highlighted that those who rate public transport as 'good' are more likely to have access to public services and less likely to report poor mental health outcomes and being under strain.[65] Using public transport tends to increase levels of physical activity and may reduce adiposity.[66,67] A systematic review of research showed that use of public transport was associated with between 8 and 33 additional minutes of walking daily.

Measures to promote public transport use should address existing barriers such as availability, reliability, and affordability to incentivise people to shift from private car use. Such barriers vary demographically and geographically, particularly affecting individuals with limited mobility and remote communities.[68]

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2.2.3 Active travel

Encouraging 'active travel' – through increased walking and cycling – should form an important part of a holistic approach to health and the environment. The health benefits are significant, and the contribution to emission reductions is a worthwhile supplement to other net-zero transport schemes. Higher physical activity levels are associated with reduced incidence of diabetes, cardiovascular disease, cancer, musculoskeletal health, and improved mental health and wellbeing.[69]

The UK's National Health Service (NHS) recommends that all adults should have 150 minutes of physical activity per week.[70] Active travel contributes significantly to this recommendation. Average physical activity for a car trip amounts to only 1 minute, compared to 17 minutes for walking trips, 22 minutes for cycling trips, and between 8 and 33 minutes for public transport trips. The use of electric-assisted bikes (or e-bikes) has the potential to incentivise the uptake of cycling by elderly or sedentary groups and can provide comparable levels of physical activity to pedal cycling owing to the longer distances travelled.[71] For elderly people, there is some evidence that e-bikes can also improve mental health and may prolong the ability to continue cycling with advancing years.[72]

Interventions to foster active travel include changes to the built environment, road reallocation, road user charging, as well as 'softer measures' such as information campaigns and personal/workplace travel plans. Walking and cycling schemes have been found to be good value for money and typically have a cost–benefit ratio greater than £4 return for every £1 invested.[73] Using the World Health Organisation's HEAT tool, the Health Foundation calculated that increasing the amount of walking and cycling in all regions of England to that of those with the highest distance walked or cycled could prevent nearly 1,200 deaths per year across all age groups (Figure 2).[68] Empirical evidence of the health impacts of active travel is growing; one study using UK Biobank data showed that bicycle commuters had a 41% and 52% reduction in all-cause mortality and cardiovascular disease respectively after five years comparatively.[74]

Despite the overall health benefits, there are some factors to consider when encouraging active travel. These include marginalising the ageing population and those with disabilities, increased commuting time, increased safety concerns and injuries, displacing other forms of physical activity, and exacerbating time constraints for time-limited groups. Promotion of active travel should therefore come in tandem with the required infrastructure, especially in rural areas where the commuting distances are much longer.

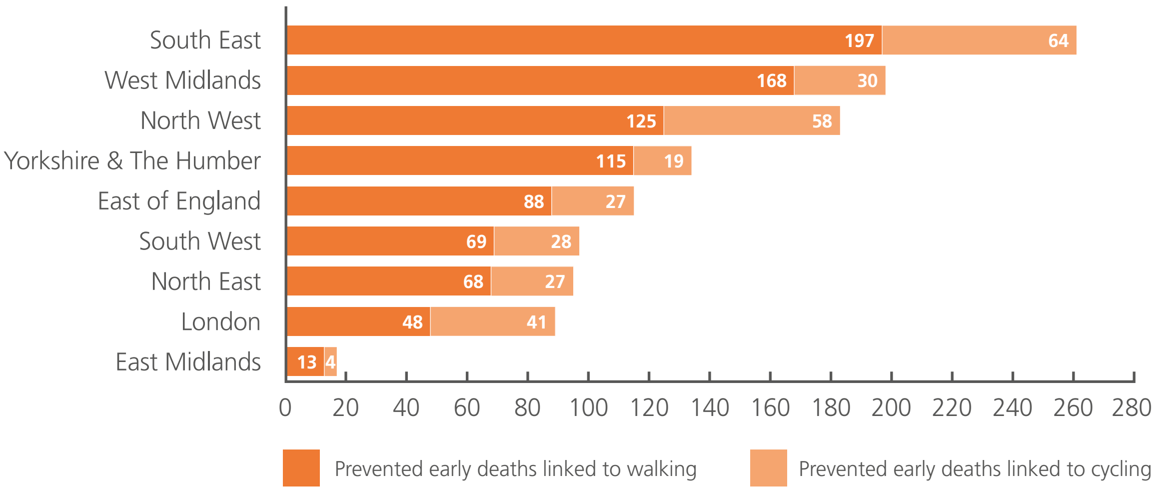

Figure 2: Early deaths prevented with increased cycling and walking (average per year and per region).[68]

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2.2.4 Shipping

Shipping accounts for 3% of UK GHG emissions, with international shipping as the principal contributor to emissions.[75] The GHG emissions have slowly declined over the past two decades, due to reduced UK maritime bunker sales. However, globally the total GHG emissions from shipping have increased with increasing demand, although improvements in carbon intensity have slowed the growth in emissions.[76]

While international shipping is not directly addressed within the Paris Agreement, nations have agreed global targets for GHG emissions reduction through the International Maritime Organisation (IMO).[77] These include reducing emissions to at least 50% below 2008 levels by 2050. Assuming a commensurate reduction in air pollutants, human health benefits can be expected.

Shipping traffic often takes place in densely populated regions and the emissions, both at sea and at berth, have an impact on the air quality of coastal areas and port cities. Shipping emissions consist of both primary and secondary particulate matter including black carbon, sulphur dioxide, NO_x, and non-methane volatile organic compounds.[78] A Health Impact Assessment of eight Mediterranean countries showed that long-term exposure to $PM_{2.5}$ from ships accounted for over 400 premature deaths per year in these countries.[79]

For small boats, electrification or hydrogen fuel cells are likely options and their feasibility has been demonstrated. However, for larger carriers, the potential zero-carbon alternatives for fossil fuels are more limited and ammonia (fuel cells and combustion) is the principal option.[80] Ammonia must be handled carefully, but the safety guidance for current applications is well known as it is widely traded and stored; however novel applications, such as for shipping fuel, are less is known.[80] The combustion of ammonia will produce NO_x emissions, but there are exhaust treatments which can manage these.[81]

2.2.5 Aviation

For aviation, switching to lower-carbon fuels could hold significant promise for reducing air pollution as well as GHG emissions; however these benefits are unlikely to be realised soon due to required technological developments and large-scale implementation.[82] Aviation is likely to be the largest contributor to GHG emissions in the UK by 2050.[83]

Air pollutant emissions from aviation consist of both primary and secondary pollutants and occur in significant volumes near airports, which are often located near heavily populated urban areas. The most harmful primary pollutants from aviation include PM, nitrogen dioxide, and volatile organic compounds. There are also several other aviation-related emissions sources, including from ground service equipment and the large volumes of road traffic that airports operate and attract, with impacts on the health of airport staff and travellers. There is limited evidence regarding the health impact of this exposure, and so far, studies have not found a significant health impact on travellers or airport workers.[84]

There is growing research regarding the health impacts of noise pollution on populations living near major airports, including increased cardiovascular disease and negative effects on children's reading and learning outcomes.[85]

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2.3 Challenges and opportunities

A transition away from the dominant use of private motor vehicles towards increased uptake of public transport, walking, and cycling, represents a dual health and environmental option.[86,87,88] However, currently the wealthiest 10% of the population receive almost four times as much public spending on their transport needs as the poorest 10%.[89] Many of these deprived areas have limited access to public transport or required travel distances are too far for walking or cycling. Further research is needed to better understand how to encourage sustainable change in mobility on a larger scale and tackle the current evidence gap in behavioural sciences regarding the public's choice of transport mode.

Some urban interventions have been trialled, including Low Traffic Neighbourhoods (LTNs). LTNs started to emerge across London in 2020 with the aim to encourage greener modes of transport, such as walking and cycling, and to decrease local air pollution. A survey of a LTN in Waltham Forest showed increased walking and cycling among residents, decreased private car ownership compared to other parts of London, and greening of the area.[90] However, more research is required to link these outcomes to health impacts. Significant consultation should be undertaken with the local residents before the introduction of LTNs, as residents have raised concerns including longer journey times, more complicated journeys, and switching to more expensive transport modes. The UK Government has recognised the potential benefit of LTNs but acknowledges that the next wave needs more consultation before introduction.

In London, studies modelling the health impacts of the current and planned expansion of the Ultra Low Emission Zone, in the London Environment Strategy, have predicted an avoidance of around 300,000 new cases of NO_2- and PM-related disease by 2050, leading to NHS and social care cost savings of just under £5 billion.[91]

86. Sustrans (2020). *What is a 20-minute neighbourhood?* https://www.sustrans.org.uk/our-blog/get-active/2020/in-your-community/what-is-a-20-minute-neighbourhood
87. The Health Foundation (2021). *How transport offers a route to better health.* https://www.health.org.uk/publications/long-reads/how-transport-offers-a-route-to-better-health
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Box 2: Impacts of COVID-19 pandemic on mobility

The COVID-19 pandemic has had an unprecedented impact on transport patterns globally, in terms of the modes of transport we use and how frequently and far we travel.

The pandemic led to an exceptional reduction in transport demand with more working from home, less business travel, more online interaction, a rise in online shopping, more journeys made on foot and by bike and lower car journey numbers.[92,93] In the UK, between March and May 2020 there was a 42% decrease in surface NO_2 levels.[94] A recent study comparing Europe and China showed that the lockdown measures led to significant reductions in $PM_{2.5}$ concentrations, and although there have been substantial deaths from COVID-19, the research suggests tens of thousands of lives may have also been saved through lower air pollution.[95] However, it was noted that low-income workers were less able to work from home and so any health benefits may be biased to higher socio-economic groups.[96]

At this stage, the long-term implications on how we travel are hard to predict and there are already indications that road traffic is returning to pre-pandemic levels.

Key insights

- Increased uptake of public transport and active travel and a transition away from private motor vehicle use represent dual health and environmental benefits. Significant improvement to health, alongside savings on healthcare costs, could be achieved with the adoption of best practice for walking, cycling, and reduced car use.
- It is important to consider existing barriers to these forms of transport, along with the uptake of EVs – including availability, reliability, affordability, and safety.
- Considering equitable access as a central focus could help avoid exacerbating social exclusion, optimise participation, and consider demographic and geographic differences, especially in rural areas least served by public transport.
- The adoption of a 'Health in All Climate Policies' approach, incorporating health considerations into decision-making for transport, could better support a fair and healthy transition to net-zero transport (see **Recommendation 1**).
- Further research to tackle the evidence gaps around behavioural and public choice of transport mode would improve understanding of how to encourage sustainable change in mobility on a larger scale.

92. Whitmarsh L (2020). *Tracking the effect of COVID-19 on low-carbon behaviours and attitudes to climate change: results from wave 2 of the CAST COVID-19 Survey.* CAST Briefing Paper 05. https://cast.ac.uk/wp-content/uploads/2020/12/CAST-Briefing-05.pdf
93. Department for Transport (2020). *Transport use by mode: Great Britain since 1 March 2020.* Transport use during the coronavirus (COVID-19) pandemic
94. Lee JD, *et al.* (2020) *UK surface NO_2 levels dropped by 42% during the COVID-19 lockdown: impact on surface O 3*. Atmospheric Chemistry and Physics **20(24)**, 15743-15759.
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3. Food: The impact of food production and consumption

3.1 Net-zero and improving health through food: the imperative for change

Food, health, and climate change are closely intertwined, with the food system estimated to account for around one-third of total global GHG emissions, approximately 18 billion tonnes of CO_2 equivalent per year ($GtCO_2e$/yr), with the vast majority coming from agriculture and land use change, such as deforestation.[97,98] In the UK specifically, food system emissions represent 23% of total GHG emissions.[97]

Agriculture is a significant source of air pollution. The main emissions from the agricultural sector are methane, NO_x, and CO_2. Methane, an ozone precursor, is principally emitted from livestock, and agricultural methane emissions contributed to 51% of the UK's total methane emissions.[99] Nitrogen-containing compounds, such as secondary particles from ammonia, are emitted from fertiliser use, farm machinery, and livestock waste. Agricultural soils are gradually becoming a substantial source of nitric oxide (NO) (around 6% of UK NO_x emissions by 2030). Reduced $PM_{2.5}$ levels can be achieved by decreasing agricultural emissions, notably of ammonia (NH_3). One estimate suggests that in Europe a 50% reduction in agricultural emissions could result in a 19% reduction in air pollution mortality from PM.[100] These emissions are projected to increase in response to population growth and shifting to higher meat and dairy dietary intakes.

The UK is facing a crisis of increasing diet-related disease, with over 60% of adults being overweight or obese.[101] The rates of obesity have more than doubled over the past 25 years, and currently cost the NHS £6.1billion each year (projected to rise to £9.7billion by 2050).[102,103] At the same time, undernutrition affects around 5% of the UK adult population and around 10% of children are reported to be living in food-insecure households.[104]

Changes to the food system, related to both production and consumption, could have multiple co-benefits for health and the climate, as well as helping the UK to meet many other Sustainable Development Goals.[105] Here we focus on behaviour-driven actions to reduce the climate and health impact of food systems.

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3.2 Behaviour changes required to achieve net-zero and their health co-benefits

3.2.1 Eating more plant-based foods and less meat

Global meat production has more than quadrupled since 1961, with the world now producing more than 340 million tonnes of meat each year.[106] This is due to a combination of global population rise and growth in per-capita consumption from 20 kg to 43 kg per person per year between 1961 and 2014.[106] Within the food system, livestock has the greatest impact on climate, especially the production of meat and dairy from ruminants such as cattle and sheep.[107] Red meat and dairy products also have a significant health impact as they are among the highest sources of saturated fat, and a high intake of red and processed meat is associated with elevated risk of several non-communicable diseases, including some cancers.[108]

Reducing red meat consumption and eating more plant-based foods, such as fruit, vegetables, and legumes, therefore can have major co-benefits for both health and the climate. In 2020, the Climate Change Committee's Sixth Carbon Budget recommended reducing meat and dairy consumption by 20% by 2035 and 35% by 2050.[109]

Even relatively modest changes to diet can result in substantial GHG reductions and health benefits. For example, if the average UK dietary intake was optimised to comply with the World Health Organisation (WHO) nutritional recommendations, there could be an estimated reduction of 17% in diet-related GHG emissions, avoidance of almost 7 million years of life lost prematurely in the UK over the following 30 years (with reductions in coronary heart disease responsible for 70% of this impact), and an increased average life expectancy by over 8 months.[110]

However, the transition to predominantly plant-based diets must be managed carefully to avoid negative nutritional consequences, as meat and dairy products are important sources of essential nutrients, such as iron, zinc, calcium, and vitamin B_{12}. These can also be found in plant-based alternatives, although the bioavailability of minerals such as iron and zinc is usually lower than in animal-based foods. Neither should it be assumed that all plant-based alternative foods are healthy as some are highly processed and high in salt and saturated fat (see Box 3).[111]

There are significant positive efforts being made to reduce carbon emissions in the agricultural sector, ranging from measures to restore natural capital to technologies to improve efficiency.[112,113] However, this does not negate the need to reduce red meat and dairy consumption in high-consuming countries such as the UK.

3.2.2 Avoiding overconsumption and ultra-processed foods

Overconsumption of food (beyond the necessary energy requirement) is associated with obesity, which increases a person's risk of many non-communicable diseases including cardiovascular disease, type II diabetes, and cancers, and as recently observed, greater severity of COVID-19 symptoms.[114,115] Avoiding overconsumption can have co-benefits for the climate, through reducing food production and process emissions, and for the economy, through fewer working days lost through ill-health.

The prevalence of obesity is highest in most deprived groups.[116] Those experiencing food poverty are more likely to follow cheaper and less perishable diets which often comprise energy-dense, high-fat, and high-sugar foods, further exacerbating health and social inequalities. Ultra-processed foods (UPF) comprise industrial food and drink formulations made of food-derived substances and additives including confectionery,

106. Ritchie H, Roser M (2017). *Meat and seafood production & consumption*. Our world in data.

107. Ripple WJ, *et al.* (2013). *Ruminants, climate change and climate policy.* Nature Climate Change **4**(1), 2-5.

108. Meurillon M (2015). *IARC Monographs – Red meat and processed meat*. https://www.iarc.who.int/wp-content/uploads/2018/07/pr240_E.pdf

109. Climate Change Committee. (2020). *Sixth Carbon Budget*. https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

110. Milner J, *et al.* (2015). Health effects of adopting low greenhouse gas emission diets in the UK. BMJ Open **5**, e007364.

111. Van Vliet S, Kronberg S & Provenza F (2020). *Plant-Based Meats, Human Health, and Climate Change*. Frontiers in Sustainable Food Systems **4**, 128.

112. Parliamentary Office of Science and Technology (POST) (2017). *Environmentally Sustainable Agriculture*, POST Note 557. https://www.parliament.uk/globalassets/documents/commons-library/Environmentally-Sustainable-Agriculture-POST-PN-0557.pdf

113. Chang J, *et al.* (2021) *The Key Role of Production Efficiency Changes in Livestock Methane Emission Mitigation.* AGU Advances **2(2)**, e2021AV000391.

114. WHO (2013). *Obesity: Health consequences of being overweight*. https://www.who.int/news-room/q-a-detail/obesity-health-consequences-of-being-overweight

115. Ho FK, *et a*l. (2020). *Modifiable and non-modifiable risk factors for COVID-19: results from UK Biobank*. BMJ Open **10(11)**, e040402.

116. NHS Digital (2018). *Health Survey for England 2018 [NS]*. https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/2018/summary#overweight-and-obesity

sugar-sweetened beverages, and many ready meals.[117] UPF often contain little or no whole foods, and are high in oils, sugar, and salt, and have few positive health or nutritional attributes, especially compared to fruit, vegetables, and legumes. Despite low emissions from agriculture for the main UPF commodities, processing can be energy intensive with resulting high emissions that are often unaccounted for in emissions estimates.[118,119]

The convenience benefit of UPF to individuals must however be factored into any policy considerations, particularly the reduced need for cooking, more instant availability when time and resources are scarce, and longer helf life than fresh alternatives.

Box 3: Plant-based burgers

Plant-based burgers generate considerably fewer GHG emissions and use substantially less water than traditional beef burgers, and can be a good source of protein, vitamins, and minerals, often being designed to replicate the nutrient content of meat burgers gram for gram.[120] However, some plant-based alternatives are not always completely 'healthy'. Meatless burgers are largely beneficial for vegetarians, who may struggle to consume the recommended amounts of protein, vitamins, and minerals. However, their salt and saturated fat content can also match and exceed that of their meat-based counterparts. Both increased public awareness of the nutritional content of plant-based alternatives and further reformulations to reduce the fat and salt content would ensure the transition to more plant-based foods achieves the full potential health and environmental benefits (Figure 3).

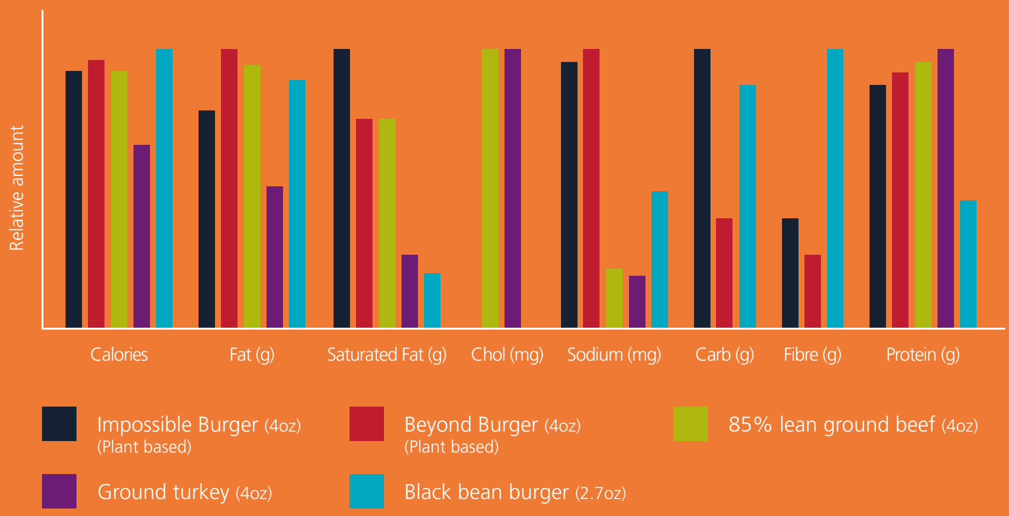

Figure 3: Relative amounts of key dietary components of meat vs meatless burgers.[120]

117. Monteiro CA, *et al.* (2017). *The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing.* Public Health Nutrition **21**, 5-17.

118. Fardet A, Rock E (2020). *Ultra-Processed Foods and Food System Sustainability: What Are the Links?* Sustainability **12(15)**, 6280.

119. Hadjikakou M (2017). *Trimming the excess: environmental impacts of discretionary food consumption in Australia.* Ecological Economics **131**, 119-128.

120. Gelsomin E (2019). *Impossible and Beyond: how healthy are these meatless burgers?* Harvard Health publishing https://www.health.harvard.edu/blog/impossible-and-beyond-how-healthy-are-these-meatless-burgers-2019081517448

3.2.3 Reducing food waste

Reducing food waste will also have benefits for the climate and health. Approximately a third of food produced globally is lost or wasted, which between 2010 and 2016 accounted for 8–10% of global GHG emissions.[121,122] Reducing food waste also means that nutrients are consumed rather than wasted: research shows that around 42 days of nutritionally adequate diets are discarded per capita per year.[119] The UK's fruit and vegetable supply is increasingly dependent on imports from climate-vulnerable countries providing added impetus to increase local production and reduce waste and loss.[123]

Salads are one of the foods most commonly thrown away, constituting 28% of all food waste, much of which is airfreighted due to its short shelf life.[124] Approximately 6% of food waste is meat and fish, which as well as having high GHG footprints are also an important sources of iron and other micronutrients. The highest micronutrient losses are vitamin B_{12}, vitamin C, and thiamin, equivalent to 160, 140, and 130 days of recommended nutrient intakes (RNI) per person per year, respectively.

Efforts taken to reduce waste include removing incentives to buy more than required such as multi-buy offers, especially for perishable foods, and schemes to redistribute surpluses to food charities.[125] Reducing portion sizes could have a positive impact on both food waste reduction and overconsumption. However, any changes would need to be reflected in the price of the food, particularly for nutrient-dense foods such as fruit and vegetables, so as not to increase inequalities.

Food waste declined during the COVID-19 restrictions. Surveys by WRAP and others show that UK households adopted new food management behaviours (meal planning, batch-cooking, using leftovers, etc.), leading to a decrease of over 40% in reported food waste during the first lockdown;[126] although this partially rebounded when restrictions were lifted.[91] Nevertheless, over one-third of the British public intend to waste less food after the COVID-19 pandemic than before it, suggesting some new sustainable food management skills may be retained.[127]

3.3 Challenges and opportunities: actions for policy, practice and research

3.3.1 Supporting behaviour change

All the proposals described above require changing behaviours. However, changing dietary habits is particularly difficult, especially when it involves reducing the consumption of foods that are popular and accessible, for example meat and UPF, which for many people are staple parts of their diet. Facilitating behaviour change requires a joined-up approach of action to promote healthy living across the food system and beyond and should build on and be informed by previous policies aiming to change dietary choice.[128,129] Reducing overconsumption of UPF, for example, will require varied and targeted interventions to tackle physical, economic, and socio-cultural factors. Dietary choices are also influenced by social and cultural traditions, and future dialogues should couple the scientific evidence with openness and respect.[103]

121. Cooper KA (2018). *Nutrition in the Bin: A Nutritional and Environmental Assessment of Food Wasted in the UK*. Frontiers in Nutrition **5**, 19.
122. Forbes H, Quested T & O'Connor C (2021). *UNEP Food Waste Index Report 2021.* https://www.unep.org/resources/report/unep-food-waste-index-report-2021
123. Scheelbeek P, *et al*. (2020). *United Kingdom's fruit and vegetable supply is increasingly dependent on imports from climate-vulnerable producing countries*. Nature Food **1(11)**, 705-712.
124. WRAP (2021). *Food surplus and waste in the UK – key facts*. https://wrap.org.uk/sites/default/files/2020-11/Food-surplus-and-waste-in-the-UK-key-facts-Jan-2020.pdf
125. Thomas N (2016). *Sainsbury's scraps 'multi-buy' offers*. Financial Times, 11 February 2016. https://www.ft.com/content/a093243b-803c-3007-85ea-87e4f799b90e
126. WRAP (2020). *Life under Covid-19: Food waste attitudes and behaviours in 2020*. https://wrap.org.uk/resources/report/life-under-covid-19-food-waste-attitudes-and-behaviours-2020
127. Ipsos MORI (2021). *Earth Day 2021: Only 3 in 10 Britons think the Government has a clear plan to tackle climate change*. https://www.ipsos.com/ipsos-mori/en-uk/earth-day-2021-only-3-10-britons-think-government-has-clear-plan-tackle-climate-change
128. Corner A, Graham H & Whitmarsh L (2019). *Engaging the public on low-carbon lifestyle change.* CAST Briefing Paper 01. https://cast.ac.uk/wp-content/uploads/2020/01/CAST-briefing-01-Engaging-the-public-on-low-carbon-lifestyle-change-min.pdf
129. Pell D, *et al*. (2021). *Changes in soft drink purchased by British households associated with the UK soft drinks industry levy: controlled interrupted time series analysis*. BMJ **372**.

The production and consumption of plant-based foods are increasing and the number of people on completely plant-based diets increased by 40% in 2020 – although these are still small numbers with only 5% of the UK population identifying as vegetarian, and less than 1% vegan.[130] Nonetheless, a 2019 survey showed that 1 in 6 meat-eaters had intentions to reduce their meat consumption.[131]

In response to this demand, new plant-based products, and novel meat alternatives such as cultured meat and insects are being developed. Although some of these options show promise, there is limited understanding of the health and environmental impacts of scaling up production of these alternatives and will require careful monitoring. Often protein replacement is the focus for most meat alternatives, although very few predominantly plant-based diets are deficient, and so safeguarding essential micronutrients in alternatives to meat products should be higher priority.[132]

There is strong public support for policies to change farming, food production, land use, retail patterns, and individual behaviour to reduce the impact of the UK food system on the climate.[133] Educational measures and public procurement decisions tend to command more support than economic or regulatory measures, as fairness and consumer choice are key factors in policies being accepted.[131]

Social factors, such as income and employment, are important in food choices.[134] Despite recognition that predominantly plant-based diets are ethical, good for the environment, and healthy, the taste, price, and convenience can be barriers to change.[129] Such barriers are being addressed for example by making easy-to-prepare plant-based foods more accessible, but this should be complemented with educational campaigns to clarify the nutritional content (see Box 3).[135]

National dietary guidelines provide a foundation for policies and public engagement to reduce diet-related disease, obesity, and undernutrition. The UK Government's Eatwell Guide is a source of advice for a healthy, balanced diet, but it does not explicitly take account of environmental impacts, although research suggests that adhering to this advice is likely to lead to a lower footprint than current standard diets.[136,137] The inclusion of environmental impacts in UK dietary guidelines could help to realise the maximum health and climate benefits and identify the trade-offs. For example, in 2019, FAO and WHO jointly published a set of guideline principles for sustainable healthy diets, which include health, nutrition, and environmental indicators, which could be used as the foundation of dietary guidelines in the UK, together with recognition of the religious, cultural, and social aspects of eating.[138]

Some suggested initiatives for sustainable and healthy diets include increasing the proportion of plant-based foods in public-sector catering such as schools and hospitals, and emission levies on producers which promote health benefits.[139,140]

130. Steentjes K, *et al.* (2021). *UK perceptions of climate change and lifestyle changes*. CAST Briefing Paper 08. https://cast.ac.uk/wp-content/uploads/2021/03/CAST-Briefing-08.pdf

131. Bryant CJ (2019). *We Can't Keep Meating Like This: Attitudes towards Vegetarian and Vegan Diets in the United Kingdom*. Sustainability. **11(23)**, 6844.

132. Parodi A, *et al.* (2018). *The potential of future foods for sustainable and healthy diets*. Nature Sustainability **1(12)**, 782-789.

133. Climate Assembly UK (2020). *The path to net zero*. https://www.climateassembly.uk/report/read/final-report.pdf

134. Behavioural Insights Team (2020). *A Menu for Change. Using behavioural science to promote sustainable diets around the world*. https://www.bi.team/wp-content/uploads/2020/03/BIT_Report_A-Menu-for-Change_Webversion_2020.pdf.pdf

135. Gehring J, *et al.* (2021). *Consumption of Ultra-Processed Foods by Pesco-Vegetarians, Vegetarians, and Vegans: Associations with Duration and Age at Diet Initiation*. The Journal of Nutrition **151(1)**, 120-131.

136. NHS (2019). *The Eatwell Guide*. https://onlinelibrary.wiley.com/doi/abs/10.1111/nbu.12211

137. Scheelbeek P, *et al.* (2020). *Health impacts and environmental footprints of diets that meet the Eatwell Guide recommendations: analyses of multiple UK studies*. BMJ Open **10(8)**, e037554.

138. FAO and WHO (2019). *Sustainable healthy diets – Guiding principles*. Rome. http://www.fao.org/3/ca6640en/ca6640en.pdf

139. Swinburn BA, et al. (2019). The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. Lancet 393(10173), 791–846.

140. Garnett E, *et al.* (2019). *Impact of increasing vegetarian availability on meal selection and sales in cafeterias*. PNAS **116(42)**, 20923-20929.

3.3.2 Avoiding trade-offs and unintended consequences

There are some trade-offs in the shift to more sustainable and healthy diets which can be managed with well-designed policies. For example, decreased meat consumption, despite having significant climate and health benefits, may affect the livelihoods of those involved in the production.[141]

Fashionable food trends can also place significant pressure on the environment. For example, the increased consumption of almond milk has been associated with severe environmental damage and drought and increasing palm and coconut oil consumption has contributed to deforestation.[142,143]

Collaboration between different government sectors will be necessary to take a systems approach to avoid disparities and increases in inequality. For example, in the USA, there is a misalignment of agricultural subsidies and dietary recommendations; it is recommended that a healthy diet should comprise 50% fruit and vegetables; however only 0.45% of subsidies go to the production of these foods.[144]

3.3.3 Monitoring policy impacts

Monitoring and evaluation of the impact of policies in this area are essential to improve our understanding of the factors influencing behaviour change and to shape further policy change. Existing national surveys (see Box 4), which are used to monitor changes in consumption and purchase patterns in the UK, could also be extended to include information on climate change and other environmental indicators.

Box 4: National dietary surveys

The National Diet and Nutrition Survey is a continuous, cross-sectional government survey funded by Public Health England and the UK Food Standards Agency. It collects quantitative information on the food consumption, nutrient intake, and nutritional status of the general population, covering around 1000 people each year.

The Living Costs and Food Survey is conducted by the Office for National Statistics, and collects information on spending patterns, household income, and food consumption (which is used and published by the Department for Environment, Food and Rural Affairs).

3.4 Conclusions

No single action would achieve a transformational diet-based behavioural change needed to mitigate climate change and improve health; it would require a coordinated programme comprising a series of measures. Efforts to encourage changes in individuals' behaviour such as encouraging plant-based choices, would need to be implemented alongside policy action to influence the physical, economic, social, commercial, and digital settings in which cooking and eating occur.

141. Office for National Statistics (2018). *Labour in the agriculture industry, UK: February 2018.* https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/internationalmigration/articles/labourintheagricultureindustry/2018-02-06

142. Fleischer D (2018). *Almond milk is taking a toll on the environment.* https://sustainability.ucsf.edu/1.713

143. Rochmyaningsih D (2020). *Claims that coconut oil is worse for biodiversity than palm oil sparks furious debate.* https://www.sciencemag.org/news/2020/07/claim-coconut-oil-worse-biodiversity-palm-oil-sparks-furious-debate

144. Penn State University (2020). *America's supersized insecurity: why are American's getting bigger, yet hungrier?* https://sites.psu.edu/deliberationnation/files/2020/03/IssueGuide_AmericasSupersizedInsecurity.pdf

Key insights

- The alignment of health, agriculture, nutrition, and climate policies could help to support a shift towards supplying food that benefits both health and the climate through both adaptation and mitigation actions. This could ensure maximum benefit and avoid unintended consequences, with health and climate included as core elements in common policies (see **Recommendation 2**). It would be important to consider the impact of any policies on inequalities.

- Robust monitoring and evaluation tools are key to assessing the climate and health impacts of food policies on a national scale (see **Recommendation 3**).

- To support monitoring and evaluation, climate impacts could be incorporated in national dietary guidelines (the UK Government's Eatwell Guide) with the FAO/WHO guideline principles for sustainable, healthy, balanced diets which combine health, nutrition, environmental, and social elements, acting as a basis for such efforts.

- Whilst education alone does not change behaviours, embedding education into wider policies and processes may enable healthier options to be more desirable, affordable, and accessible. For example, educational campaigns around dietary choice could play a valuable role in managing perceptions that all plant-based foods are healthy and counteracting the mistaken belief that meat consumption is essential to avoid deficiencies in key nutrients.

4. Buildings

4.1 Reducing building emissions

In 2019, buildings were responsible for 87 million tonnes of CO_2 equivalent ($MtCO_2e$) in direct emissions of GHGs, or 17% of the UK total, mainly from burning natural gas for heating and cooking.[145] Around two-thirds of the UK's electricity use is within buildings, of which the GHG emissions and health impacts are covered in Chapter 1. Reducing emissions from buildings to zero by 2050 is a key objective of net-zero ambitions.

Broad categories of approaches to reduce emissions from buildings include energy efficiency measures, such as insulation; switching from fossil fuels to low-carbon alternatives, such as use of heat pumps, hydrogen, electric or geo-thermal heating; and behavioural change, such as altering thermostat temperature set points.

There are also opportunities to reduce emissions through urban planning, which can influence transport patterns, opportunities for district heating, and other factors, and by decreasing the 'embodied' emissions of construction methods and materials. Key to achieving the required reductions will be effective planning policy, building regulations, and standards. It is also important to note that in the UK, the majority of homes that will be inhabited at mid-century are already built and will remain the principal source of dwelling-related GHG emissions, so retrofitting existing dwellings is an important target for both health and sustainability objectives.[146]

4.2 What are the potential health co-benefits?

4.2.1 Relevant determinants of health – the example of energy efficiency in housing

The pathways that connect health with a building's energy and energy efficiency profile include the fabric, ventilation characteristics, fuel sources, and use.[147] Here we use housing as an example of the link between net-zero buildings and health, but buildings that serve groups of people, such as workplaces, schools, hospitals, and care homes, also play an important role. The link between environmental and health factors is often strongest in the cases of risk groups such as older people and young children, and housing conditions, in general, have an influence on social inequalities in health.[148] While we do not focus on these inequalities in this section, we note the importance of addressing them.[149]

Making a dwelling more energy efficient by increasing the insulation of its fabric (the walls, floor, windows, and roof) and reducing uncontrolled ventilation (draughts) has an influence on indoor temperatures in both winter and summer. Such energy efficiency features form part of a wider range of design and retrofit measures that can improve indoor and local environments.[150,151]

i) Housing fabric – In the UK, there is a substantially larger number of cold deaths than heat deaths each year, and that is likely to remain the case in the coming decades despite climate change.[152] In 2019-2020, it is estimated the excess winter mortality was 28,000 deaths while the estimate of specifically cold-related

145. Climate Change Committee (2020). *Sixth Carbon Budget*. https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

146. Climate Change Committee (2019). *UK housing: fit for the future?* https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

147. Wilkinson P, *et al.* (2009). *Public health benefits of strategies to reduce greenhouse-gas emissions: household energy.* Lancet **374(9705)**, 1917-1929.

148. Braubach M, Savelsberg J & World Health Organisation Regional Office for Europe (2009). *Social inequalities and their influence on housing risk factors and health: a data report based on the WHO LARES database.* https://apps.who.int/iris/bitstream/handle/10665/107955/E92729.pdf?sequence=1&isAllowed=y

149. Thomson H & Thomas S (2005). *Developing empirically supported theories of change for housing investment and health.* Social Science & Medicine **124**, 205–214.

150. Gilbertson J, *et al.* (2006). *Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front).* Social Science & Medicine 2006; **63(4)**, 946-956.

151. Murage P, *et al.* (2020). *What individual and neighbourhood-level factors increase the risk of heat-related mortality? A case-crossover study of over 185,000 deaths in London using high-resolution climate datasets.* Environment International **134**, 105292.

152 Gasparrini A, *et al.* (2015). *Mortality risk attributable to high and low ambient temperature: a multicountry observational study.* Lancet **386(9991)**, 369-375.

deaths across all months was 50,000 a year.[153] Although it is unclear what proportion arises from exposure to cold in the indoor environment, it is probable that the risks would be appreciably reduced by warmer home environments, especially for some risk groups that spend a high proportion of time indoors. There is evidence that colder homes are specifically linked to higher burdens of winter- and cold-related mortality from cardiovascular disease, and that home energy efficiency interventions reduce various forms of cold morbidity.[154,155]

However, improved energy efficiency measures also have the potential to exacerbate overheating in summer – and hence to increase heat mortality and morbidity – if appropriate countermeasures are not taken.[156] This risk arises because solar gain through windows can heat homes more quickly if the fabric has a lower effective thermal mass and if insulation means that internal heat is dissipated less quickly. Fortunately, judicious use of shading (for example external shutters and shading by trees) can reduce the risks of overheating, although there are limits from such passive controls alone.[157] Such measures should also reduce the need for energy for cooling. Heat-related mortality is projected to increase under climate change, hence the importance of combining energy efficiency with adaptations for heat.

ii) Air exchange and uncontrolled ventilation – The objective of energy efficiency upgrades is to reduce uncontrolled ventilation, or draughts, to reduce heat loss. This has both beneficial and negative consequences for the health of dwelling occupants. While reduced air change is beneficial in reducing the ingress of harmful pollutants such as fine particles ($PM_{2.5}$) and nitrogen dioxide (NO_2) from the outdoor environment, it may also lead to higher indoor concentrations of pollutants of indoor origin such as particles, NO_2, volatile organic compounds and second-hand tobacco smoke, as well as radon, which enters the home from the rocks and soil on which the dwelling is built.[158,159] Mould and other biological agents may also be exacerbated, depending on the changes in temperature, relative humidity, and air change. The COVID-19 pandemic has also highlighted that ventilation characteristics are important for the transmission of respiratory infections.[160,161,162] However, the energy costs of increasing air flow rates in ventilation systems could be substantial.[163]

Current evidence remains inconclusive about the net effect of energy efficiency measures on overall air exchange and thus on the balance of positive and negative health effects relating to indoor air quality and those effects may vary in relation to setting, dwelling type and occupant characteristics.[164,166]

iii) Fuel cost for heating, cooling, and other purposes – Improved energy efficiency should reduce fuel use for heating in winter, and in some circumstances may reduce cooling costs in summer.[165,166] This may be important for those on low income and at risk of fuel poverty, who could gain some

153. Office for National Statistics (2020). *Excess winter mortality in England and Wales: 2019 to 2020 (provisional) and 2018 to 2019* (final). https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/excesswintermortalityinenglandandwales/2019to2020provisionaland2018to2019final#main-points
154. Wilkinson P, *et al.* (2001). *Cold comfort. The social and environmental determinants of excess winter deaths in England, 1986-96*. Joseph Rowntree Foundation.
155. Gilbertson J, Grimsley M & Green G (2012). *Psychosocial routes from housing investment to health: Evidence from England's home energy efficiency scheme*. Energy Policy **49**, 122–133.
156. Shrubsole C, *et al.* (2014). *100 Unintended consequences of policies to improve the energy efficiency of the UK housing stock*. Indoor and Built Environment **23(3)**, 340-352.
157. Taylor J, *et al.* (2018). *Comparison of built environment adaptations to heat exposure and mortality during hot weather, West Midlands region, UK*. Environment International **111**, 287-94.
158. Hamilton I, *et al.* (2015). *Health effects of home energy efficiency interventions in England: a modelling study.* BMJ open **5(4)**, e007298.
159. Milner J, *et al.* (2014). *Home energy efficiency and radon related risk of lung cancer: modelling study.* BMJ **348**.
160. Morawska L, *et al.* (2021). *A paradigm shift to combat indoor respiratory infection*. Science **372**, 689–691
161. Health and Safety Executive (2021). *Ventilation and air conditioning during the COVID-19 pandemic*. https://www.hse.gov.uk/coronavirus/equipment-and-machinery/air-conditioning-and-ventilation/index.htm
162. Public Health England (2021). *Guidance: Ventiliation of indoor spaces to stop the spread of Coronavirus (COVID-19)*. https://www.gov.uk/government/publications/covid-19-ventilation-of-indoor-spaces-to-stop-the-spread-of-coronavirus/ventilation-of-indoor-spaces-to-stop-the-spread-of-coronavirus-covid-19
163. Dietz L, *et al.* (2020). *Novel Coronavirus (COVID-19) Pandemic: Built Environment Considerations To Reduce Transmission*. mSystems **5(2)**, e00375-20.
164. Armstrong B, *et al.* (2018). Public Health Research. *The impact of home energy efficiency interventions and winter fuel payments on winter- and cold-related mortality and morbidity in England: a natural equipment mixed-methods study.* Public Health Research **6(11)**, 1-110.
165. Sanchez-Guevara C, *et al.* (2019). *Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London*. Energy and Buildings **190**, 132-143.
166. Hamilton IG, *et a*l. (2011). *The impact of housing energy efficiency improvements on reduced exposure to cold – the 'temperature take back factor'*. Building Services Engineering Research and Technology **32(1)**, 85-98.

additional disposable income to help with other household costs such as food bills.[167] While direct estimates of the effect of such health savings are uncertain, relief of fuel poverty is recognised as contributing to the health and wellbeing of householders.[168]

iv) Household emissions and local air quality – A final pathway for health is through the improvement of outdoor air quality via reduced energy demand as household emissions are an important contributor to local air quality. Around 38% of UK primary PM emissions come from burning wood and coal in domestic open fires and solid-fuel stoves.[169] Reductions in residential biomass burning and shifts to meeting demand with clean low-carbon sources will reduce these emissions.

4.2.2 Other environments

Although this section of the report has focused on housing, there are many similarities across other indoor environments such as care settings, offices, schools, hospitals, prisons, and other communal living and working spaces. For example, care home populations are especially vulnerable to the effects of low and high temperature due to residents' age and pre-existing morbidity.[170] Measures used to improve energy efficiency of care homes will need to include actions to guard against cold environments in winter and overheating in summer. Research suggests that interventions to protect against heat risks would be cost-beneficial and provide tangible positive health outcomes, with window shading implemented to reduce indoor temperatures by just 0.6°C during an average summer estimated to avert 0.05–0.31 heat deaths per year in a care home with 50 inhabitants.[171]

One strategy to reduce indoor heat exposure and heat-related deaths, is increased use of air conditioning. Recent evidence suggests however that it is only responsible for reducing a small proportion of heat-related death rates observed in some countries.[172] Further, it has important limitations, including increasing energy demands and associated GHG emissions and air pollution, the potential to increase inequities, vulnerability to grid failures during heatwaves, and increases in the urban heat island effect by displacing heat outdoors.[173]

For office buildings, recent research in the USA has explored the health and productivity benefits of energy-efficient buildings, concluding that those certified with green building standards may have health benefits from improved indoor environmental quality, possibly from lower levels of air pollutants and more comfortable thermal and light conditions.[174,175]

4.3. The importance of a systems approach

A high-performing and sustainable built environment is essential for:

(i) reducing GHG emissions
(ii) enabling energy affordability and security
(iii) adapting to climate change and
(iv) improving the health and wellbeing of the population, including health inequalities.

167. Hills J (2012). *Getting the measure of fuel poverty. Final report of the fuel poverty review.*

168. Marmot Review Team (2011). *The health impacts of cold homes and fuel poverty*. https://www.instituteofhealthequity.org/resources-reports/the-health-impacts-of-cold-homes-and-fuel-poverty/the-health-impacts-of-cold-homes-and-fuel-poverty.pdf

169. *Department for Environment Food & Rural Affairs (2019).* Clean Air Strategy 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf

170. Hajat S, Kovats RS & Lachowycz K (2007). *Heat-related and cold-related deaths in England and Wales: who is at risk?* Occupational and environmental medicine **64(2)**, 93-100.

171. Ibbetson A, *et* al. (2021). *Mortality benefit of building adaptations to protect care home residents against heat risks in the context of uncertainty over loss of life expectancy from hea*t. Climate Risk Management **32**, 100307.

172. Salamanca F (2014). *Anthropogenic heating of the urban environment due to air conditioning.* Journal of Geophysical Research: Atmospheres **119(10)**, 5949-5965.

173. Sera F, *et al.* (2020). *Air conditioning and heat-related mortality: a multi-country longitudinal study.* Epidemiology **31(6)**, 779-787.

174. MacNaughton P, *et al.* (2017). *The impact of working in a green certified building on cognitive function and health.* Building and Environment **114**, 178-186.

175. Cedeño-Laurent JG, *et al.* (2018). *Building Evidence for Health: Green Buildings, Current Science, and Future Challenges.* Annual Review of Public Health **39(1)**, 291-308.

176. Crane M, *et al.* (2021). *Transforming cities for sustainability: A health perspective.* Environment International **147**, 106366.

177. Rydin Y, *et al.* (2021). *Shaping cities for health: complexity and the planning of urban environments in the 21st century.* Lancet **379(9831)**, 2079-2108.

This applies to both rural and urban settings, although cities, around the world, have not yet been successful in meeting key environmental and associated health challenges.[176] Cities are complex systems.[177] People living in them have diverse priorities and they and the systems that support them, such as food, transport, buildings, and waste management, are interdependent. Changes tend to be incremental and slow, and often improvements are fragmented or focused on one small area. Big changes often disrupt settled patterns of living and incur initial cost and unpopularity, which makes them difficult to implement, despite their eventual substantial benefits.

Effective climate action requires clarifying the issues, by investigating their causes and co-developing integrated solutions with a range of stakeholders, focusing on interconnected systems, people's behaviour, and implementation. Understanding the systemic nature of a sustainable built environment poses a critical and urgent global challenge, especially as large investments are planned for reducing the GHG emissions of the built environment worldwide over the next three decades. As outlined in **Recommendation 2** of this report, whilst attempting to mitigate climate change, there should be consideration of the required adaptation measures to ensure they are not antagonistic at a minimum and synergistic where feasible.

Consultation with stakeholders from different disciplines during policymaking and research could help expose some of the tensions, trade-offs, and unintended consequences, such as by the use of methods such as participatory system dynamics modelling.[178] This brief overview suggests the need for additional robust transdisciplinary research evidence on strategies that integrate assessment of health, climate, and socioeconomic impacts of energy efficiency measures in buildings. Targeted funding for systems approaches within research and design could help to facilitate efforts.[179]

Key insights

- The pathways that connect health with a building's energy and energy efficiency profile include the fabric, ventilation characteristics, fuel sources, and use.
- Efforts should be underpinned by work to identify and address the potential trade-offs between climate mitigation and adaptation actions in building design (see **Recommendation 2**). For example, a drive to combine improvements in energy efficiency with adaptation measures against heat risk such as passive ventilation, 'cool roofs', and shading, could help to offset some of the trade-offs.
- Action is needed to retrofit existing homes, improve new builds, and enhance systemic integration with urban planning, such as promoting more sustainable transport. Given the complexities involved, innovative policy analysis, design, and implementation is needed, using tools to understand system interconnections and avoid unintended consequences (see **Recommendation 4**).

178. Pineo H, *et al.* (2021). *A new transdisciplinary research model to investigate and improve the health of the public*. Health promotion international **36(2)**, 481-492.

179. Canadian Academy of Health Sciences & Academy of Medical Sciences (2021). Systems-based approaches in public health: where next? https://acmedsci.ac.uk/more/news/complexsystems

5. Natural environment

5.1 The contribution of natural environments to climate change mitigation

Over the past several decades, there have been a series of frameworks and approaches to both explore and understand how a healthy environment influences human health, and the recognition that human activity is damaging, often with irreversible impacts, the global systems on which we rely for health and wellbeing.[180]

The concept of ecosystem services has emerged with the Millennium Ecosystem Assessment as well as frameworks such as One Health, focusing largely on animal/human health interlinkages and most recently, Planetary Health, encompassing broader systemic threats to health and environmental sustainability and the actions needed to adapt to and mitigate such changes.[180,181,182] There is now a rapidly growing evidence base linking the health of the natural environment to human health, including in the context of climate change.

The UK transition to net-zero within the natural environment is focused around reduced GHG emissions from food production and waste, enhanced carbon sequestration through woodland expansion, reduced CO_2 loss from degraded peatlands via restoration, and an increase in bioenergy crop production.[183] Some current green policies include the UK's Green Recovery Plan,[184] DEFRA's 5 Year Plan for the Environment,[185] the UN Ocean Decade,[186] and the UN Sustainable Development goals.[187]

5.2 Links between the natural environment and health

5.2.1 Direct health impacts

Health impacts from climate and other environmental change include injury and mortality from extreme weather events and flooding, increases in infectious diseases due to vector-borne diseases (including in the UK, tickborne Lyme disease), and mortality from increasing temperatures that can be mediated through changes in natural systems. These impacts often have the most severe effects among vulnerable populations such as the elderly, the poor, children, and people with chronic conditions.[188]

The natural environment also provides a place for exercise, with many health benefits including lowering the risk of cardiovascular diseases and other chronic diseases. Green and blue spaces can improve wellbeing and mental health, connect people and communities, and, with equitable access, help to reduce health inequalities.[189]

Vegetation cover in both rural and urban areas can provide cooling and shading, clean the air, and prevent flooding (see Box 5).[190] Individuals living in urban areas with greater amounts of green space display lower levels of mental distress and higher levels of wellbeing compared to those living in urban areas with less

180. Whitmee S, *et al.* (2015). *Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health.* The Lancet **386(10007)**, 1973-2028.

181. One Health Commission (2020). *What is One Health?* https://www.onehealthcommission.org/en/why_one_health/what_is_one_health/

182. Millennium Ecosystem Assessment (2005). *Ecosystems and Human Wellbeing: A Framework for Assessment*. https://www.millenniumassessment.org/en/Framework.html

183. Royal Society (2021). *Climate change and land: the science of working with nature towards net zero*. https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-land.pdf

184. Department for Business, Energy & Industrial Strategy (2020). *The Ten Point Plan for a Green Industrial Revolution*. https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title

185. HM Government (2020). *A Green Future: Our 25 Year Plan to Improve the Environment*. https://www.gov.uk/government/publications/25-year-environment-plan

186. United Nations Decade of Ocean Science for Sustainable Development. (2021). https://www.oceandecade.org

187. United Nations. (2021). *The 17 Goals*. https://sdgs.un.org/goals

188. Haines A, *et al.* (2006). *Climate change and human health. Impacts, vulnerability and human health*. Public Health **120(7)**, 585-596.

189. Lovell R, Depledge M & Maxwell S (2018). *Health and the natural environment: A review of evidence, policy, practice and opportunities for the future.* https://ore.exeter.ac.uk/repository/bitstream/handle/10871/36923/Health%20and%20the%20Natural%20Environment_Full%20Report.pdf?sequence=1&isAllowed=y

190. Kabisch N, *et al.* (2016). *Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action*. Ecology & Society, **21(2)**.

green space.[191] There is also growing evidence that interacting specifically with high-quality 'blue' environments, areas dominated by water from rivers and lakes to swimming pools and beaches, can improve physical health and mental wellbeing.[192]

5.2.2 Indirect health impacts

Studies linking biological diversity on land and in the ocean to human health highlight human reliance on natural products for drug discovery, supporting medical advances, and other resources.[193] Biodiversity is also integral to food security, for example through intercropping and reliance on pollinators. Biodiversity loss and ecosystem disturbance of natural environments may also be linked to increased risk of zoonotic diseases.[194]

Beyond acting as a major buffer for the impacts of climate change and temperature increases, the seas, coasts, and the global ocean provide both risks and benefits to human health and wellbeing, including food, livelihoods, trade, and culture.[195,196]

5.3 Potential health co-benefits of reducing emissions

5.3.1 Example - Nature-based solutions

Nature-based solutions (NbS) work with nature, both on the land and with the ocean, to solve societal challenges by providing integrated approaches to address climate change, reverse biodiversity loss, and help to meet multiple sustainable development objectives.[197] Solutions that seek to enhance nature straddle both mitigation and adaptation. As outlined in **Recommendation 2**, the integration of both mitigation and adaption may warrant an increasing focus in policy and research, given the dual potential to reduce negative impacts of climate change on health and yield health co-benefits of climate change mitigation actions.

NbS can be divided into six strategies: restoration, protection, management, combined approaches and the creation of new, or modified, ecosystems.[198] Besides reducing GHG emissions and mitigating climate change through carbon sequestration, NbS can increase resilience by helping communities adapt to the impacts, for example, restoring forests or woodland in elevated catchment areas to reduce flooding in lower-lying settlements, or rejuvenating partially degraded grasslands in arid climates to buffer local communities against extreme climate conditions such as drought.[197] Some further examples of NbS and links to health include:

- ecosystem-based coastal defences providing equitable access to coastal environments for individual and community physical health and mental wellbeing.
- transformative adaptation solutions in urban areas that enable cities to successfully navigate the water–energy–climate relationship and transform living conditions.[199]
- dietary shifts towards more plant-based (land and marine) foods that offer improvements in human health, reductions in GHG emissions, reduced pressure on land, and freeing more space for NbS (see Chapter 3).[200]

In addition, NbS go beyond the traditional conservation approaches by intentionally integrating societal factors such as human wellbeing and poverty alleviation, thereby opening up opportunities for inter- and transdisciplinary research, in line with **Recommendation 4** of this report.[201]

191. White MP, *et al.* (2013). *Would you be happier living in a greener urban area? A fixed-effects analysis of panel data.* Psychological Science **24(6)**, 920-928.
192. White MP, *et al.* (2020) *Blue space, health and wellbeing: A narrative overview and synthesis of potential benefits.* Environmental Research, 110169.
193. WHO Regional Office for Europe (2021). *Nature, biodiversity and health: an overview of interconnections.* https://apps.who.int/iris/bitstream/handle/10665/341376/9789289055581-eng.pdf
194. Keesing F, *et al*. (2021). *Impacts of biodiversity and biodiversity loss on zoonotic diseases. Proceedings of the National Academy of Sciences* **118(17)**.
195. Fleming LE, *et al.* (2019). *Fostering human health through ocean sustainability in the 21st century. People and nature.* People & Nature **1(3)**, 276-283.
196. Fleming LE, *et al.* (2021). *The Ocean Decade – Opportunities for Oceans and Human Health Programs to Contribute to Public Health.* American Journal of Public Health, 808-821.
197. Seddon N, *et al.* (2020). *Understanding the value and limits of nature-based solutions to climate change and other global challenges.* Philosophical Transactions of the Royal Society B **375(1794)**, 20190120.
198. Chausson A, *et al.* (2020). *Mapping the effectiveness of nature-based solutions for climate change adaptation.* Global Change Biology, **26(11)**, 6134-6155.
199. Wendling LA, *et al.* (2018). *Benchmarking Nature-Based Solution and Smart City Assessment Schemes Against the Sustainable Development Goal Indicator Framework*. Frontiers in Environmental Science **6**, 69.
200. Smith P, *et al.* (2020). *Which practices co-deliver food security, climate change mitigation and adaptation, and combat land-degradation and desertification?* Global Change Biology, **26(3**), 1532-1575.
201. Eggermont H, *et al.* (2015). *Nature-based Solutions: New Influence for Environmental Management and Research in Europe.* GAIA – Ecological Perspectives for Science and Society, **24(4)**, 243-248.

Box 5: The health and sustainability benefits of green infrastructure

Changes to urban environments have the potential for appreciable benefits to health and are now a large focus of the 'Build Back Better' movement after COVID-19.[202] The expansion of 'green infrastructure', such as green walls and roofs, parks, street trees, and urban woodlands, can deliver substantial cumulative impacts across a city, such as reductions in carbon, air and noise pollution, flooding, and overheating, and subsequent positive outcomes for health, although quantifying these effects is complex.[203,204]

The health benefits of green infrastructure include a reduction in all-cause mortality and improved mental health.[205,206,207] There is also potential for adverse effects; for example, some tree species emit biological Volatile Organic Compounds that act as precursors of tropospheric ozone which is both a short-lived climate pollutant and damaging to health.[208,209] Trees can remove modest amounts of $PM_{2.5}$, for example by deposition on leaves, but they can also trap $PM_{2.5}$ in immobile air, thus increasing local levels.[210] Furthermore, some trees, for example birch, produce allergenic pollen.

Urban tree planting initiatives are an important tool to help cities mitigate and adapt to climate change as well as being of importance to human health and wellbeing through regulating the air quality and through aesthetics and cultural services.[211] The choice of tree species, their density, and their location will determine health benefits, and potential disbenefits, of tree planting.

202. Milner J, *et al.* (2021). *Emerging from COVID-19: Lessons Action for Climate Change and Health in Cities*. Journal of Urban Health, 1-5.
203. van den Bosch M & Ode Sang Å (2017). *Urban natural environments as nature-based solutions for improved public health – a systematic review of reviews*. Environmental Research **158**, 373-384.
204. European Commission Directorate-General for Research & Innovation (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: final report of the Horizon 2020 expert group on 'Nature based solutions and re naturing cities'* (full version). https://op.europa.eu/en/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202
205. Rojas-Rueda D, *et al.* (2019). *Green spaces and mortality: a systematic review and meta-analysis of cohort studies*. Lancet Planetary Health **3(11)**, e469-e77.
206. Gascon M, *et al.* (2015). *Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review.* International Journal of Environmental Research & Public Health **12(4)**, 4354-4379.
207. Twohig-Bennett C & Jones A (2018). *The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes*. Environmental Research **166**, 628-637.
208. https://www.frontiersin.org/articles/10.3389/ffgc.2019.00050/full
209. Samson R, *et al.* (2017). *Species-specific information for enhancing ecosystem services*. In Pearlmutter D, *et al.* eds. (2017). The Urban Forest, Springer, Cham.
210. Fitzky AC, *et al.* (2019). *The Interplay between Ozone and Urban Vegetation – BVOC Emissions, Ozone Deposition & Tree Ecophysiology*. Frontiers for Global Change.
211. Salmond JA, *et al.* (2016). *Health and climate related ecosystem services provided by street trees in the urban environment*. Environmental Health **15(1)**, 95-111.

5.3.2 Balancing co-benefits and trade-offs

As well as realising the benefits, there are possible trade-offs that should be identified and managed, for example:

- Land restoration initiatives may increase human–animal conflict by increasing proximity to wildlife, pests, and vector–borne diseases.
- Narrowly focusing on tree planting for carbon sequestration, especially using monocultures, can adversely affect biodiversity, food, and water security.[212]
- In some countries, NbS have been viewed with concern by many indigenous communities who perceive them as threats to their customary land and resource rights.[213] Solutions that are not co-developed with participation from local and indigenous populations can hinder progress and reinforce social injustices in land ownership, resource distribution, and access.[214]
- The potential to distract attention from the urgent need to decarbonise economies, particularly those of high-consuming nations, by focusing on offsetting of their carbon emissions using NbS rather than reducing emissions. While such projects help reduce the aggregate total of emissions at a global level, they could delay action and therefore health co-benefits at the local level if they reduce the public and political appetite to cut GHG emissions.
- For the land use sector in particular, woodland expansion in the UK – planned to exceed 30,000 ha per year from 2025[184] – highlights the delicate balance between realising health benefits and incurring risks (see Box 6).

Box 6: Benefits and risks of woodland expansion

Expansion of woodland in urban and peri-urban areas would be expected to provide physical human health benefits through reducing urban heat island effects, UV exposure, heat stress, flood risks, and ozone formation.[215] Likewise, in some rural areas it has the potential to capture ammonia and particulate emissions from strong point sources, such as poultry farms, and so reduce air quality impacts.[216] Furthermore, increased access to green spaces, including woodland, as part of the transition to net-zero can be expected to provide mental health benefits, such as reduced depression, anxiety, and stress.

However, such large-scale woodland expansion poses human health risks including the enhanced risks of wildfires, resulting from a combination of increased woody biomass with drier, hotter summers and droughts.[217] There is further risk of enhanced pollen and VOC emissions (see Box 5).[218] Woodland expansion in both urban and rural areas, coupled with increased human use and changing distributions of vectors particularly due to climate change, may also pose increased human health risks via vector–borne disease.[219]

212. McElwee P, *et al.* (2020). *The impact of interventions in the global land and agri-food sectors on Nature's Contributions to People and the UN Sustainable Development Goals.* Global Change Biology **26(9)**, 4691-4721.

213. Griscom BW, *et al.* (2020). *National mitigation potential from natural climate solutions in the tropics.* Philosophical Transactions of the Royal Society B **375**(1794), 20190126.

214. Seddon N, *et al.* (2021). *Getting the message right on nature-based solutions to climate change.* Global Change Biology **27(8)**, 1518-1546.

215. Pataki DE, *et al.* (2021). *The Benefits and Limits of Urban Tree Planting for Environmental and Human Health.* Frontiers in Ecology and Evolution **9**, 155.

216. Bealey WJ, *et al.* (2016). *The potential for tree planting strategies to reduce local and regional ecosystem impacts of agricultural ammonia emissions.* Journal of environmental management **165**,106-116.

217. Arnell NW, *et al.* (2021). *Changing climate risk in the UK: a multi- sectoral analysis using policy-relevant indicators.* Climate Risk Management **31**, 100265.

218. Wolf KL, *et al.* (2020). *Urban Trees and Human Health: A Scoping Review.* International Journal of Environmental Research and Public Health, **17(12)**, 4371.

219. Medlock JM, *et al.* (2015). *Effect of climate change on vector-borne disease risk in the UK.* The Lancet Infectious Diseases **15(6)**, 721-730.

5.3.3 An equitable systems approach

The biggest tension is in balancing restoration and sustainable management of natural resources with the need to sustain a human population of nearly 8 billion globally and rising, with all the required transformational changes outlined in the other areas of this report to reduce GHG emissions. Addressing these challenges would lead to a more environmentally sustainable and equitable society and environment as well as providing associated health benefits. Removal of fossil fuel subsidies and the introduction of appropriate carbon pricing can accelerate GHG mitigation and improve health. One estimate suggested that taxation reflecting the costs of carbon dioxide emissions, local air pollution, and additional transport-related externalities (e.g. congestion and injuries) could have major health and environmental benefits globally. The proposed carbon tax could reduce carbon dioxide emissions by 23% and air pollution-related mortality by 63%. The benefits were equivalent to about 2.6% of global gross domestic product.[220] Similar approaches could be applied to other GHGs. However, it is important to ensure that carbon pricing interventions act as progressive, redistributive mechanisms to reduce inequities. As outlined in **Recommendation 4** of this report, it will be important to adopt a greater focus on transdisciplinary approaches across research and policy design and implementation to realise the range of potential benefits and to ensure that they contribute to reducing inequities.[221]

Key insights

- Opportunities for human mental and physical health from well-designed nature-based climate action integrating where possible adaptation and mitigation (**Recommendation 2**) should spur implementation and support the case for an increasing focus in policy and research.
- There is a need for further transdisciplinary research to support efforts, particularly to introduce metrics that can be used to monitor, report, and verify interventions, evaluate baselines and outcomes including detecting unintended consequences of nature-based actions (**Recommendation 3**).
- A greater focus on transdisciplinary systems approaches across research and policy will be crucial (see **Recommendation 4**) to address the complex interaction of pro-environmental mitigation policies and health impacts in the context of national and global systems.
- Co-development of nature-based solution initiatives with local communities and other key stakeholders could garner support, confront issues such as land ownership and access up-front, and promote a just and equitable approach.

220. Parry IW, *et al.* (2014). *Getting energy prices right: from principle to practice.* International Monetary Fund, Washington, D.C.

221. Cuevas S & Haines A (2016). *Health benefits of a carbon tax.* The Lancet **387(10013)**, 7-9.

6. Employment

6.1 Net-zero transition, employment, and health

Employment is a core driver of human health outcomes. An individual's job, working conditions, and income affect both mental and physical health. The transition to net-zero GHG emissions requires large-scale changes in the number and nature of jobs right across the economy.

These changes will entail both occupational health implications and potential challenges to wellbeing, particularly health implications associated with potential unemployment as part of the net-zero transition. This chapter focuses on these links between employment and health through the lens of climate change mitigation and the net-zero transition, covering the issues from both occupational and wellbeing perspectives.

6.2 Employment context

Globally in 2017, about 58 million people were employed in the energy sector, half of them in fossil fuel industries. A move to net-zero would bring an end to many of these jobs.[222] There is significant historical evidence that major shocks to employment can have significant health impacts on the individuals, families, and communities affected.[223]

The medium-term job prospects are positive. The UK aims to create some 250,000 new 'green jobs' – here defined as 'decent jobs that contribute to a sustainable and just transition to net-zero' – by 2030.[224] However, the adjustments needed could be a source of stress for some workers in the short-term. The zero-carbon job transition is part of a wider transformation in the nature and future of work, which also includes automation, the 'gig economy', and homeworking, all of which may affect health. COVID-19 has changed working patterns in ways that may persist, at least in part.[225] Climate change itself will have an impact on occupational health, for example related to heat stress and associated productivity loss.[226]

6.3 Jobs and net-zero: relevant determinants of health

There are few systematic, quantitative estimates of the employment effects of climate change mitigation in the UK, let alone their link to employee health. However, important information can be gleaned from sector-specific assessments.[227,228] Together with existing, albeit limited, examinations of the health outcomes of 'green jobs', it is possible to identify potential effects, both positive and negative.[229,230,231]

222. Czako V (2021). *Employment in the Energy Sector: Status Report 2020*. https://publications.jrc.ec.europa.eu/repository/handle/JRC120302

223. Davies AR, *et al.* (2020). *Health and mass unemployment events – developing a framework for preparedness and response*. Journal of Public Health **41**, 665-673.

224. UK Government (2020). *UK government launches taskforce to support drive for 2 million green jobs by 2030*. https://www.gov.uk/government/news/uk-government-launches-taskforce-to-support-drive-for-2-million-green-jobs-by-2030

225. Howarth C, *et al.* (2020). *Building a social mandate for climate action: lessons from COVID-19*. Environmental and Resource Economics **76**, 1107-1115.

226. Hooyberghs H, *et al* (2017). *Influence of climate change on summer cooling costs and heat stress in urban office buildings*. Climatic Change **144**, 721-735.

227. CITB (2021). *Building Skills for Net Zero*. https://www.citb.co.uk/media/vnfoegub/b06414_net_zero_report_v12.pdf

228. Aldersgate Group (2020). *Upskilling the UK Workforce for the 21st Century*. https://cusp.ac.uk/themes/s1/ag-policy-briefing-upskillinguk/

229. World Health Organisation (2012). *Health in the green economy: Occupational Health*. https://www.who.int/publications/i/item/health-in-the-green-economy-occupational-health

230. Chen CJ, *et al.* (2017). *Chemical and Physical Exposures in the Emerging US Green-Collar Workforce*. Journal of Occupational and Environmental Medicine. **59**, e91-e96.

231. Guidotti TL, *et al.* (2019). *The Sustainable Energy Transition and Occupational Health*. Journal of Occupational and Environmental Medicine **61**, e306-e307.

6.3.1 Reducing inequalities

If handled well, the expansion in green employment has the potential to provide good employment opportunities across the UK and reduce inequalities in access to training and job opportunities (including regional, ethnic, and gender disparities). As such, it could deliver significant positive health outcomes.[232] Table 2 highlights some of the major areas for planned green job creation and support in the UK through to 2030.

Table 2: Green jobs supported in the UK to 2030.[23]

Green jobs supported by 2030		
10 Point Plan Priority	**Drivers**	**Jobs Supported by 2030**
Offshore Wind	Aim to provide 40GW of offshore wind by 2030 £160 investment into modern ports and manufacturing infrastructure	Up to 60,000
Low Carbon Hydrogen	Aim 5GW of low carbon hydrogen production capacity by 2030	Up to 8,000
Nuclear	Up to £385m investment into an Advanced Nuclear Fund	10,000 per large-scale plant during construction
Zero Emisison Vehicles	Ending the sale of new petrol/diesel cars by 2030 and all vehicles must be 100% zero emissions from 2035	40,000
Public Transport	£9.2bn investment into city public transport, buses, cycling and walking	Up to 30,000
Aerospace	£15m competition to support the production of Sustainable Aviation Fuels (SAF) in the UK	Up to 5,200 (by a domestic SAF industry)
Buildings	• Aim 600,000 heat pump installations per year by 2028 • Green Homes Grant • Public Sector Decarbonisation Scheme • Home Upgrades Grant • Implementation of Futire Home Standard • Social Housing Decarbonisation Fund	50,000
Carbon Capture, Usage and Storage (CCUS)	Aim to establish CCUS in two industrial clusters by the mid 2020s and in four sites by 2030	50,000
Natural environment	£5.2bn investment into a six-year programme for flood and costal defences	20,000

232. Paul KI & Moser K (2009). *Unemployment impairs mental health: Meta-analyses.* Journal of Vocational Behavior **74**, 264-282.

Whilst the expansion of some zero-carbon industries, for example wind energy, will inevitably be centred on particular geographical regions, supply chain development can extend job creation and any associated health benefits much more widely across the UK. The assessment of potential green jobs in major national growth sectors, such as the energy efficiency of buildings and zero-emissions transport, suggests a wide regional distribution of job opportunities across UK regions, with similar opportunities for health benefits (Figure 4). Additional employment opportunities may result from the transition to a circular economy focusing on recycling, re-manufacturing, and re-use of material resources.[233]

However, well-designed implementation of opportunities is crucial to ensure regional and other inequalities are reduced, for example, consideration of potential inequities in the rural economy, disproportionate impacts on employment of COVID-19, along with pre-existing equalities in access to education training and jobs. The recent Green Jobs Taskforce report to the UK Government urges the critical need to seize the current transition as an opportunity to improve the diversity, and wellbeing, of the UK workforce.[25]

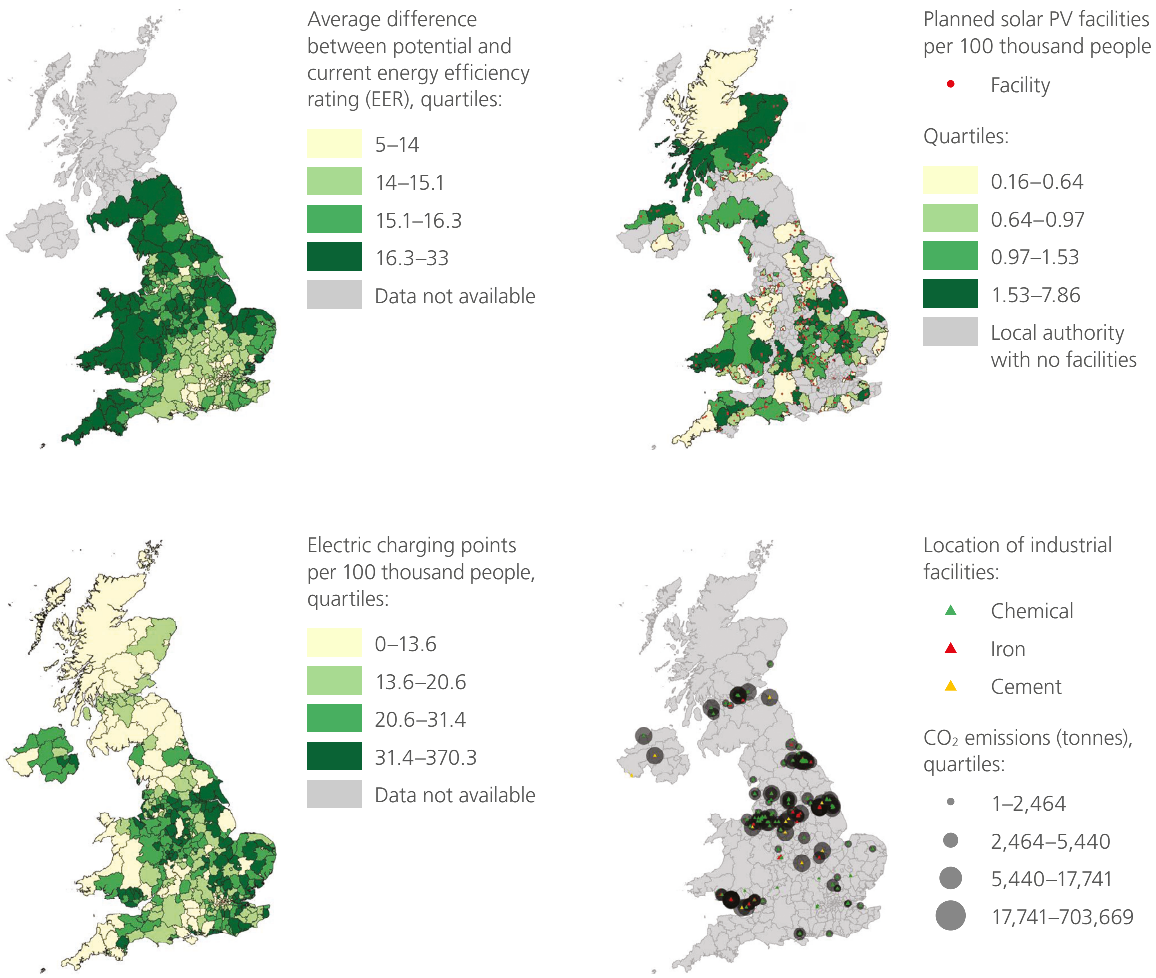

Figure 4: Indicators of zero-carbon jobs potential in energy efficiency, renewable energy, electric vehicles, and hydrogen/CCS.[234]

233. Morgan J & Mitchell P (2015). *Employment and the circular economy: Job creation in a more resource efficient Britain.* https://wrap.org.uk/sites/default/files/2021-02/WRAP-Employment-and-the-circular-economy-summary.pdf

234. Unsworth S, *et al.* (2020). *Jobs for a strong and sustainable recovery from Covid-19.* https://www.lse.ac.uk/granthaminstitute/publication/jobs-for-a-strong-and-sustainable-recovery-from-covid-19/

Box 7: Occupational health and wind energy

Many wind energy jobs will be land-based as part of the supply chain, but a significant number will involve offshore work. By 2030, roughly 60,000 UK jobs are expected to be supported in this sector. Recent years have seen an increase in accidents in the wind energy sector (Figure 5), a trend that was expected due to rapid expansion. However, the true global figures are unknown and researchers expect that these numbers represent the 'tip of the iceberg'. For the UK, the RenewableUK accident database (which may be more realistic due to confidentiality) indicated that between 2007 and 2011 around 1,500 accidents and other incidents occurred. Overall, incidents occur in roughly equal numbers in a turbine, on vessels, and on shore.[235]

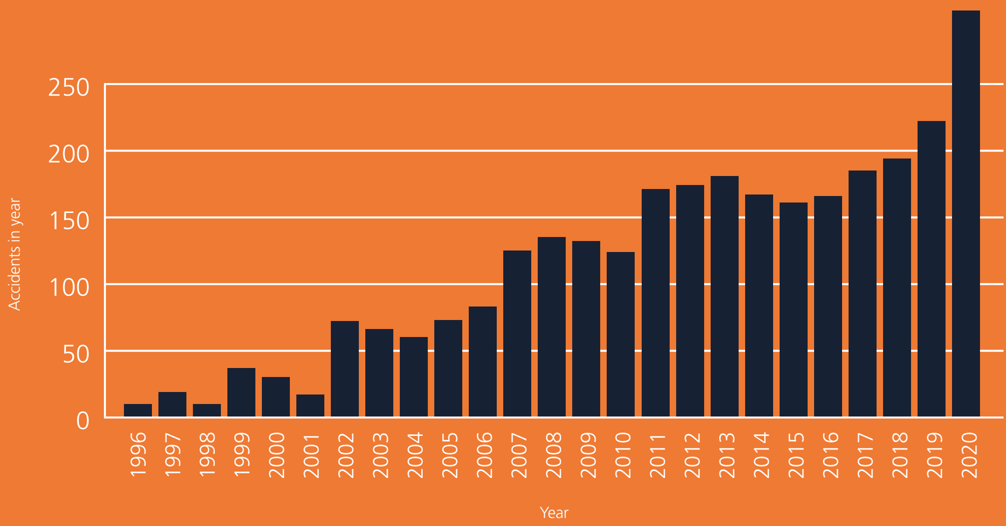

Figure 5: Wind turbine-related accidents reported globally by year (1996–2020).[236]

In terms of physical risks, working at heights presents obvious dangers in terms of falls during construction, assembly, and maintenance. For near-shore and offshore wind energy, which will feature significantly in the UK's wind power expansion, there are additional risks due to working over water, while indirect human health impacts may arise via shadow flicker for those in near proximity.[237] More wind energy installations in more remote areas and exposure to more extreme weather conditions may pose significant risks to physical and mental health. There are relatively few assessments available on the mental health impacts of offshore wind work, though studies of analogous sectors, like offshore oil and gas, suggest common factors such as long shifts, down times, and periods away from home may have negative impacts.[237]

The rapid expansion in the wind energy workforce in the UK, especially offshore, poses a challenge, not just in terms of addressing severe skills shortages, but also in ensuring health and safety training is comprehensive and able to adapt to the demands of more extreme locations and larger-scale operations.[238] If handled well however the employment and wider health benefits will be substantial.

235 G+ Global Offshore Wind Health and Safety Organisation (2019). *2019 Incident Data Report*. https://www.gplusoffshorewind.com/__data/assets/pdf_file/0004/752863/PDF-G-2019-incident-report.pdf

236. Caithness Windfarm Information Forum (2021). *Summary of Wind Turbine Accident data to 31 March 2021*. http://www.caithnesswindfarms.co.uk/AccidentStatistics.htm

237. Mette J, *et al.* (2018). *Healthy offshore workforce? A qualitative study on offshore wind employees' occupational strain, health, and coping*. BMC Public Health **18**, 172.

238. European Agency for Safety and Health at Work (EU-OSHA) (2013). *Occupational safety and health in the wind energy sector*. https://osha.europa.eu/en/publications/occupational-safety-and-health-wind-energy-sector/view

6.3.2 Occupational health

Employment-related health outcomes depend not just on job numbers, but also on working conditions and the quality of the jobs. Job quality affects health and wellbeing directly through occupational health and safety and work-related stress, but also indirectly through productivity levels, which in the long-term carry through to wages and income.

In 2019/2020, some 700,000 UK workers sustained injuries at work and 1.6 million people suffered from work-related illnesses.[239] Fatalities are comparatively rare, however, with just 111 work-related deaths reported in 2019/2020.

It is still difficult to assess the occupational health impact of the net-zero transition; however some experts believe the shift could mean fewer big hazards and more small hazards.[231] For example, there could be comparatively fewer falls from height, when comparing green employment with fossil fuel-intensive industries, which was the biggest cause of work-related deaths in 2020.

Fossil fuel-related jobs pose a range of occupational health risks, for example during fossil fuel extraction. Green jobs are however not risk-free, with the renewables sector posing a number of potential occupational health risks, including falls, electrocution, and other accidents, during construction and maintenance, and dockside handling of equipment (see Box 7).[240]

6.4 Challenges and opportunities

Maximising work-related health benefits of the net-zero transition requires a well-informed and well-targeted approach from both government and employers. The introduction of appropriate safeguards will be important to manage issues such as job insecurity, for example in the oil and gas sectors, and changes in exposure to other hazards, such as from more outdoor work.[241]

6.4.1 Ensuring a just transition: the challenge of re-skilling and job insecurity

The UK's net-zero transition will have profound implications for employment and skills. High-emitting sectors, such as oil and gas, will see a steep contraction in job numbers, while others, such as transport, construction, manufacturing, and industry, are likely to see large-scale changes in employment types. Wider societal changes may also serve to indirectly reduce emissions, such as moving away from heavy industry and into services, which has already led to a partial decarbonisation of UK employment. The high-carbon activities that remain, in sectors such as steel, have refocused on higher value-added products, which are often less polluting. The COVID-19 pandemic may also have forced some permanent changes to working patterns, such as an increase in online and homeworking, and may have a similar effect on transport emissions.[242]

Structural change of this magnitude will impose adjustment costs on some workers, with potentially detrimental impacts on physical and mental health. Job insecurity is a widespread source of mental stress and ill health, associated with reactions such as anxiety, burnout, depression, emotional exhaustion, and low life satisfaction.[243,244,245,246] Concerns about job security are influenced by objective factors such as a disconnect between people's existing skills and those demanded in the zero-carbon workplace.[247]

239. Health and Safety Executive (2020). *Health and safety statistics*. https://www.hse.gov.uk/statistics/
240. Health and Safety Executive (2010). *Health and safety in the new energy economy: Meeting the challenge of major change*. https://www.hse.gov.uk/eet/assets/pdf/new-energy-economy.pdf
241. Chen CJ, *et al.* (2017). *Chemical and Physical Exposures in the Emerging US Green-Collar Workforce*. Journal of Occupational & Environmental Medicine **59**, e91-e96.
242. Hook A, *et al.* (2020) *A systematic review of the energy and climate impacts of teleworking*. Environmental Research Letters **15**, 093003.
243. Cheng GHL & Chan DKS (2008). *Who suffers more from job insecurity? A meta-analytic review*. Applied Psychology **57**, 272-303.
244. Sverke M, Hellgren J & Näswall K (2002). *No security: a meta-analysis and review of job insecurity and its consequences*. Journal of Occupational Health Psychology **7**, 242.
245. Lee C, Huang GH & Ashford SJ (2018). *Job insecurity and the changing workplace: Recent developments and the future trends in job insecurity research*. Annual Review of Organizational Psychology and Organizational Behavior **5**, 335-359.
246. De Witte H, Vander Elst T & De Cuyper N (2015). *Job insecurity, health and wellbeing*. Springer Science + Business Media, 109-128.
247. Greenpeace (2020). *Offshore: Oil and gas workers' views on industry conditions and the energy transition*. https://www.greenpeace.org.uk/wp-content/uploads/2020/09/Oil-Gas-Workers-Report-Final-Web.pdf

Empirical evidence about the skill gaps between traditional and zero carbon jobs in the UK is still scarce. Initial data suggest that about 10% of the UK workforce is likely to require enhanced green skills necessitating additional training. A similar share of workers might see increased demand for their existing skills, creating new opportunities, for example electrical engineers.[248] This picture is mostly uniform across UK regions.

Evidence from the USA suggests that in the most affected sectors – construction, utilities, manufacturing, transport – between 20% and 30% of the workforce may need reskilling to move into directly green jobs.[249,250,251] For most other workers, for example in agriculture and forestry, current skills will co-exist, and compete or complement new 'green skills', depending on the context.

6.4.2 Supporting the skills transition

The zero-carbon transition will have fewer adverse health and social impacts if skills can be transferred relatively smoothly. One study using data from the US labour market indicates that there may be differences in the cognitive and interpersonal skills required between green and non-green jobs, placing great importance on potential training programmes implemented to provide the labour force with the necessary skills to successfully transition into green jobs.[251] In many cases though, green and non-green jobs only differ in a few selected aspects, suggesting that the skill gaps may be addressed primarily on-the-job. For some occupations, like professional drivers, labour market disruption is more likely to come from other sources, such as the shift to driverless technology, rather than EVs.

However, there are sectors which are invested heavily in industry-specific skills, and often they have strong regional roots, such as steel making in South Wales.[249] These are the areas where the social, economic, and health impacts of the zero-carbon transition will be most keenly felt, and where active industrial and labour market policies will be paramount to minimise these impacts.

There are few examples of successful industrial transitions, but where they have occurred, such as in Germany's Ruhr region, they have entailed: close collaboration between government, industry, labour unions, and local communities; targeted social protection, such as in respect of healthcare benefits and pension rights; substantial investment in education, skills, and retraining; and a clear long-term vision for industrial renewal.[252]

Similar efforts, particularly the development of a long-term vision for green jobs, with a focus on wellbeing and health and safety, will be important in supporting the UK employment transition. The recommendations of the Green Jobs Taskforce reinforce that building clear, accessible, and lifelong pathways into green careers will be fundamental to the UK realising it's 2050 net-zero ambition in a just and sustainable manner.[24]

6.4.3 Improving the health and safety profile of the zero-carbon economy

In addition to creating new jobs, the zero-carbon transition will alter demand for existing occupations, thereby changing the occupational health and risk profile of the economy. In some cases, risks will increase, for example as jobs grow in natural environment sectors such as forestry, which has the highest incidence of fatal injuries per worker in the UK and accident rates that are twice the all-industry average. Building construction, another sector slated for expansion, also has above-average accident rates. However, these negative effects can be reduced by training and regulation and they will probably be balanced by an increased demand for safer jobs, such as in the services sector.

Some of the supply-chain effects extend beyond UK borders. For example, there are reports about forced labour in China's polysilicon industry, which supplies a large part of the UK solar sector.[253] There are also concerns about the safe handling and disposal of the hazardous chemicals that go into the production of solar panels.[254]

248. Robins N, *et al.* (2019). *Investing in a just transition in the UK. How investors can integrate social impact and place-based financing into climate strategies.*

249. Bowen A & Hancke B (2019). *The social dimensions of 'greening the economy'*. https://op.europa.eu/en/publication-detail/-/publication/24c67b4c-3293-11ea-ba6e-01aa75ed71a1

250. Bowen A, Kuralbayeva K & Tipoe EL (2018). *Characterising green employment: The impacts of 'greening' on workforce composition*. Energy Economics **72**, 263-275.

251. Consoli D, *et al.* (2016). *Do green jobs differ from non-green jobs in terms of skills and human capital?* Research Policy **45**, 1046-1060.

252. Gambhir A, Green F & Pearson PJ. (2018). *Towards a just and equitable low-carbon energy transition*. https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/26.-Towards-a-just-and-equitable-low-carbon-energy-transition.pdf

253. Reinsch WA & Arrieta-Kenna S (2021). *A Dark Spot for the Solar Energy Industry: Forced Labor in Xinjiang*. https://www.csis.org/analysis/dark-spot-solar-energy-industry-forced-labor-xinjiang

254. Aman MM, *et al.* (2015). *A review of Safety, Health and Environmental (SHE) issues of solar energy system*. Renewable and Sustainable Energy Reviews, **41**, 1190-1204.

There is reason to believe that the occupational safety record of the zero-carbon economy may improve over time. New industries sometimes lack the ingrained safety culture which traditional high-risk industries have developed over the years. However, as incumbent industries show, occupational health can be improved through a determined focus on health and safety among employers, regulators, and workers, suggesting that, with the correct policies, it is possible to make zero-carbon jobs safe.

The 2017 HSE Foresight report discusses the potential hazards from developments in the energy sector to address climate goals, including the decarbonisation of heat, the transport sector, energy efficiency, energy storage, decommissioning of oil and gas facilities, and the transition to hydrogen.[255] Regular review of such hazards and development of effective strategies to manage risks can enable emerging energy and other technologies to be developed and adopted safely.

Further research will be needed to study and document the occupational health profile of clean jobs, relative to traditional jobs and to understand the health and safety profile of the zero-carbon economy as a whole, both in the UK and internationally.

Key insights

- For new jobs in the net-zero economy there may be a need to anticipate and manage short-term disruptions, with associated health consequences, particularly in communities heavily dependent on fossil fuels and associated infrastructure for employment.
- Developing a long-term vision for green jobs, with a focus on wellbeing and health and safety, could help to support the major shift in employment which will accompany the UK's transition to net-zero.
- Ensuring a just transition requires greater regional granularity of data to inform actions. It will be critical to mitigate impacts for certain regions and sectors where the transition may be felt hardest and to maximise positive outcomes for all (see **Recommendation 3**).
- The net-zero transition in the UK has the potential to bring many employment benefits; however there is currently little evidence on the balance of positive and negative health impacts posed.
- Targeted research on the skills gap between clean and traditional jobs and the interlinked impacts on health could help to understand and respond to the impacts of the transition, along with assessment of the occupational health impacts of clean net-zero versus traditional jobs.

255. Health and Safety Executive (2017). *Foresight Annual Report 2017/18*. https://www.hse.gov.uk/horizons/assets/documents/foresight-report-2017.pdf

7. Healthcare systems

7.1 Net-zero NHS: a complex system example

Healthcare systems are themselves responsible for about 4–5% of global GHG emissions, and providers worldwide are committing to reduction targets. In 2020, the National Health Service (NHS) England was the first national healthcare system to make a commitment to net-zero direct emissions by 2040 and indirect emissions by 2045.[256] The NHS is the largest single-payer healthcare system in the world, with an annual budget of £134 billion, serving a population of nearly 56 million and employing around 1.3 million people. It is estimated to account for around 5–6% of the UK's total GHG emissions, with most of the emissions coming from the supply chain (Figure 6).[256] The NHS has reduced total emissions by 26% since 1990. While this has been supported by the wider shift to lower-carbon energy in the UK, the NHS's GHG reductions have been achieved while the provision of care has doubled, the population has increased by 17%, and healthcare spending has tripled.[257]

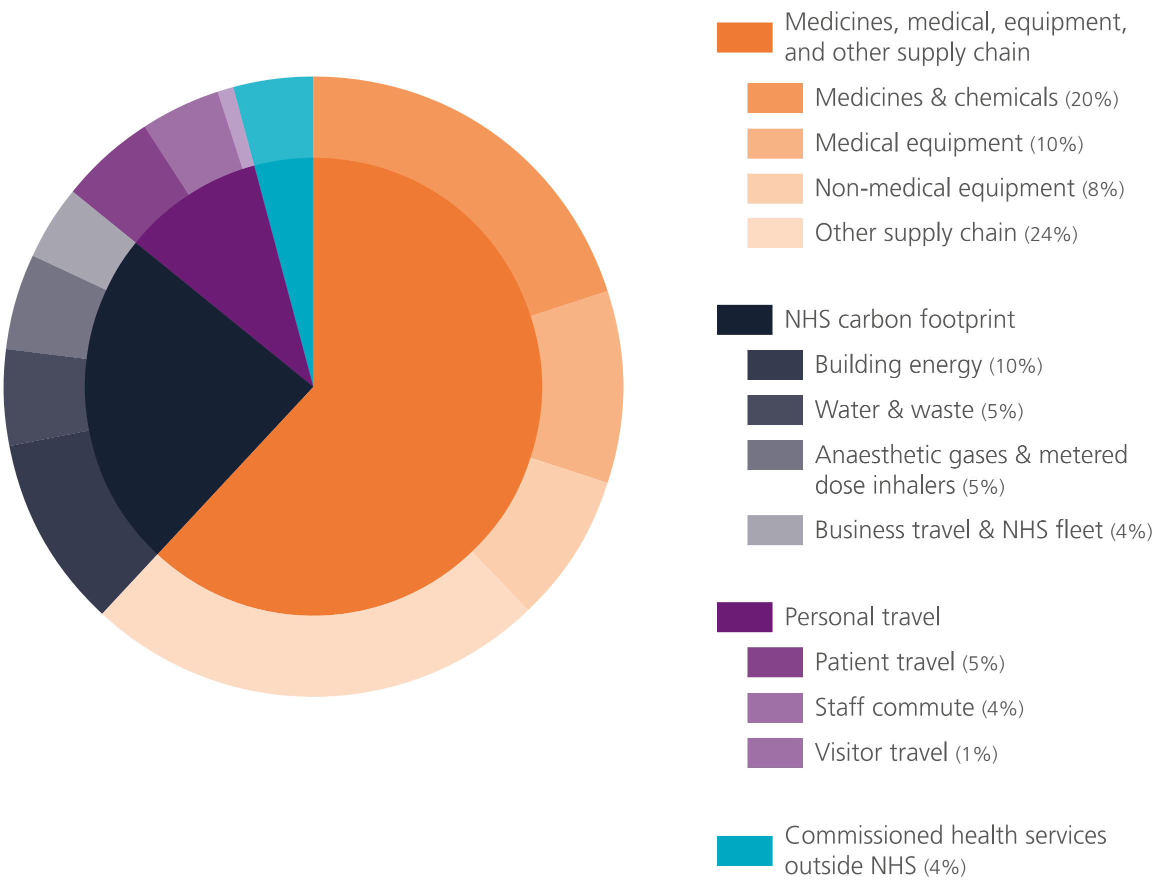

Figure 6: Sources of carbon emissions from NHS England.[256]

255. Health and Safety Executive (2017). *Foresight Annual Report 2017/18*. https://www.hse.gov.uk/horizons/assets/documents/foresight-report-2017.pdf

256. National Health Service (2020). *Delivering a 'Net Zero' National Health Service*. https://www.england.nhs.uk/greenernhs/publication/delivering-a-net-zero-national-health-service/

257. Tennison I, *et al.* (2021). *Health care's response to climate change: a carbon footprint assessment of the NHS in England*. The Lancet Planetary Health **5**, e84-e92.

7.1.1 Pathways to net-zero: key areas to support change

Further reductions in the GHG footprint of NHS services could be achieved through optimising the efficiency of the system by matching the supply of health services to demand, avoiding over- or under-capacity of resources. This will reduce the substantial natural resources required, for example through energy and water use, single-use consumables, waste production and removal, transport of goods, and emissions from resource use and patient travel. The NHS is a major purchaser of goods and services and can use its buying power to drive change, such as encouraging its supply chain, towards a truly circular economy model and galvanising action across and beyond the healthcare sector. For example, with around 80% of the NHS's equipment, medicines, and chemicals being delivered via container ships, the NHS Ocean initiative is seeking to address this challenge (see Box 8).[258]

Understanding the lifecycle assessment of different treatment pathways would highlight where major environmental costs are incurred; for example, primary care has a major influence on emissions dependent on prescribed medicines, and by reducing demands on hospital services. Patient–doctor consultations have carbon footprints ranging from 0.70 to 372 kg CO_2e. The wider use of telemedicine and telephone consultations can substantially reduce emissions; however, care must be taken to ensure that face-to-face consultations are available where necessary for high-quality care.[259]

There are also assets unique to healthcare, such as ambulances, inhalers, volatile anaesthetic agents, and nitrous oxide, which will need to be innovatively redesigned and practices transformed, to be more sustainable. The COVID-19 pandemic has illustrated the challenge of introducing more sustainable supply chains, by increasing the need for personal protective equipment (PPE), cleaning products, ventilators, single-use plastics, as well as changing patterns of prescribing and clinical interventions.

Further options for reducing emissions include upgrading the NHS building stock for greater energy efficiency; renewable energy replacing fossil fuels; zero emission vehicles; sustainable catering options; and 'green procurement' of medical goods and pharmaceuticals. NHS land can also be used for carbon sequestration, such as through tree-planting. Such areas can in turn provide a location for 'social prescribing', where a doctor prescribes a social activity such as exercise, community involvement, or contact with support workers instead of pharmaceuticals (see Section 7.2.1).[260]

Box 8: NHS Ocean

NHS Ocean has been created with the aim of conserving and protecting coastal and marine ecosystems through minimising harm resulting from the procurement and delivery of healthcare.[258] At the same time, it seeks to increase awareness of the benefits to human health and wellbeing from healthy seas, coasts, and waterways. Activities range from guiding suppliers of NHS goods on how to choose the most sustainable freight forwarders/carriers, to supporting development of 'blue' social prescribing.

NHS Ocean builds on the United Nations Global Compact's 'Sustainable Ocean Principles' that provide a framework for responsible practices for a healthy and sustainable ocean. These recognise the ocean's role in providing food and medicines contributing to improved health and wellbeing.[261]

258. NHS Ocean. https://www.nhsocean.org

259. Purohit A, Smith J & Hibble A. (2021). *Does telemedicine reduce the carbon footprint of healthcare?* A systematic review. Future Healthcare Journal **5**, e85-e91.

260. Health Care Without Harm. *Climate Change: an Opportunity for Action.* https://noharm-global.org/issues/global/climate-change-opportunity-action

261. UN Global Compact (2019). *Sustainable Ocean Principles.* https://d306pr3pise04h.cloudfront.net/docs/publications%2FSustainable+Ocean+Principles.pdf

7.1.2 Potential health co-benefits

As a trusted and highly visible entity, the NHS can add significant social and economic value through its actions: it can be a system-wide (beyond sector) example of delivering on all three pillars of sustainability (environmental, economic, and social) and is well placed to measure and demonstrate the importance of health and other co-benefits when taking significant steps towards climate change mitigation and adaptation.

i) Reducing demand for health services and capitalising on co-benefits – A multi-faceted systems approach will be crucial in realising these health co-benefits, starting with increased investment in the equitable prevention, not only the treatment, of acute and chronic diseases.[262] Significantly increased investment in public health interventions with environmental benefits, ranging from promoting changes in diet to active travel, can help reduce demand for health services. It is also important to act on the social determinants of health, including access to education and jobs with a liveable wage, food security, affordable housing, and a clean and safe environment.[263]

ii) Health and environmental improvements via green space – The introduction of green spaces and rewilding projects in healthcare facilities represent one opportunity to achieve parallel health and environmental benefits. There is evidence that the design of health facilities to include more green space can positively influence patient health, as well as the performance and satisfaction of caregivers.[264,265,266,267] Beneficial effects have been shown to be greatest for those from socio-economically disadvantaged groups, who have the least access to green spaces.[268]

iii) Designing healthy and net-zero healthcare facilities – Reducing the GHG emissions of buildings is crucial for the net-zero transition, for both for new and existing facilities. Healthcare locations have added requirements, such as demand for areas with high air-change rates, which can often impede GHG emission reductions. In 2019, the UK Government pledged to fund the construction of 40 new hospitals, which should be aligned with net-zero targets. However, there is also an opportunity to design buildings to promote healthier environments such as optimising daylight exposure, which are associated with improved patient outcomes.[269] A more significant challenge will be reducing the GHG emissions of existing hospitals, many of which are historic buildings with existing maintenance issues.

7.2 Challenges and opportunities: policy and research actions

Reducing the GHG emissions of the healthcare system has the potential to play a significant role in the net-zero transition of the wider economy. Beyond its size, the healthcare system has a highly visible and trusted role which could be used as an exemplar for other complex systems and demonstrate the way in which co-benefits flow from a net-zero transition. At the local level, the healthcare system can serve as an 'anchor institution' to promote health and wellbeing in local communities through influencing local transport and environmental sustainability of other services through changes being demonstrated by healthcare system suppliers.[270]

7.2.1 Driving change in the healthcare sector – embedding social prescribing

'Social prescribing' may present an opportunity for GPs to help prevent and manage long-term conditions by enabling patients to experience spaces such as parks, rivers, and swimming pools – 'green and blue spaces'.[271]

262. MacNeill AJ, McGain F & Sherman JD (2021). *Planetary health care: a framework for sustainable health systems*. Lancet Planetary Health **5**, e66-e68.
263. National Health Service (2019). *The NHS Long Term Plan*. https://www.longtermplan.nhs.uk/wp-content/uploads/2019/08/nhs-long-term-plan-version-1.2.pdf
264. Health Care Without Harm (2016). *A comprehensive environmental health agenda for hospitals and health systems around the world*. https://www.hospitalesporlasaludambiental.net/wp-content/uploads/2016/07/Global-Green-and-Healthy-Hospitals-Agenda.pdf
265. Cooper Marcus C (2007). *Healing Gardens in Hospitals*. Interdisciplinary Design and Research e-Journal **1**, 1-27.
266. NHS Forest. https://nhsforest.org/
267. Rojas-Rueda D, *et al.* (2019). *Green spaces and mortality: a systematic review and meta-analysis of cohort studies*. Lancet Planetary Health **3**, e469-e477.
268. White MP, *et al.* (2020). *Blue space, health and wellbeing: A narrative overview and synthesis of potential benefits*. Environmental Research **191**, 110169.
269. ARUP (2021). *Net zero carbon healthcare*. https://www.arup.com/perspectives/publications/research/section/net-zero-carbon-healthcare
270. Reed S, *et al.* (2019). *Building healthier communities: the role of the NHS as an anchor institution*. https://www.health.org.uk/publications/reports/building-healthier-communities-role-of-nhs-as-anchor-institution
271. Husk K, *et al.* (2019). *What approaches to social prescribing work, for whom, and in what circumstances? A realist review*. Health & Social Care in the Community **28**, 309-324.

Feedback from the NHS Net Zero report suggests that a very high proportion of NHS staff are motivated by this issue.[256] There is an opportunity to use the expertise and passion of NHS staff to create a movement that will drive the health sector towards the changes needed (see Box 9). This should include embedding relevant content into training and support. For example, the NHS has recently announced a Chief Sustainability Officer's Clinical Fellowship scheme to provide opportunities for clinicians to take an active role in supporting the system's net-zero targets.[272]

Box 9: Green GPs – Frome Medical Practice

The Frome Medical Practice in Somerset has been given the Green Impact award for the third year running for its sustainability efforts, including energy use, recycling, procurement, and staff and patient wellbeing.[273] The Green Impact award is part of wider campaign by the National Union of Students called 'Green Impact for Health' and is an opportunity for General Practices across England to demonstrate how they are working in an environmentally sustainable way.

The Frome Medical Practice's activities include: discussing sustainability in staff appraisals, interviews, and newsletters; improving energy efficiency; renewable electricity suppliers; commitment to sourcing local, healthy, and fair-trade food where possible; reduced use of single-use plastics; and promoting active travel for staff and patients.

7.2.2 Leveraging ongoing efforts

Topic-specific initiatives are emerging in the NHS, including the Greener NHS Programme, NHS Forest, and NHS Ocean (see Box 8).[258,266] Such initiatives could serve as exemplars to drive transformational change in a large complex system. They highlight the multiple co-benefits that can be achieved, for example the advantages that sustainable and healthy food procurement brings to health, biodiversity, and employment.

7.3 Conclusions

For the healthcare sector, there is strong evidence that delaying action on climate change will be more expensive in the long-term through greater environmental and health damage and higher costs associated with the increasing burden of chronic diseases, as well as needing to implement rapid and stringent actions to limit and reduce our GHG emissions.[274]

The UK healthcare system has the opportunity to set an example net-zero framework for other countries and other sustainability interventions, including through the establishment of standardised metrics needed for monitoring and evaluation of progress.

272. Faculty of Medical Leadership and Management (2021). *Chief Sustainability Officer's Clinical Fellow Scheme*. https://www.fmlm.ac.uk/clinical-fellow-schemes/chief-sustainability-officer%E2%80%99s-clinical-fellow-scheme
273. Frome Medical Practice. *Sustainability – what are we doing?* https://www.fromemedicalpractice.co.uk/sustainability-what-we-are-doing
274. The Council of Economic Advisers (2014). *The Cost of Delaying Action to Stem Climate Change*. https://scholar.harvard.edu/files/stock/files/cost_of_delaying_action.pdf

Key insights

- The NHS has the opportunity to lead efforts towards net-zero GHG emissions, acting as a system-wide exemplar of how complex systems can achieve an equitable, healthy transition.
- Establishing a robust set of metrics to monitor and evaluate progress against agreed targets, and measure both environmental and health impacts will be important and could enable the UK's healthcare systems to act as a net-zero framework for health and sustainability systems globally (see **Recommendation 3**).
- For example, the introduction of lifecycle assessments of different treatment pathways could help to highlight where major environmental costs are incurred.
- Introducing sustainability requirements for procurement, and a drive towards a truly circular economy model, could achieve further reductions in GHG emissions within and beyond the healthcare sector, with the potential for wide-ranging influence on supply chains.
- Public health interventions should focus on initiatives which can improve health, promote sustainability, and reduce inequalities simultaneously.
- Embedding of social prescribing in strategies and training for the health care sector, for example experiences of blue/green spaces, could support efforts.

8. Global health implications of the UK's transition to net-zero

8.1 The UK and the transition to net-zero: the global context

The UK's transition to net-zero will be a profound economic and industrial shift taking place in the context of a globally connected economy. Huge changes in the structure of economic activity, food and farming, cities, and transport are taking place, which involve new patterns of trade in technologies, commodities, goods, and services, among other shifts. This chapter is concerned with the international implications for human health of the UK's transition to net-zero, with a particular focus on trade and aid.

8.2 Potential health co-impacts

All industrial revolutions have been accompanied by changing patterns of health and morbidity. The transition to net-zero will be no different. While co-benefits have been identified and analysed, there is likely to be a set of health and environmental health consequences, such as massively increased use and circulation of metals used in batteries (see Box 10). Understanding and regulating these trends to limit negative impacts and enhance positive impacts are important tasks for researchers and policy-makers. International trade and aid policy are important tools to achieve the potential benefits.

The growth of zero-carbon energy systems will see changes such as a rise in industries linked to batteries (see Box 10), bioenergy (see Box 13), and a decline in carbon-intensive activities with a shift towards more circular economies (see Box 11). International trade enables the required reshaping of global economic activity and will have potentially positive and negative health implications, for both workers and those using or affected by relevant products. Given the uncertainties, it is not yet possible to make a global assessment of these multiple effects on human health, but trends can be identified with the case studies illustrated in this chapter. Over the longer term, it will be important to monitor and analyse developments.

Box 10: Cobalt mining for electric vehicle (EV) production

By 2030, the Government's ambition is that at least 50–70% of new car sales – and up to 40% of new van sales – should be ultra-low emission.[57] For passenger vehicles and vans, this means accelerating the uptake of EVs in the UK from around 400,000 in 2020 to 23 million by 2032.[275] Many of the raw materials used in the production of batteries for EVs and other renewable energy systems currently have few substitutes and are not widely distributed globally.[276] One such raw material is cobalt, which has seen global production increase from 38,000 tonnes per annum over the 1970–2009 period to around 145,000 tonnes per annum over the 2010–2019 decade.[277] This growth is driven by the increased market for EVs, which represented nearly 60% of total cobalt consumption by the end of 2020.[278] Recycling and reuse of lithium-ion batteries and the cobalt within are not well developed and there are currently no well-defined routes available.[279]

The Democratic Republic of Congo (DRC) supplies 70% of the world's mined cobalt.[280] The cobalt mines and processing plants are often near residential areas, with entire communities suffering from exposure to industrial pollutants from mining operations and the transport of mined cobalt by truck.[281] For example, in south Katanga, people living near mining or metallurgical activities are highly exposed to cobalt, arsenic, and uranium, which have been linked to increased birth defects in neonates.[282,283,284,285] Expansion of the mining industry is also leading to deforestation, loss of agricultural land, and loss of access to clean water, all of which have direct health effects on local populations.[281,286,287,288] Occupational health hazards are amplified by the high proportion of informal or artisanal workers in the mining industry, and recent attempts to introduce responsible sourcing schemes may inflict further economic and health precarities upon local communities.[289]

The growing recognition of the specific risks associated with cobalt and copper mining in the DRC contributed to the expansion of OECD guidance to cover all minerals. This guidance aims to promote responsible supply chains of minerals from conflict-affected and high-risk areas, but implementation is not universal; for example, current EU legislation does not yet cover cobalt.

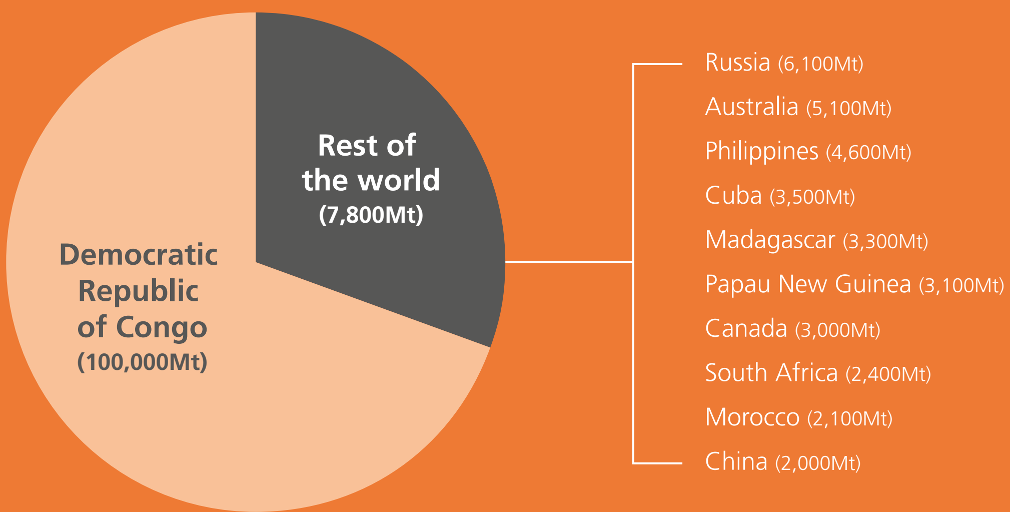

Figure 7: Global cobalt production by country (2019).[290]

Box 11: Circular economy and health

The circular economy is one that enhances resource efficiency and reuse while minimising resource input, waste, and emissions. There is growing evidence of potential health co-benefits specific to the circular economy, for example, reducing environmental pollution from decreased use of landfills and waste incinerators.[291]

However, as discussed throughout this report, there are also many potential adverse unintended consequences if actions to achieve a circular economy, and to yield the health co-benefits, do not attempt to minimise the risks. These risks include the exposure to harmful chemicals during recycling processes and contamination risks of untreated sewage sludge for agricultural fertilisation.[292] Unfortunately, these negative impacts fall disproportionately on vulnerable groups, especially in low- to middle-income countries to which developed countries export waste (see Box 12).

There remain many knowledge gaps on the specific health impacts of the circular economy, including a quantitative analysis of exposure and outcomes. However, developing indicators to monitor progress to both highlight health benefits and the risks could help to inform policy development.

275. Committee on Climate Change (2020). *The UK's transition to electric vehicles*. https://www.theccc.org.uk/publication/the-uks-transition-to-electric-vehicles/
276. United Nations Conference on Trade and Development (2020). *Commodities at a glance: special issue on strategic battery raw materials*. https://unctad.org/system/files/official-document/ditccom2019d5_en.pdf
277. The Faraday Institution (2020). *Building a responsible cobalt supply chain*. https://faraday.ac.uk/wp-content/uploads/2020/05/Insight-cobalt-supply-chain1.pdf
278. Benchmark Mineral Intelligence (2020). *Cobalt's price rises highlight shift to battery-driven pricing dynamics*. https://www.benchmarkminerals.com/membership/cobalts-price-rises-highlight-shift-battery-driven-pricing-dynamics/
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Box 12: E-waste exportation to Ghana and Nigeria

Studies following the fate of electronic waste (E-waste) exported from the UK demonstrates an urgent need to prevent discarded technology becoming a major hazard to citizens in low- and middle-income countries. In 2020, the UK generated 23.9 kilograms of E-waste per person, the second highest amount in the world, of which most is exported, mainly to Ghana and Nigeria.[293,294,295] Evidence presented to the House of Commons Environmental Audit Committee estimates the amount of E-waste leaving the UK to developing countries is 209,000 tonnes per year, nearly 50% of the 494,000 tonnes of E-waste collected in the UK in 2019.[296]

Agbogbloshie, a slum in central Accra, Ghana, is the site of an E-waste site which has achieved international notoriety as one of the most polluted slums in the world.[297] Exported UK E-waste which ends up in Agbogbloshie is transformed or broken down by informal workers for reuse or resale in second-hand markets. Due to the pervasive nature of environmental toxins from the dumpsite in the local atmosphere, residents of the nearby settlement of Old Fadama, and those working and residing in the central business district, are at risk of experiencing high exposure levels daily. This goes beyond an occupational hazard, as blood samples from both workers and the general population have consistently revealed dangerously elevated levels of heavy metals and other toxic chemicals, with particular risks for neonatal health.[297]

Production of E-waste is predicted to continue to rise over the coming decade and increases in solar and battery usage from the transition to net-zero will only accelerate this process (Figure 8).[293] Efforts to transition to a circular economy by increasing recycling and reuse will need to consider where these activities will be located and how they will be regulated to minimise occupational and environmental health hazards.[291]

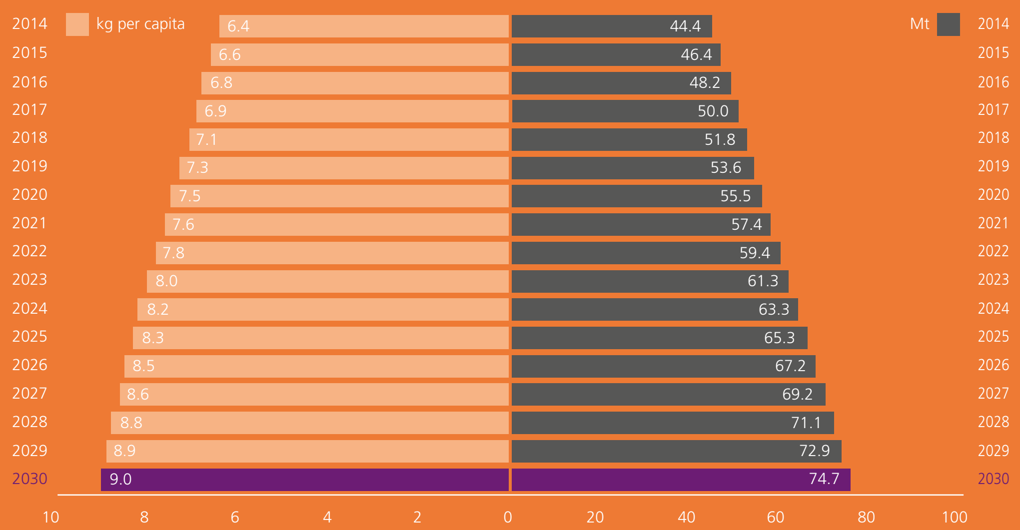

Figure 8: Global E-waste production per year.[293]

Box 13: Bioenergy in the UK

The amount of bioenergy used in the UK has more than doubled over the last decade and it now provides around 7% of total primary energy demand.[39] Bioenergy is produced from a mixture of domestically produced and internationally sourced biomass: the UK now imports over one-quarter of its bioenergy feedstocks. Uncertainty surrounds the carbon savings which can be achieved by using biomass for energy generation and there are concerns around the sustainability of large-scale bioenergy due to land, water, and energy needs.[298,299,300] However, at smaller scales, bioenergy plantations could contribute positively if implemented carefully on degraded land, or used wastes and residues, or have benefits to biodiversity if integrated into a sustainably managed landscape.[301]

The increased demand for biomass could have international health implications. Food, animal feed, and biofuel production compete intensively for limited resources, such as land, water, labour, and capital.[47] If net-zero policies rely on bioenergy crops imported at scale, poorly designed land-management policies could exacerbate existing food security challenges in the short to medium term, with the negative impacts most prevalent in vulnerable, low-income regions such as sub-Saharan Africa and South Asia.[302] In addition, there are direct health impacts from the combustion of woody biomass through air pollutions and the local emission of particulates and NO_x.[39]

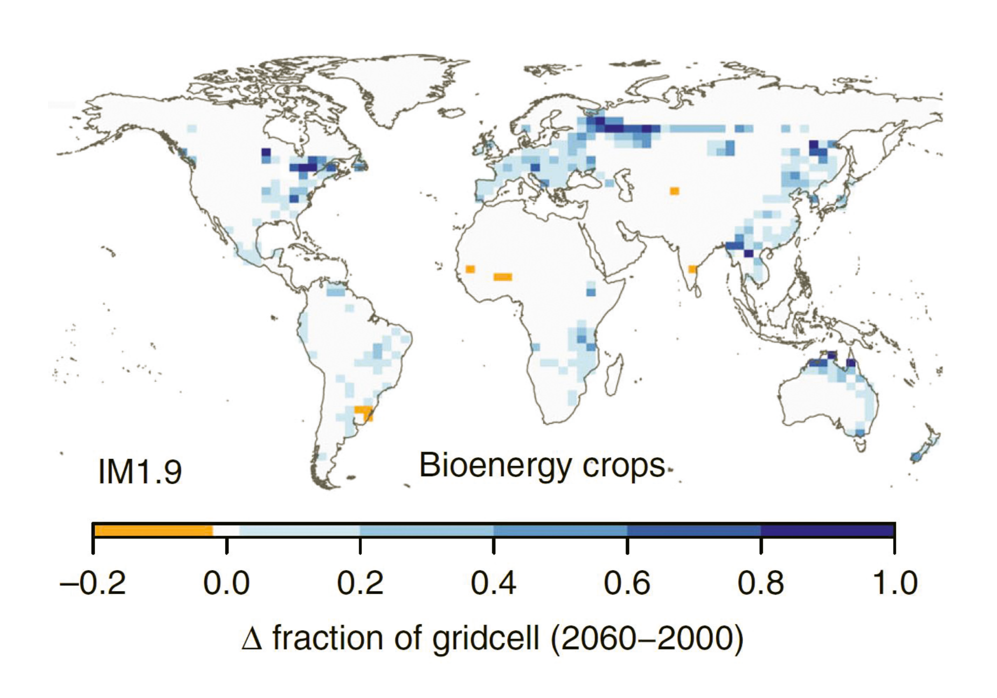

Figure 9: Simulated increase in land use for bioenergy required to meet a 1.5°C target.[303]

8.3 Challenges and opportunities

8.3.1 The need for data on international dimensions

Overall, data on the international dimensions of national energy transitions tend to be sparse and incomplete. 'Spill-over' effects are recognised but lack clear conceptual frameworks for measurement. The lack of data and concepts derives partly from the complexity of the issues, and partly from the lack of mandate given to national bodies such as the Office for National Statistics to measure international dimensions of changes in the UK. Translating findings from case studies into metrics available at the national level would help to drive coherent policy design that is able to monitor and address complex cross-border effects on health.[304]

Developing metrics to monitor international effects of the UK net-zero programme would lead to increased transparency in respect of supply chains, waste recycling chains, and health risks, as the lack of available data is frequently cited as a barrier to progress in these areas.[305]

Building such a thorough understanding will require systems approaches to capture the full range of effects.[306] It will also require learning and capacity building in the local environments where the outcomes of transition processes are felt. The scales at which the health effects of the UK transition are realised vary from the micro to macro scales (see Table 3). These disparate scales mean that while it is often possible for planners to identify solutions and mitigations for these issues, the responsibility for governance is spread between many different actors, such as governments, corporations, and local authorities.[307] The UK has the opportunity to put in place forward-looking approaches in research and policy to anticipate, monitor, record, and respond to potential international impacts in an evidence-based manner. This will require international coordination between governments, business, and civil society to ensure that the net-zero transition is just and healthy on a global scale.

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Table 3: Conceptual framework for whole-systems energy justice. Adapted from Sovacool *et al*. (2019).[307]

SPATIAL ↕ / TEMPORAL →	Production/distribution	Consumption	Disposal/recycling
Macro scale (global)	Mineral extraction – environmental and occupational health and exposure to pollutants. Competition for biomass – unsustainable nutrition and biodiversity.	Increased demand for energy and resources.	Rising global waste – exposure to pollutants from E-waste.
Meso scale (national)	Subsidy programmes influencing demands for zero-emissions energy sources.	Inequality of health benefits from net-zero initiatives.	Waste disposal – costs or benefits to health from recycling domestically or internationally.
Micro scale (local)	Emissions from biomass combustion worsening local and potentially regional air quality. Loss of employment in legacy systems.	Electric vehicles improving local air quality.	Legacies of local pollution.

Key insights

- To better avoid negative global outcomes and incentivise systems thinking, mechanisms for monitoring and evaluating the global impacts of net-zero initiatives in the UK – such as standardised metrics – should be developed and incorporated into policy design (see **Recommendation 3**).
- The global community should look to achieve a well-coordinated policy mix to reduce vulnerability and inequality across the multiple dimensions of raw material production, planning and policy processes, adoption and use of low-carbon technologies, and the management of waste in a growing circular economy.
- Developing a broad conceptual framework to document the impacts of the international transition will better enable health outcomes of policy decisions and consumer choices to be captured.
- Improved transparency about raw materials and waste streams could provide valuable insights. The Extractive Industries Transparency Initiative in the oil and gas sector and the World Commission on Dams in the hydropower sector are examples on which future efforts could build.
- Targeted transdisciplinary funding for research to map the positive and negative impacts on climate mitigation actions across regions and different time periods, with a specific focus on health, will be critical (see **Recommendation 4**). Such efforts could look to build on existing sector-specific work.

9. Conclusions

This report has focused on the way in which policies can act to protect the global climate and human health at the same time. It has also noted that the co-benefits of climate action extend beyond health as such to encompass drivers that impact on wellbeing, such as job creation, as well as identifying scope for international cooperation.

However, health is at the centre of this set of co-benefits. The net-zero transition can save millions of lives worldwide over years to come and promote direct benefits from healthier lifestyles. The health co-benefits are potentially very substantial, improving citizens' lives in many ways, from air quality to transport, buildings, and urban planning to land use.

The potential for improving health, both physical and mental, provides policymakers with a strong incentive for change. Progress on mitigation and adaptation is not only about the future climate, but about the health and wellbeing of populations over the coming years, and the overarching recommendations of this report suggest ways to begin to maximise this potential. **Following its Presidency of the upcoming COP26, the UK Government has an opportunity to take global leadership in promoting human health in all actions taken to address climate change, and to also demonstrate the health gains which can accompany the net-zero transition. We call for the Government to use this opportunity to highlight the importance of the climate–health link and encourage a stronger focus on health within the climate narrative going forwards.**

At the same time, this report highlights areas where there could be downsides for health in the net-zero transition, flagging up the risks up in time for them to be identified and managed. For example, equity considerations are vital. Whilst the transition should help to reduce inequalities and create a more level playing field rather than exacerbating divisions, **integrating mitigation and adaptation measures could help to minimize potential trade-offs and unintended consequences for health and should be an increasing focus of climate policy and action.** For example, in areas such as building design, improvements in energy efficiency should be combined with adaptation measures against heat risk such as passive ventilation, 'cool roofs', and shading that could reduce negative impacts.

To fully achieve these ambitions, there is an **urgent need for governments at national and local levels, with research teams, to refine, improve, and standardise metrics to monitor and evaluate the impacts of climate mitigation policies. Integrating these metrics into all mitigation policies, with regular review and reporting of the broad scope of health impacts, should inform the design of policies which avoid or address possible negative health impacts as the transition gains momentum.** Existing health and environmental impact assessment procedures, such as those previously introduced by Public Health England, could provide a solid basis for these efforts going forwards. Improving the spatial granularity of data collection on net-zero policies will also be important in understanding how impacts vary geographically and demographically.

Underpinning all the themes in this report is the complexity of interactions between climate and health and addressing these in tandem. This will require systems thinking in many areas, **and we identify the need for research funders to support transdisciplinary systems approaches in research design and implementation. Given the urgency of the challenge, there should be a focus on working with policymakers and wider stakeholders, whose actions affect health, to provide solution-focused evidence**.

Research priorities

Research funders should focus on supporting the research and data priorities and evidence gaps linked to climate change and health highlighted in this report, including:

- Potential direct and indirect health impacts of policies that play a role in meeting the net-zero target – including emerging energy technologies such as BECCS.

- Factors influencing both incremental and transformational behaviour change and areas for targeted behavioural change interventions to address health and climate action.

- Understanding how to achieve transformational change and the importance of systems approaches in achieving this. The broad expertise of the National Academies could be valuable here.

- Exploring the balance of positive and negative health impacts posed by the net-zero transition, including assessment of occupational health impacts.

- Targeted research on the skills gap between clean and traditional jobs and the interlinked impacts on health.

- Improving the spatial granularity of data and ensuring compatibility between datasets linking data on climate (and other environmental changes) with those on health outcomes.

Whilst this report did not address transformational change to accelerate progress towards a healthy, net-zero emission and resilient society it underlines the importance of systems approaches in achieving the scale and scope of the changes required. It will be important for separate work to address these questions going forwards. In doing so, a fully transdisciplinary approach – including the perspectives of social and political science, as well as health – should be adopted, to better understand how these profound and far reaching changes can be achieved over coming decades.

10. Acronyms/abbreviations

BECCS	Bioenergy with carbon capture and storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COVID-19	Coronavirus disease 2019
EU	European Union
EV	Electric vehicle
FAO	Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
GP	General practitioner/practice
Gt	Gigatons
kt	Kilotons
LNG	Liquefied natural gas
Mt	Megatons
NbS	Nature-based solutions
NHS	National Health Service
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
OECD	Organisation for Economic Co-operation and Development
$PM_{2.5}$	Particulate matter (with a diameter of less than 2.5 μm)
PPE	Personal protective equipment
QALYs	Quality-adjusted life years
SO_2	Sulphur dioxide
UPF	Ultra-processed food
UN	United Nations
VOCs	Volatile organic compounds
WHO	World Health Organisation

11. Glossary of Terms

Active travel
Active travel refers to making journeys by physically active means, such as walking or cycling.

Air pollution
Air pollution refers to the release of pollutants into the air that are detrimental to human and environmental health. It primarily consists of gases (such as nitrogen dioxide, ozone, sulphur dioxide, and carbon monoxide) and small particulate matter, made up of solid and liquid particles such as soot and dust.

Bioenergy with carbon capture and storage (BECCS)
BECCS involves the generation of energy through the burning of biomass (wood and agricultural products, solid waste, landfill gas and biogas or ethanol and biodiesel) coupled with the capture (via post-combustion, oxyfuel, or pre-combustion) and storage of the resulting CO2 (CCS) in geological or other long-term reservoirs.

Biofuels
Biofuels refer to any fuel that is derived from biomass – organic material including plant materials and animal waste.

Carbon dioxide equivalent (CO_2e)
As each GHG differs in its contributions to warming, GHG emissions are commonly expressed as the CO_2 equivalent – the amount of CO_2 which would need to be emitted to have the same warming effect.

Carbon neutral
See Net-zero emissions.

Clean energy
Types of electricity generating technologies that emit little or no GHGs from fossil fuels.

Climate change adaptation
Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Climate change mitigation
Mitigation is a human intervention to reduce the sources or enhance the sinks of GHGs.

Co-benefit
A co-benefit is the result of simultaneously meeting several interests or objectives with one intervention. With regards to climate change, co-benefits are the added benefits from acting to control climate change, above and beyond the direct benefits of a more stable climate. Since co-benefits are defined as ancillary benefits, whether benefits are classified as primary or co-benefits depends on the primary aim of the action. An alternative approach is to use the term 'multiple benefits' of policies, technologies, and interventions. This avoids having to make judgements about the main motivation for the action. In this report we use the term 'co-benefits' because our main focus is to document the benefits of GHG mitigation strategies, but we acknowledge that the 'multiple benefits' approach may be desirable in other contexts.

Decarbonisation
Decarbonisation refers to the process of removing or reducing the CO_2 output of the economy – removing carbon from the production of energy and supply chains. While the term strictly refers to the reduction of CO_2 emissions, it is commonly used to describe efforts to reduce all GHG emissions.

Energy efficiency
Energy efficiency means using less energy to perform the same task or using the same amount of energy to perform better.

Environmental health
Environmental health encompasses all the external factors from the natural and built environment which affect human health and wellbeing.

E-waste
E-waste, otherwise referred to as waste electrical and electronic equipment, describes discarded electrical or electronic devices which have ceased to be of value to their users or no longer satisfy their original purpose.

Food waste
Food waste refers to food that completes the food supply chain up to a final product which is fit for consumption, but it is instead discarded. Food waste typically takes place at retail and consumption stages in the food supply chain.

Fossil fuels
Carbon-containing fuels including oil (and fuels derived from oil), coal, and natural gas.

Fuel poverty
Fuel poverty relates to households which must spend a high proportion of their household income to keep their home at a reasonable temperature. In the UK, a household is said to be fuel poor if it has above-average energy costs, and if paying those costs would push it below the poverty line.

Greenhouse gas (GHG) emissions
GHGs are gases which trap heat in the atmosphere. The primary GHGs emitted through human activities include carbon dioxide, methane, nitrous oxide, and fluorinated gases.

Green technology
Green technology is an umbrella term for innovations and technologies which are intended to mitigate or reverse the effects of human activity on the environment.

Health inequalities
Health inequalities are unfair and avoidable differences in health across the population, and between different groups within society.

Low-carbon industries/low-carbon economy
A low-carbon industry or low-carbon economy is one which is based on low-carbon power sources, and therefore has a minimal output of GHG emissions into the atmosphere.

Natural environment
The natural environment encompasses all living and non-living things occurring naturally, i.e. not artificial, on Earth.

Nature-based solutions (NbS)
NbS involve working with and enhancing nature to help address societal challenges. The IUCN defines NbS as actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits.

Net-zero emissions
The terms carbon neutrality and net-zero emissions reflect the same intention: neutralising the impact of human activity on the climate system. The IPCC considers net-zero emissions to be achieved when anthropogenic emissions of GHGs are balanced by anthropogenic removals over a specified period. Where multiple GHGs are involved, the quantification of net-zero emissions depends on the climate metric chosen to compare emissions of different gases.

Paris Agreement
A legally binding international treaty on climate change, establishing a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C.

Predominantly plant-based diet
Predominantly plant-based diets are dietary patterns that have a greater emphasis on foods derived from plants and contain lower amounts of animal-derived products than current average diets.

Quality- adjusted life years (QALYs)
A measure of the state of health of a person or group in which the benefits, in terms of length of life, are adjusted to reflect the quality of life. One QALY is equal to one year of life in perfect health.

Renewable energy
Energy generated by resources which are naturally replaced in human timescales including sunlight, wind, and waves.

12. Annexes

Annex 1: Project conduct and timeline

This policy project and its report were led by an expert working group who collectively contributed a broad set of experience and expertise. Details of the working group members, their affiliations, and areas of expertise are in **Annex 2**. The working group was supported by a secretariat of staff representing both Academies. Their details are also provided in **Annex 2**.

The working group met four times over the course of 9 months and was also informed by a range of additional activities to gather external input including several evidence-gathering roundtables, oral evidence, and desk-based research. These evidence-gathering activities were comprehensive within the constraints of time and resources but a formal systematic literature review has not been performed, and as such the references used throughout this report should not be considered as exhaustive.

The project was launched in January 2021 with the working group convening to discuss the scope and focus of the project. The group identified 8 areas the report should cover: Energy; Mobility; Food; Buildings; Natural Environment; Employment; Healthcare; and International Spill-overs.

A number of cross-cutting themes were also identified as the focus of the series of evidence-gathering roundtables which informed the report. The first roundtable '*The Green Recovery*' was held in March 2021. The second and third roundtables, focusing on '*A just and healthy transition*' to net-zero and '*Behavioural change*' respectively were held in May 2021. Finally a series of evidence-gathering calls were also undertaken to explore international spill-over impacts. The input from these roundtables has been instrumental in ensuring that the recommendations of this report are relevant. Summaries of the roundtables will be published on the Academies' websites.

To help ensure the evidence in the report was relevant both to the target audience and policymakers, the early stages of the project were also supported by expert contributors on the focused chapters. The contributors were not present when the report's recommendations were finalised by the working group, and only contributed to individual chapters. We are grateful to those contributors who supported the project in this manner; names and affiliations are provided in **Annex 2** acknowledgements.

The report has been reviewed, and approved, by an external review group which was appointed by the Council of the Academy of Medical Sciences and approved by the Royal Society. Care was taken to ensure this group benefited from expertise which covered the breadth of the report, and details of the review group are provided in **Annex 3**.

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