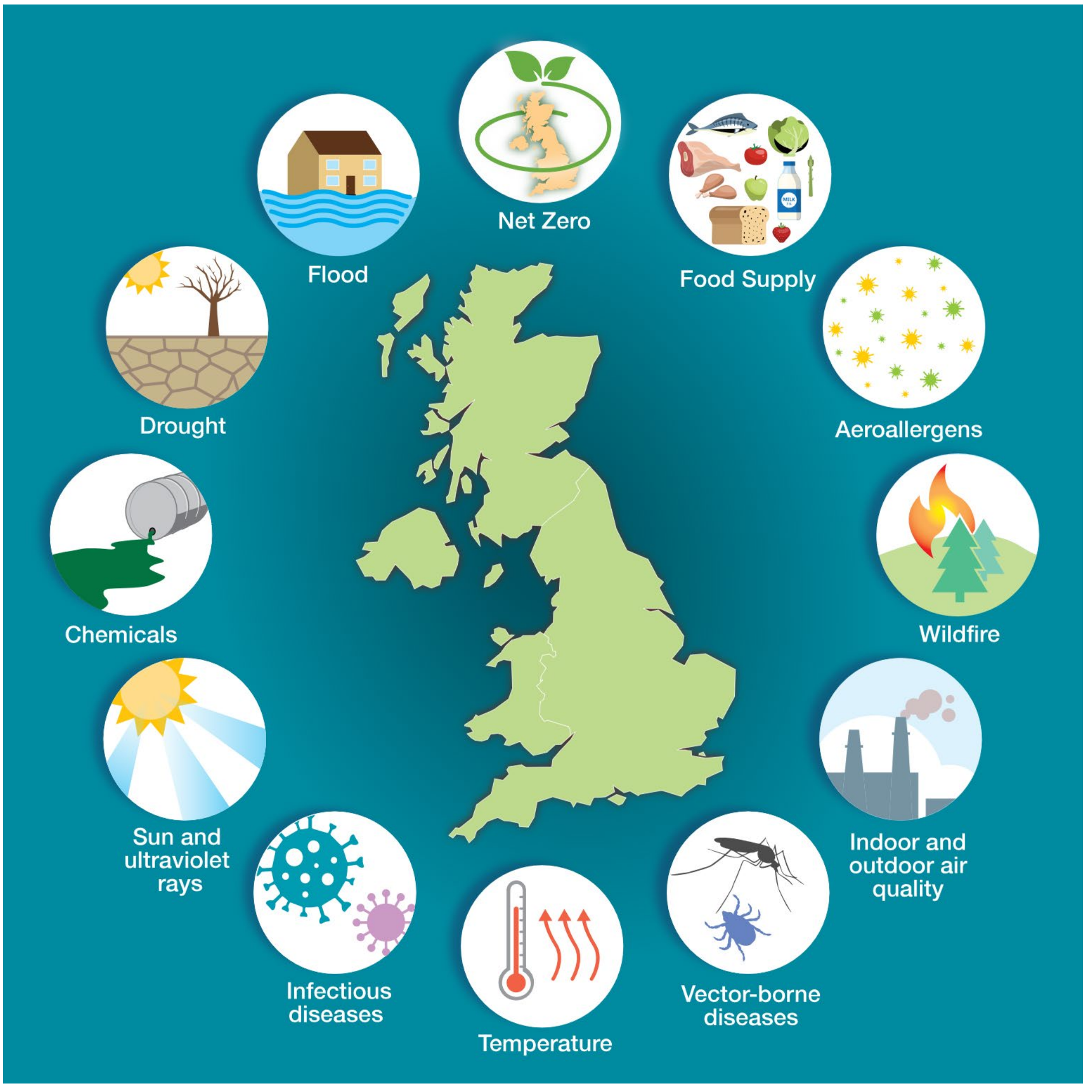
UK Health Security Agency

Health Effects of Climate Change (HECC) in the UK: 2023 report

Chapter 14. Net zero: health impacts of policies to reduce greenhouse gas emissions



Summary

The UK has committed to reaching net zero greenhouse gas (GHG) emissions by 2050. Actions to reduce emissions will benefit health by averting some of the anticipated adverse health impacts from climate change and such actions will also have other positive impacts on health or co-benefits. Chapter 14, led by UK Health Security Agency (UKHSA) scientists, with contributions from academics from University College London, University of Exeter and London School of Hygiene and Tropical Medicine, reviews this evidence.

Transport is currently the largest contributing sector to UK GHG emissions and is therefore a key focus for decarbonisation actions. Actions to shift from vehicles towards active travel by walking or cycling, for example, have major health co-benefits. As well as reducing carbon emissions, active travel can reduce ambient air pollution and improve physical and mental health. Where vehicles are used, shifting from fossil fuels to electric vehicles can benefit health by reducing exposure to vehicle exhaust air pollution, though they will still produce some particulate matter emissions from tyre and brake wear.

The UK housing stock is relatively poorly insulated compared to other countries in northern Europe, and improvements in thermal efficiency and airtightness could substantially reduce heating demand and GHG emissions. In addition, improved insulation could help reduce cold-related mortality and morbidity. Insulation improvements should be accompanied by adequate ventilation to avoid increasing build-up of indoor air pollutants or summertime overheating. Upgrades to the UK housing stock that are carefully designed and implemented to integrate multiple health considerations represent one of the greatest opportunities for health co-benefits from decarbonisation.

The food sector currently contributes approximately one third of global GHG emissions. Transitioning farming practices through innovation and technology will be a key contributor to reducing GHG emissions. Reducing intake of foods with a high emission ‘footprint’ and increasing intake of plant-based foods will help reduce emissions and can be associated with nutritional health benefits.

Nature-based solutions such as expanding or creating new forests, protecting marine environments and building green roofs or walls, can help reduce temperatures and can have positive impacts on ecosystems, biodiversity and human health and well-being. Urban greenspace can provide a local cooling effect, with trees providing shade and improving thermal comfort, as well as positively impacting health and well-being, particularly mental health.

The health sector can make an important contribution to decarbonisation. Vehicles could be switched to electric without impacting the delivery of care, although there are some operational challenges for vehicles such as ambulances that need to be operational at all times. Anaesthetic gases and inhalers are an important source of health sector emissions due to their

widespread use and the types of gases used. Action to switch to low-carbon alternatives and reducing inappropriate prescribing and waste can also help reduce emissions.

Action to mitigate climate change and achieve net zero will prevent some of the anticipated adverse health effects and, as this chapter demonstrates, will also have major health co-benefits. It is important to increase awareness of the wider health benefits of climate change mitigation actions. Given the UK's commitment to Net Zero and decarbonisation across sectors, there is significant opportunity for health care and health systems to continue engaging and supporting this transition in ways that provide a range of health co-benefits. Maximising the health benefits of decarbonisation represents a key opportunity for health in the UK this decade.

This chapter highlights several priority research gaps and the need to gain a better understanding of:

- health benefits, co-benefits, inequalities, trade-offs and any potential harms to health associated with net zero actions, so that findings can be integrated into climate policies and actions to ensure health benefits are maximised and health harms are avoided
- modelling and quantitative studies that integrate mitigation and adaptation options and their relative benefits for health and GHG emissions reductions, including health economic assessments
- behavioural dimensions of transitions to net zero to assess potential effectiveness, accessibility, and equity of alternative decarbonisation strategies
- implications for health of new technologies and processes associated with climate mitigation
- how impacts and benefits of different net zero policies will be distributed across the population, including how actions may be targeted to support effective, accessible, and equitable outcomes for health

UKHSA is establishing work programmes focused on increasing understanding of co-benefits and building the evidence base for healthy climate change mitigation including greening. In addition, UKHSA is conducting research to improve our understanding of the barriers and opportunities for 'win-win' behavioural shifts that provide both health and decarbonisation benefits.

Contents

Chapter 14. Net zero: health impacts of policies to reduce greenhouse gas emissions

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1. Introduction

1.1 Summary of previous HECC reports

While this is the first time the 'Health Effects of Climate Change in the UK (HECC)' report has included a dedicated chapter on net zero specifically, the health implications of reducing greenhouse gas (GHG) emissions are included in previous reports. The 2002 HECC report outlined some co-benefits of actions to reduce GHG emissions, including transport-related actions such as decreased dependence on road vehicles which could have health benefits associated with more physical activity (for example active travel) as well as improving air quality, alongside reducing traffic speeds (which can reduce road collisions) (1). The first report also noted that reducing energy demand via measures including improving home energy efficiency (improving home insulation and efficiency of appliances) can reduce household energy use and the burden of cold-related morbidity and mortality. However, potential trade-offs or health risks were identified, for example, increasing home insulation without ensuring appropriate ventilation may lead to reduced indoor air quality, and negatively impact health. GHG emission reduction actions in the agricultural sector are briefly mentioned but potential health impacts are not described. The 2002 report also highlighted the need for adaptation considering modest emission reduction targets agreed in Kyoto at the United Nations (UN) Convention on Climate Change (1).

The UK Climate Change Act (2008) (2) was passed in 2008, setting out a pathway of actions across government to reduce emissions. At the time of publication of the second HECC report in 2008 (3), the Department of Health, the National Health Service (NHS) and the Carbon Trust were establishing a set of mandatory public sector targets around energy and carbon efficiency, and the NHS began working toward mandatory energy and carbon efficiency targets for NHS estates and buildings. However, while the energy performance of the NHS was improving, overall energy use was increasing due to the expanding size of the healthcare estate, growing levels of service provision, and use of medical and other technologies. The role of air conditioning in protecting health in a warming world was acknowledged although, as it consumes energy, it may accelerate global warming. As such, its use was minimised to situations where alternative strategies cannot be implemented adequately, such as in hospitals or care homes when only small numbers of carers are available to attend to large numbers of people (3).

In the third HECC report (2012), the final chapter was dedicated to health co-benefits of measures to reduce GHG emissions from household energy use, urban transport, electricity generation, and food and agriculture, although it was not yet termed net zero (4). As in previous reports, health benefits from improved air quality, increased physical activity due to modal shift and reduced car use in urban centres, and reduced dietary saturated fat consumption from animal products were identified; importantly, when these health co-benefits were considered, climate change mitigation policies became more attractive. Potential disbenefits were again acknowledged, particularly related to housing and ventilation, and a chapter was dedicated to the role of the indoor environment on health. This highlighted the need for climate change mitigation policies to be subject to health impact assessments to identify both benefits and risks of policies to our health, as well as modelling the macroeconomic effects of emission mitigation policies that consider health impacts. A key recommendation from the 2012 HECC report was the need for public health professionals' education and training to include interventions and adaptation to climate change. Furthermore, the report highlighted that public health professionals should work in collaboration and across agencies to maximise health co-benefits and minimise health risks of mitigation policies (4).

1.2 How the field has evolved since the last report

In 2019, the UK followed the Climate Change Committee's (CCC) recommendations and adopted a legally binding target to reduce its territorial emissions "by at least 100%" by 2050, through the 2050 Target Amendment Order (5) to the Climate Change Act 2008, raising the ambition on climate action to the highest possible level. Energy use per person in the UK has fallen from 37,385 kilowatt hours (kWh) in 2012 to 29,641kWh in 2021, and energy sources have changed, with coal combustion reduced and wind and solar increasing (6). Although energy from low-carbon sources has increased from 1% in 2000 to 24% in 2021, the share of primary energy from fossil fuels is still over 75% in the UK in 2021 (6). There is now a growing body of research on net zero and health particularly related to air pollution which has recently been comprehensively reviewed (7, 8), though these reports do not quantify health impacts specifically. However, there have been advances through better understanding of the impacts of air pollution on the body (9). A recent review found a connection between hospitalisation and mortality from COVID-19 and long-term exposure to air pollution, highlighting the potential wider health impact from poor air quality (10).

Following the onset of the COVID-19 pandemic, there have been behavioural changes, with many people home-working during COVID-19 'lockdown' restrictions and a rise in hybrid working since such restrictions were eased (11). Thus, there is the potential for people to be more exposed to their home environments, as well as using more energy at home and changes in transport patterns. In addition, an increase in the cost of living has placed further pressures on household budgets, with concerns for keeping homes warm in winter (12), potentially leading to people using high-polluting, cheaper fuels as reported by the media.

There have also been changes relating to diet, health care sector ambition and policy integrated modelling. Availability and popularity of vegan and plant-based dietary options has increased, and the UK already has one of the largest markets in Europe for meat-substitutes (13), although the environmental and health impacts of some highly processed meat alternatives are currently inconclusive. The health system in England accounts for around 4% of carbon emissions in England; in October 2020, the NHS became the world's first health service to commit to become net zero (14). All 4 UK health services have united to commit to net zero carbon emission targets (15).

Recent advances in modelling include how implementation of net zero measures may impact humans and the environment (16 to 18), and publishing of international consensus recommendations for daytime, evening, and night-time indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults (16 to 18). However, there is still much more to be done.

1.3 State of the current science: aims and objectives of the chapter

The most recent Sixth Carbon Budget published by the CCC in 2020, set recommendations to help reach a 78% reduction in UK emissions by 2035 (on 1990 levels), bringing forward the UKs previous 80% target by almost 15 years (19). Four key recommendations are included:

- take-up of low-carbon solutions (low-carbon transport, boiler replacement, industry shift to renewable)
- expansion of low-carbon energy supplies (zero-carbon electricity production, scale-up of wind power and hydrogen to replace natural gas, carbon capture and storage)
- reducing demand for carbon-intensive activities (reduced heating demand by improving building energy efficiency, reduce consumption of high-GHG emission meat and dairy, fewer car-miles driven and slowing demand for flights)
- land and GHG removals (agricultural transformation, planting of new mixed woodlands, producing energy crops for biofuel, peatland restoration)

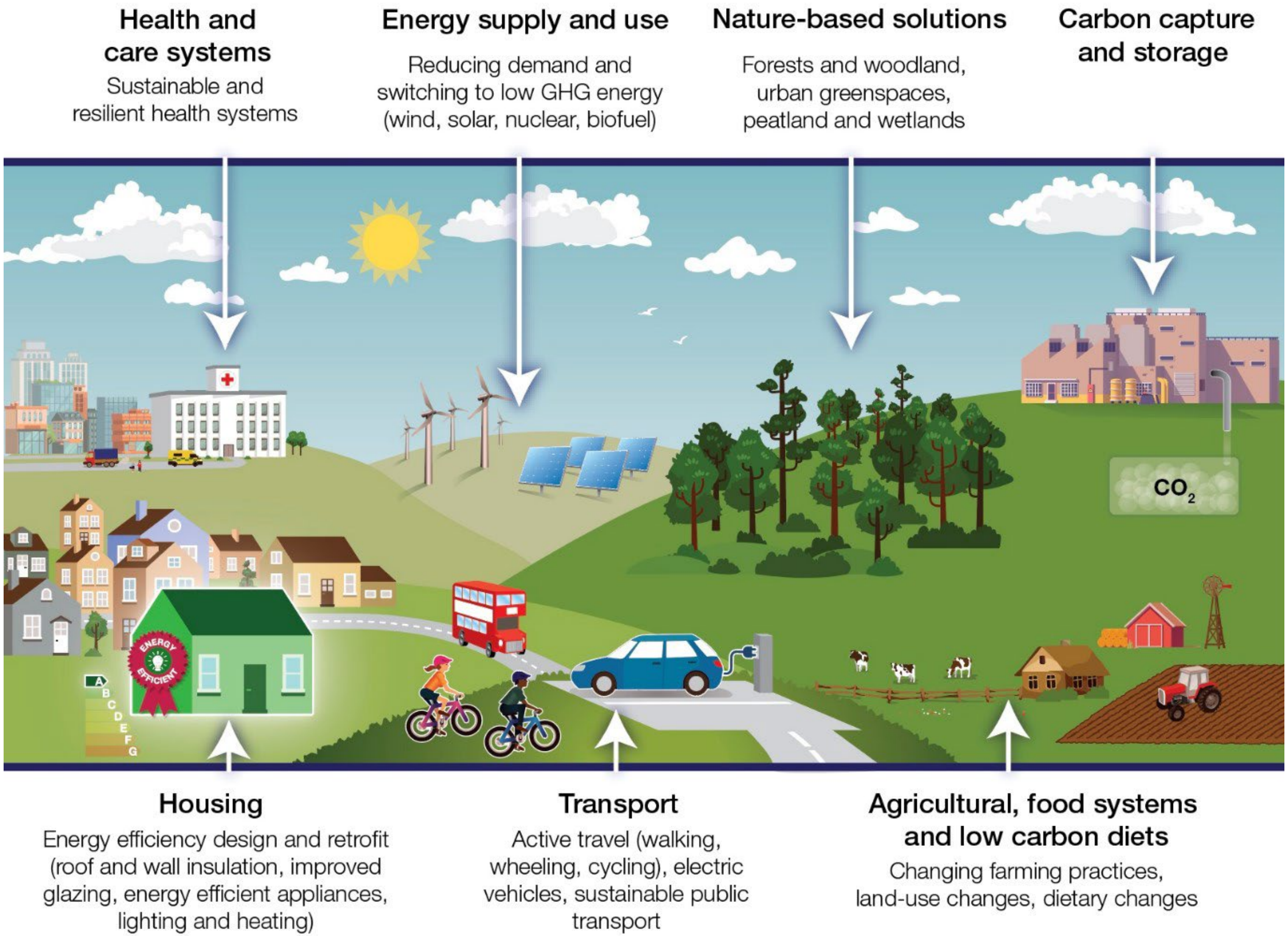
While the concept of net zero has taken shape relatively recently, the health benefits of reducing GHG have been alluded to for some time (see section 1.1), and the extent to which these are understood and have been quantified is variable. Quantitative estimates for some of the impacts on health have been possible, for example with advances in modelling techniques, though challenges to quantify the health impacts remain.

The background to net zero legislation in the UK is briefly outlined below, before addressing different net zero measures individually (based on those included in the Sixth Carbon Budget and expanded where appropriate) in relation to their potential impacts on human health. The aim is to bring together the current evidence on health impacts associated with different actions and policies aimed at reducing the UK's net GHG emissions, and where possible identify gaps and provide recommendations for future work. While the focus of this chapter is mitigation actions (as adaptation considerations are primarily covered within other chapters), potential for mitigation actions to support adaptation are highlighted where relevant.

2. Net zero

The Climate Change Act 2008 was the first of its kind globally, establishing a long-term legal framework to underpin the UK's contribution to tackling climate change, and put in place a clear and credible emissions reduction pathway to reduce carbon dioxide (CO_2) and other GHG emissions by 2050 (excluding aviation and shipping). When the Act was first proposed, it was thought that 60% emissions reduction would limit CO_2 to 550ppm (parts per million), which was thought would keep to 2°C global mean warming, thus avoiding the worst consequences of climate change. However, a conference held under the G8 UK presidency in 2005 concluded that the 60% target would only cut GHG concentrations by 35% to 50% on 1990 levels by 2050, and hence the 80% reduction target was enacted. The Climate Change Act 2008 (2050 Target Amendment) Order 2019 stipulated that the 80% target be changed to 100% or net zero, meaning emissions of GHG must be eliminated as much as possible, and any emissions which cannot be eliminated must be offset through removal of GHG from the atmosphere, for example through carbon sequestration to the terrestrial biosphere, or carbon capture and storage (CCS), though long-term success of carbon offsetting via such means is unclear (20).

Figure 1. Measures to help achieve net zero that have implications for human health



Text version of Figure 1.

The figure shows measures to help achieve net zero that have implications for human health.

Health and care systems – sustainable and resilient health systems.

Energy supple and use – reducing demand and switching to low GHG energy (such as wind, solar, nuclear, biofuel).

Nature-based solutions – for example forests and woodland, urban greenspaces, peatlands and wetlands.

Carbon capture and storage solutions.

Housing – energy efficiency design and retrofit (for example roof and wall insulation, improved glazing, energy efficient appliances, lighting and heating.

Transport – active travel (such as walking, wheeling, cycling), electric vehicles and sustainable public transport.

Agriculture, food systems and low carbon diets – changing farming practices, land-use changes, dietary changes.

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While actions to reduce emissions will ultimately benefit health by reducing climate change itself and thus the negative associated health impacts, different types of emission-reduction actions and interventions will also have effects on health themselves, as recognised in previous reports (section 1). These impacts, where beneficial, are important mutual or co-benefits to health and can help make the case for strong actions on climate change while harnessing opportunities to improve public health (21) and can support a comprehensive cost-benefit analysis of climate action. Providing information on such benefits can increase public and political support for health mitigation locally, as well as support international negotiations (such as the Conference of Parties (COP)) to support decision-makers in committing to reduce GHG emissions. Agreeing and publishing Nationally Determined Contributions (NDCs), which sit at the heart of the Paris Agreement, embody efforts by each country to reduce national emissions and adapt to climate change. The World Health Organization (WHO) noted that while public health considerations are mentioned in 70% (129 out of 184) of countries' NDCs, just 10% (18 out of 184) emphasise the health benefits of mitigation. Of those 18, only 2 signal quantifying or monitoring health benefits to inform decision-making, and 3% (5 out of 184) emphasise the health benefits of adaptation (22, 23). With ambitious climate targets to meet, the implementation of measures will be important in the immediate future, and health considerations should be mainstreamed into climate actions to harness opportunities for mutual benefits, while ensuring that any disbenefits to health are minimised, and maladaptation is avoided (24).

3. Health impacts associated with net zero actions

This section outlines and discusses the main net zero measures (summarised in Figure 1) and their potential impacts to human health, highlighting co-benefits and any associated trade-offs or unintended consequences.

3.1 Energy supply and use

The burning of fossil fuels contributes to global warming through the release of GHG and significantly impacts our health, primarily through its contribution to air pollution, via the release of ultra-fine and fine particulate matter ($PM_{2.5}$, particles with aerodynamic diameter less than 2.5μm) and other air pollutants. These pollutants contribute to cardiovascular and respiratory morbidity and mortality along with other illnesses and are thought to contribute to one in 6 deaths worldwide (16, 25) (see Chapters 4 and 5). It has been estimated that of the 3 million to 9 million global annual excess deaths attributable to air pollution (26), 65% of these are a result of fossil fuel use. Health savings from reduced air pollution could be between 1.4 to 2.5 times greater than the costs of climate change mitigation globally (27). Currently, 78% of UK energy comes from fossil fuels across multiple sectors, including, transport, industry and energy for heating and electricity (28). Total territorial emissions from the UK in 2021 were 427MtCO_2e (million tonnes of CO_2 equivalent), 5% up from 2020, but down from pre-pandemic in 2019, and 48% lower than 1990 (29). The CCC states that fossil fuel supply emissions will need to reduce from 2018 levels by 75% by 2035 (19). There will be 2 main ways of reducing fossil fuel use to reach net zero: reducing the overall demand for energy and switching to low-carbon energy sources.

3.1.1 Reducing demand for energy

Reducing energy demand can take the form of increasing energy efficiency and reducing energy-intensive activities (for example, changing how we travel and reducing air travel). Such changes may require considerable shifts in behaviour and in policy to develop extensive infrastructure to help facilitate these. Increasing energy efficiency will include measures such as home energy efficiency (see section 3.3) and increasing efficiencies in transport and industry (see section 3.2). Reducing energy consumption generally will benefit health through reduced air pollution currently associated with fossil fuel combustion; however, this will be dependent upon equity of access to affordable energy. Uptake of such solutions may therefore require significant support from policies and schemes as it will only happen if consumers have access to the right technologies via increased affordability and enhanced infrastructure, and are aware of the benefits (30).

3.1.2 Switching to low-carbon energy sources

Low-carbon energy sources include renewables (such as wind, solar, and hydroelectric power), alongside nuclear power. Low-carbon fuels may include bioenergy (for example, biogas or crops grown for biofuels) and hydrogen. A major health benefit of switching to renewable energy sources will be potential improvements in air quality from reduced fossil fuel burning, though biofuels (such as crops grown for bioethanol or biomass burning) may still emit air pollution; adverse effects of wood burners on air pollution are being increasingly recognised (see Chapter 5). Taking land for bioenergy crops also competes with land for growing food (see section 3.4.2.), though planting forests can act both as a carbon sink and increase well-being (see section 3.5) (31). Another health benefit may be from reducing risks associated with fossil fuel extraction, which could help avoid exposure to toxic compounds for both occupational populations and those living within proximity of such sites. Exposure to these toxic compounds have been associated with a range of negative health effects such as some cancers and developmental defects (32). There may also be health impacts related to implementation of solutions infrastructure. For example, solar energy involves the use of photovoltaic cells (PVCs), whose production involves silica mining, with unsafe mining practices associated with ill health (33). Hydroelectric power may be associated with environmental impacts including altered water flow in river systems, reduced water quality and loss of wetland areas. These factors may have a wider detrimental impact on biodiversity and greenspace, with a knock-on impact for health. Onshore wind power has been shown to reduce quality of life through noise annoyance and sleep disturbance for those who live close to turbines (34). However, these health risks are likely to be much lower than those associated with the burning of fossil fuels, and if well managed, the risks posed by solutions infrastructure to health should be low (33, 34). There are additional indirect benefits of transitioning to renewable energies through reducing dependence on volatile international fossil fuel prices, improving energy access in remote areas not connected to the grid, and reducing energy poverty.

The CCC states that an increase in energy generation from nuclear power will be required to help reach UK's net zero emissions targets under the 'balanced pathway' (19). For radiation plant workers, a primary occupational health concern is radiation-induced cancer, and some studies have demonstrated small excesses of cancers in some occupational cohorts, including leukaemia (33, 35). For populations living in the vicinity of power stations, major accidents at nuclear power plants (such as Fukushima in 2011 and Chernobyl in 1986) also pose a risk to health, although such events are thankfully rare. The health impacts of such accidents can have long-lasting effects on the surrounding populations, including displacement and resettlement, cancer development and mental health illness (33). Another issue is the nuclear waste produced, which can remain radioactive for many years; safe storage and disposal to minimise the risk of leakage into the environment can be difficult (36). However, the UK's regulatory system achieves world-leading health and safety standards, with radioactive discharges and occupational radiation exposure making up less than 0.05% of the average UK radiation dose (37).

There are potential risks from transitionary localised air pollution impacts associated with construction of infrastructure to expand the renewable, nuclear, transport and decarbonisation sectors in the UK (7, 8) and developers must demonstrate how they will minimise local air quality impacts during the construction (and demolition) phase of new developments (38). Given the potential scale of infrastructure development needed, additional control measures for large infrastructure projects would be beneficial to health.

3.2 Transport

Transport is now the biggest contributing sector to GHG emissions in the UK (39) and will therefore be a key focus for mitigation actions. The transport sector contributes significantly to air pollution, with pollutants coming from engine exhaust (tailpipe) emissions, and non-exhaust emissions. Engine exhaust emissions include particulate matter (PM), as well as carbon monoxide (CO), nitrogen dioxide (NO_2) and hydrocarbons (HCs), which are also ozone (O_3) precursors. Non-exhaust emissions include PM from tyre- and brake-wear and resuspended road dust. A compressive systematic review conducted by the Health Effects Institute concluded a moderate-to-high or high level of confidence in the association between long-term exposure to traffic-related air pollution (TRAP) and a range of adverse health outcomes including lung cancer, asthma onset in children, ischaemic heart disease and acute lower respiratory infections in children, as well as all-cause mortality (40). Transport interventions aiming to reduce GHG emissions and or air pollution and discuss impacts on health are outlined below.

3.2.1 Decarbonising transport

In 2019, transport was responsible for 27% of total UK GHG emissions (41). In 2021, the Department for Transport (DfT) published the government’s commitments and plans to decarbonise the transport system within the UK (41), crucial to achieving net zero, with plans for decarbonising cars, vans and rail set out in the ‘Transitioning to zero emission cars and vans: 2035 delivery plan’ (42) and ‘Rail environment policy statement: on track for a cleaner, greener railway’ (43).

Electric vehicles (EVs) are included in decarbonisation plans due to their zero tailpipe emissions. EVs benefit health through reduced exposure to air pollution, as energy generation is taken away from population centres. However, the extent of the benefits may be determined by location of power plants relative to populations, with research showing that the energy grid and location of emissions (on-road or power plant) are key when considering the impact of EV technology on air quality and thus on health (44). The existing energy mix is important for overall health impacts of EV rollout, and countries with polluting fuel mixes for electricity generation won’t fully realise the health benefits (45), thus decarbonising electricity generation is important. In the UK, where the energy generation sector does not heavily rely on coal power, no increase in SO_2 should be expected, but the energy supply chain should be considered (44).

Additionally, a Public Health England (PHE) report concluded that EV benefits through reducing air pollutants depends on:

- type of EV
- source of energy generation
- driving conditions
- charging patterns
- availability of charging infrastructure
- government policies
- climate of regions (46)

Co-benefits to health include reduced non-communicable diseases burden (cardiovascular and respiratory disease), injuries, and better mental health, among others (47).The electrification of the passenger vehicle fleet is underway in the UK, with decarbonisation predicted to be complete by 2050; for battery vehicles the UK Net Zero strategy identifies that electricity will come from zero carbon emission sources, but this can require rare elements, such as lithium and cobalt, which have raised environmental and ethical issues in countries where these are mined. To make the transition to EV, a set of actions for local authorities and businesses to plan the rollout of EV charge-points was published in December 2022 (48). However, it is estimated that EV could increase electricity demands from current levels at 300 terawatt-hours (TWh) by around 30TWh by 2030 and by 65TWh to 100TWh by 2050 (19). In addition, the promotion of EVs could be associated with social inequality, as they are more expensive to purchase and most private EV owners in the UK lived in urban areas with households containing multiple cars and had the ability to charge their cars at home (49).

Unambiguous benefits for air quality should be expected arising from the elimination of exhaust NO_x (nitric oxide (NO) and NO_2), with significant reductions in ambient NO_2 concentrations likely to be experienced at the roadside and in enclosed stations (8). A consequence of eliminating nitric oxide (NO) from vehicle exhaust will be localised roadside increases in O_3, from reduced consumption of O_3 through chemical reaction with NO, presenting a possible disbenefit to health of reducing NO emissions (see Chapter 4).

There are notable outstanding uncertainties around future non-exhaust emissions related to increased vehicle weight (increasing tyre and road wear) traded-off against the benefits of regenerative braking (decreasing brake-wear), and emerging vehicle PM reduction technologies (such as capture from brake callipers and low emissions tyres). Wider uncertainties are associated with the size of the vehicle fleet and total distance driven, in a future where relative costs-per-mile may be lower than today and UK population higher (8). Thus, as exhaust PM emissions are expected to decrease, non-exhaust PM emissions are expected to become proportionately more important (50, 51). Therefore, the Committee on the Medical Effects of Air Pollution (COMEAP) recommended new epidemiological and toxicological research to further understand potential health risks of this aspect of vehicular pollution, and to provide a basis for further policy (see Chapter 4).

The Clean Air Fund technical report (2022) addressed the impacts of future emissions changes which stem from existing legislation and net zero forecasts relating to transportation in the UK (52). A scenario was based on the 2030 emissions projections including the Department for

Environment, Food and Rural Affairs' (Defra) 'Business as Usual (BAU)' forecast – a 'conservative' estimate of future emissions changes from UK sources – combined with widespread electrification of the UK vehicle fleet (taken from the CCC's Sixth Carbon Budget forecast and including London's Scenario 1 (LS1)). This scenario found important air pollution benefits that will improve people's health, reduce climate impacts and help achieve net zero commitments (52). Expected benefits to health were estimated to be 11.5 million life years gained across the UK population over the time period 2018 to 2134 compared with 2018 concentrations remaining unchanged, considering deaths from all causes including respiratory, lung cancer and cardiovascular deaths. In terms of costs and benefits of key policies, a reduction in air pollution following existing government policies and government net zero commitments could lead to total benefits of £383 billion (including value of life years gained, reduction in diseases, fewer hospital admissions, and improved productivity) between 2018 and 2134.

3.2.2 Low emission zones and UK and EU engineering standards

Localised policies can have an impact on reducing air pollution in local hotspots. Low Emission Zones (LEZ), Ultra Low Emission Zones (ULEZ) and Clean Air Zones (CAZ) are created to reduce the level of pollutants most harmful to health in areas with high pollution levels and high population densities (53). Vehicle emissions can be controlled by the ever-tightening Euro engineering standards, and new vehicles must show they meet these limits to be approved for sale. The most recent Euro 6 (VI) was applied from 2014 for heavy-good vehicles (HGVs) and 2015 for newly registered light-duty vehicles (LDVs), the newest Euro 7 (VII) is anticipated to be implemented in financial year 2025 to 2026 (53). The Euro emission standards are used to determine if vehicles may enter the different low-emission zones, or face a daily charge (53, 54). The impact of the LEZ in central London between 2009 and 2014 led to a reduction in the number of children living in areas where NO_2 levels exceed the EU's annual limit (40μg per m^3) (55), and $PM_{2.5}$ concentrations have reduced in the ULEZ by 27% between 2017 and 2020 (56). It's further estimated that the ULEZ led to an average 4% reduction in CO_2 between 2019 and 2022 (57).

3.2.3 Active travel

Active travel is any mode of transport that involves varying degrees of activity, including walking, wheeling and cycling as a journey, including trips made by wheelchair, mobility scooters, adapted cycles, electric cycles (e-cycles) and scooters (58). Active travel can benefit health through increasing physical activity (53); the expected effect of increased cycling in just a few major cities in England on NHS costs could lead to savings of about £319 billion between 2017 and 2040 (59). Reducing the use of motorised transport will reduce air pollution (see section 3.2.1). Individual and population health benefits of walking and cycling have been recently reviewed (60), with risk factors for multiple diseases reducing, including cardiovascular disease, respiratory disease, some cancers, dementia and type II diabetes, as well as mental health improving (as a result of improved sleep quality, and greater sense of wellbeing), with benefits outweighing any risks from injury or pollution exposure. For active travellers, concentrations of air pollutants were often lower than those experienced by car commuters, but consideration should be given to provide options for walking and cycling routes separated from roads carrying motorised transport (61). This would also reduce the time waiting at busy road junctions (61), and would potentially reduce the risk of road accidents caused in a shared space between active travel and motorised transport. There is little specific evidence on benefits of walking and cycling for people with disabilities and those living with long-term conditions, or about the effects on groups living with different levels of deprivation – these gaps should be addressed, particularly regarding practical methods to improve access to physical activity for these groups (60). Where active travel takes place through green areas, this may also bring health benefits through increased contact with nature (62) (see section 4.e).

Walking and cycling are the least carbon-intensive ways to travel. However, walking currently accounts for only 5% of the total distance travelled in England (63) while journeys under 2 miles made up approximately 25% of all car trips in England, and journeys below 5 miles made up 49% of all trips in towns and cities in England in 2021 (63) If those trips could be walked or cycled, it would help to reduce GHG emissions from cars, and promoting active travel can lead to increased road safety, thus developed travel plans should consider ways to ensure safe walking and cycling (58, 64).

E-cycles are becoming more popular and could overcome some commonly reported barriers to cycle commuting (such as riding up hills, travelling long distances, or those who may be put off by the physical effort of an ordinary bicycle), and can contribute to meeting physical activity recommendations and increasing physical fitness. In addition, e-cycles are a potentially more affordable alternative to car usage in an urban environment, which may impact on health inequalities by enabling economically disadvantaged populations greater travel opportunities, although barriers may remain in the form of initial costs, charging and storage (65).

Ambitions for active travel are outlined in England's second statutory Cycling and Walking Investment Strategy (CWIS2) and includes a range of objectives, including that half of all journeys in towns and cities being walked or cycled by 2030 (64). £3 billion is projected to be invested in active travel over the CWIS2 period up to 2025 from across government; to help commit to this goal the new executive agency 'Active Travel England' was founded in 2022, and is now a statutory consultee on all planning applications for future large developments, helping deliver walking, wheeling and cycling infrastructure in England (53). For new urban development, the Local Transport Note 1/20 (covering England and Northern Ireland) and Manual For Streets (primarily covering England and Wales) support the delivery of high-quality cycle and walking infrastructure, setting out current best practice, legal requirements and guidelines and standards for developments to include well-lit, overlooked and direct cycle and pedestrian routes (66, 67). In Scotland, Cycling by Design aims to ensure that cycling is a practical and attractive choice for the everyday and occasional journeys of all people, particularly new, returning or less confident users (68). Active Travel Wales' vision is for walking and cycling to be the natural mode of choice for short everyday journeys, or as part of a longer journey in combination with other sustainable modes (69). For active travel policies to be successful, accessibility and barriers to uptake (besides lack of existing infrastructure) should be considered, including safety, air pollution, and practicalities such as travelling with children or bags (as key barriers to cycling), and time commitment, safety, and a pedestrian friendly environment (for walking) (70). Key barriers identified by disabled cyclists include inaccessible cycling infrastructure, the prohibitive cost of adaptive cycles, and absence of legal recognition that cycles are mobility aids for many people (71). Measures should be tailored accordingly, promoting inclusivity while ensuring wider successful uptake.

Increased active travel would change outdoor exposure to visible daylight and ultraviolet radiation (UVR). The timing of exposure determines the body's regulation of a wide range of functions, such as metabolic and sleep general (72 to 74), and outdoor daylight is typically several hundred times stronger than lighting indoors, even for overcast skies (75) (see Chapter 13).

Recommended daytime exposures (76) may be supported by active versus motorised journeys, not least because of longer journey times. Daily morning light has established anti-depressant effects (77), and afternoon and early evening exposures can help protect against disruption from later evening light (78). Myopia onset and progression in school-aged children is associated with time spent outdoors, as a protective factor independent of physical exercise (79).

Skin over-exposure to UVR can have negative health impacts, such as increased risk of skin cancers and sunburn; however, insufficient exposure may often be the greater long-term health risk, so sun protection messages should be balanced for optimal health (see Chapter 13). Depending on the time of day during spring and summer months and the area of exposed skin, sunlight supports vitamin D synthesis (80, 81). UVR levels depend on many variables, such as season and time of day, hence some of the health effects of UVR may be insignificant if commuting only early or late in the solar day (82). Exposure is also dependent on duration of travel, shade and clothing (83).

3.2.4 Public transport and sustainability

Well thought-out public transport can shift journeys from private vehicles, reducing emissions and thus improving air quality. Encouraging and improving access to public transport can also improve equity, for example, for those without private vehicles. Costs need to be considered, as well as options for those in rural areas where public transport may be non-existent (84, 85).

Policies encouraging shifts to public transport can lead to a variety of co-benefits. While buses and trains are fossil fuel-powered, there may be unintended consequences through potential increased exposure to poor air quality in enclosed bus and railway stations. Interventions may be required to ensure public health is not adversely affected, for example by air pollution from stationary diesel trains (86) and buses. Pollution from electric trains may produce metal-rich ultrafine particles from brake linings, friction between wheel and rail, and from overhead pantographs. Measurements of air pollution levels in enclosed railway stations could be undertaken to better understand impacts of policies to increase public transport use. WHO's International Agency for Research on Cancer (IARC) reclassified diesel engine exhaust and related ambient air pollution to be carcinogenic and associated with increased mortality from lung cancer (85); diesel trains in the UK are set to be phased out by 2040 and up to 4,000 zero-emission buses are to be funded by the government (41). It should be noted that public transport use was significantly affected during the COVID-19 pandemic; in 2021 there were 68% fewer passenger journeys made on public transport in Great Britain compared to 2020 (87) and this is still below pre-pandemic levels. The 'Active Travel: Getting people back to work safely toolkit', describes some of the challenges and opportunities in promoting active travel in light of the COVID-19 pandemic and the necessity to respond to the climate emergency (88).

People's exposure to air pollution may vary by transport mode, though evidence is mixed and depends on multiple parameters (61), with bus users exposed to similar concentration levels as cyclists, though this varied by bus characteristics (for example interior air filtration and extraction), route travelled and location and frequency of stops. In comparison to active travellers, bus commuters were more exposed to coarse particles (PM_{10}, particles with aerodynamic diameter less than 10µm) and black carbon, but less exposed to ultrafine particles. In addition, traveller position may affect exposure to air pollution in buses and trains, with frequent door openings along high-traffic bus routes also resulting in high pollutant concentrations inside buses. It is important to note that concentrations of air pollutants experienced by travellers is only one aspect of many important considerations when planning transport or in communicating about public health; for example, public transport use is associated with increased physical activity (89). Factors including physical activity, personal safety and environmental equity should be considered when developing holistic transport planning and communication strategies.

A systematic review and meta-analysis compared the effectiveness of interventions with different strategies on changing population-level travel behaviour and identified which intervention functions, or mechanisms of how interventions seeking to alter behaviour (including by addressing safety or accessibility), affect transport outcomes (90). The study found interventions combining both positive (such as new cycle share programmes) and negative (such as congestion charging) strategies might be more effective at encouraging alternatives to driving at the population level (90). Functions thought to change behaviour using financial means were effective at decreasing driving, whereas those improving access, safety, and space were effective for increasing active travel outcomes (90).

3.3 Housing

Within the Sixth Carbon Budget, the CCC grouped actions that may be taken to reduce GHG emissions from buildings, and homes in particular, under 4 categories: (i) behaviour change; (ii) improved building energy efficiency; (iii) improved lighting and electrical appliance energy efficiency; and (iv) low-carbon heating.

Behaviour change at home can contribute to net zero largely through a reduction in energy use and the shifting of energy demand. For example, reduced use of lighting and electrical appliances, turning the thermostat down, zonal heating where only occupied rooms are heated, and the use of low-flow shower heads are all examples of reducing energy demand through behaviour change. Such actions may be supported using smart meters that can provide real-time data on energy use and savings. Shifting demand where possible, in the form of pre-heating homes or using energy-intensive appliances such as dishwashers and washing machines during non-peak hours can help smooth overall demand. Actions taken by occupants to reduce or shift energy demand are unlikely to have health implications, provided they are in line with advice on the safe operation of appliances and on maintaining a healthy indoor environment. For example, maintaining an indoor temperature of 18°C poses minimal health risks (91), and can potentially reduce heating demand; though 18°C is recommended, there needs to be more research on vulnerable groups and their adaptive nature to cold (92).

The UK housing stock is relatively poorly insulated in comparison to other countries in northern Europe, and improvements in its fabric thermal efficiency and airtightness can result in substantial reductions in heating demand and GHG emissions and are thus a key action for achieving net zero. Recognising this, the UK government has adopted a 'fabric first' approach that will prioritise improvements in existing homes that fall below its energy performance standard, while all new homes are expected to be built to a high level of energy efficiency (30). The insulation of walls, roofs and floors, and the installation of double or triple glazing can reduce heat loss from homes, and thus, heating demand. In turn, this offers the potential to increase wintertime indoor temperatures, especially in fuel poor homes, reducing cold-related mortality, morbidity, and the financial pressure of heating costs on occupants. High heating costs can turn people towards cheaper, but high-polluting forms of heating (for example wood burning) as reported in the media during the winter of 2022 to 2023 (93). The UK experiences a substantial burden of cold-related mortality and morbidity, and overall the evidence suggests that energy efficiency and heating interventions that improve home warmth may improve the health of some population groups, especially those with existing respiratory and other chronic diseases, with benefits for disease symptoms, improved mental well-being, reduced health service contacts, and fewer days of absence from school and work (17).

The reduction of unintended air exchange (infiltration) from improved insulation levels can also reduce ingress of outdoor-sourced pollutants, such as externally-generated $PM_{2.5}$ and NO_2 whose negative health implications are well-established (94, 95). However, improved insulation levels may also have unintended consequences for health; in the absence of adequate purpose-provided ventilation, an increase in airtightness can result in greater accumulation of indoor-sourced air pollutants, including radon, volatile organic compounds (VOCs) and internally-generated $PM_{2.5}$ (96 to 98). While the complete spectrum of health effects of indoor-sourced pollutants remains uncertain, the negative impact of indoor radon exposure is well-established; 1 in 516 deaths in the UK in 2006 were due to radon exposure (99). Reduced ventilation can also increase the transmission of air-borne diseases and the risk of mould growth, which can pose significant risks to respiratory health, the eyes, skin and immune system (although risks may depend on several other parameters) (100, 101), and strategies to address mould should consider ventilation together with energy efficiency measures. The balance of health effects associated with improved insulation levels and indoor air quality will be determined by the ensuing change in airtightness, the strength of indoor and outdoor pollutant sources, which vary both spatially and temporally, and the provision of ventilation, with heat recovery. In one of the earliest studies of its kind, the co-benefits of energy efficiency on UK homes were quantified and determined that the magnitude and direction of health effects depend on the implementation and maintenance of interventions, although they were generally beneficial for health (102). Later modelling found that fabric and ventilation retrofits, assuming ventilation requirements under the building regulations are met, would result in positive effects on mortality and morbidity of 2,241 (95% confidence intervals (CI): 2,085 to 2,397) quality-adjusted life years (QALYs) per 10,000 people over the course of 50 years (96). Scenarios where little or no additional purpose-provided ventilation measures were installed resulted in overall negative effects on health. Another study determined that improved insulation could offer the greatest health benefit amongst the various actions taken to reach net zero, yet in the absence of adequate purpose-provided ventilation, it could result in more than 200,000 life-years lost by 2050 and more than 1 million lost by 2100 (17).

The impact of home energy efficiency interventions on summertime overheating is also subject to uncertainty. Evidence suggests that loft insulation decreases indoor overheating risk in the rooms adjacent to the loft (103, 104), though the impact of other insulation measures, such as wall insulation, is less clear (105). The reduction in unintended air exchange (infiltration) from improved insulation levels discussed earlier in the context of air quality may also be a factor in overheating, hence the need to provide adequate ventilation for retrofits. Overall, modelling suggests that carefully designed and implemented overheating interventions such as external shutters, adequate ventilation, or night-time cooling, can offset risks posed by energy efficiency retrofit on indoor overheating risk (106). However, in the absence of such interventions, it is possible for energy efficiency measures to exacerbate indoor overheating (106 to 108).

There is a critical lack of empirical evidence on the effects of retrofitting on ventilation, indoor environmental quality (especially indoor air quality) and human health. To ensure that the potential benefits of improving home energy efficiency are maximised, while unintended negative health effects are minimised, there is an urgent need for monitoring indoor air quality in thousands of homes pre- and post-retrofit in a systematic manner (107). A randomised control trial would be most informative (109), or a dedicated initiative to combine existing evidence and help understand long-term health implications, and studies could also consider the use of indoor air quality control measures to adequately assess the potential climate and health benefits of improving energy efficiency (see Chapter 5). Home energy efficiency also includes low-energy lighting; connections between indoor lighting and the health effects of energy efficient LED (light-emitting diode) technology are covered in Chapter 5.

3.4 Agricultural, food system emissions and lower-GHG diets

The food system sector contributes approximately 30% of global GHG emissions, with emissions released at multiple points in the food system during production, processing, distributing and waste management (110, 111). It is estimated that by 2050, due to population growth and changes in consumer demand, food-related emissions may increase by 30% to 40% if no action is taken (110). Global food production also contributes to 80% of deforestation, 70% of water use and is a major contributor to biodiversity loss (112). To reach net zero by 2050, global food systems need to reduce their emissions by 3.3% annually, with greatest reductions needed in high-income countries (111, 113).

The food and drink sector contributed to 35% of the total UK territorial emissions (emissions that occur within UK borders) and 21% of the UK's total carbon emissions in 2019 (110, 114). Agricultural emissions mainly comprise more potent gases such as nitrous oxide (N_2O) and methane (CH_4), and only a small percentage of CO_2 (115). Across total emissions from this sector, 34% were attributable to UK agriculture, 32% were from food supply imports, and the remainder were produced through the lifecycle of foods (110).

Although total GHG emissions from the UK food system declined, between 2015 and 2019 primarily due to decarbonisation of the electricity grid (114), agricultural emissions have remained static, and the rate of reduction in emissions is not sufficient to meet 2050 net zero targets (116). The focus areas for net zero actions in the UK's agri-food system can be grouped as follows (116, 117):

- changing farming practices
- land use changes
- consumer behaviour change

The potential health impacts of net zero actions in each of these areas are discussed below.

3.4.1 Changing farming practices

Agricultural emissions result from multiple processes including how livestock are reared, use of soil fertiliser, waste and manure management and fossil-fuel powered machinery (use of fossil fuels in agriculture contributes to 8% of total UK transport-related GHG emissions (118)). Changing farming practices through innovation and technology will be a key contributor, but not sufficient alone to reduce agricultural emissions to reach 2050 net zero targets. A key challenge remains on farming practices that grow the same amount of food sustainably, whilst reducing the amount of land used for agriculture, benefitting both the environment and human health (117).

Progress is being made in the livestock sector through multiple partnerships that aim to improve management practices to reduce global emissions, particularly CH_4, from livestock by 30% (119). Livestock emissions may also be reduced by dietary change, though it has been shown this may only happen with complementary low-emission agricultural practices (111). In the UK, measures have been outlined in a plan from the National Farmers Union (NFU), including use of controlled-release fertilisers, feed additives, precision crop farming, preventing soil compaction and gene editing for livestock to increase farming efficiencies and potentially reduce overall GHG emissions by 11.5MtCO_2e annually (120). Changing to lower-GHG farming practices will likely benefit human health in ways such as reducing air pollution, reducing nutrient pollution and eutrophication, restoring biodiversity, and improving water quality (121). There may, however, be some risks to health associated with practices such as gene editing in crops and livestock through 'off-target' effects and adverse impacts on biodiversity and the environment if not carefully regulated (122 to 124). Research into the potential health implications in this area, however, is lacking.

3.4.2 Land use changes

Around 20% of current agricultural land in the UK will need to be repurposed for alternative land uses moving towards increasing carbon sequestration and forestry cover, producing bioenergy crops, and peatland restoration to reach net zero targets, thus reducing land available for livestock rearing and food crops (125). Currently 85% of land used to feed the UK population is for animal rearing, and therefore large changes in population dietary habits will contribute significantly to achieve land-use change targets (121, 126). Land use changes associated with net zero action will also likely have other population health benefits associated with them, including increasing forestry areas, access to greenspace, potential improvement in air quality, restoring biodiversity and flood risk alleviation (see section 3.5) (19).

Land-use changes to farmland associated with net zero actions may also have potential risks to health. Open habitats such as heathlands and semi-natural grassland sequester and store more carbon than modern agricultural landscapes (127), but less than in peatlands, saltmarsh and established woodlands, with peatlands considered to be the most important and largest natural carbon stores of UK natural habitats. Strategies such as 'no-mow meadows' and allowing scrub development can improve biodiversity and sequester more carbon. However, higher densities of *Ixodes ricinus* ticks were reported in scrub grassland than non-scrub grassland, which may have implications for tick-borne disease risk (128).

Vector ecology should also be considered with converting arable farmland to wetlands. Summer flooded wetlands subject to repeated wetting and drying likely support mosquitoes that cause significant nuisance biting to humans and may be a disease risk (129). However, if water is maintained and not allowed to dry out, it would become unsuitable for *Aedes* species (130). Effects of woodland expansion on vector ecology and associated health risks are discussed here in section 3.5, and suitability of vectors in UK climate in Chapter 8.

3.4.3 Consumer behaviour change

Whilst there is much research and investment across food systems to reduce GHG emissions and other environmental impacts, consumer behaviour and population dietary changes can have a much greater effect on reducing environmental impacts through 'demand-side change' (131, 132). It is likely that population dietary change will also lead to changes in land use and farming practices. Foods such as meat and dairy are generally more land- and water-intensive than plant-based foods and emit more GHG during production (132, 133). In the UK, from primary production to distribution centre, 1kg of beef creates 12kg CO_2e, compared with 1kg of beans or pulses at 1.5kg CO_2e (134); the same 1kg of beef uses around 15,000 litres of water, compared with roughly 4,000 litres for 1kg of pulses (135).

Multiple studies therefore suggest that reducing meat (particularly red meat) and dairy consumption and replacing them with plant-based foods will help reduce GHG emissions along with their associated land, water, energy use and other environmental impacts (111, 112, 132, 133). Reducing the amount of meat produced could also decrease the risk of zoonotic diseases and antimicrobial resistance by limiting the number of available animals (136), although the UK has already halved the amount of antibiotics used in livestock since 2014 (137). Dietary change could also provide benefits through freeing-up land for other processes (19), such as rewilding, which could improve biodiversity (138, 139). Simultaneously, modelling studies suggest that a reduction in meat consumption could increase nutritional benefits and improved health outcomes within the population, if replaced with fruits and vegetables (112).

Currently, the average UK adult's (aged 19 to 64) diet is characterised by overconsumption of saturated fats (23% higher than UK government recommendations), and underconsumption of fruits and vegetables (14% and 67% lower than UK government recommendations, respectively) (140).

In 2019, 48,100 deaths were attributable to excess consumption of red meat and dairy products in the UK (141). Unhealthy diets also contribute to obesity, Type 2 diabetes, cardiovascular disease, and some cancers (112, 142). Obesity-related illness costs the NHS £6.5 billion a year and is estimated to have a wider societal cost of £58 billion per year – switching to healthier diets could reduce the risks and costs of these morbidities (143). There have previously been worries with regards to policy on dietary shifts introducing inequalities, and that moving towards plant-based diets may be more costly. However, it has been demonstrated that a shift to plant-based diets can still be achieved at no extra cost to the consumer (144).

The UK national food-based dietary guidelines (the Eatwell Guide) were developed to visually depict the proportion and types of different food groups for a healthy balanced diet (145). The Eatwell Guide was primarily developed to meet UK dietary recommendations but also delivers a more sustainable pattern of consumption (146, 147). Those who demonstrate intermediate to high adherence to Eatwell Guide recommendations had 30% lower dietary GHG footprints and a 7% reduction in total mortality risk (99% CI: 3% to 10%) compared to those with very low adherence (147). In general, overall adherence levels to Eatwell Guide recommendations are currently low, demonstrating the scale of behaviour change required to meet dietary guidelines, but may also be an opportunity to improve health and reduce GHG emissions. Further emission reductions from diets beyond what would be achieved by adherence to the Eatwell Guide (up to a 60% reduction from current emissions) are also possible, but there may be limits to the acceptability of such diets to the general population (148).

Food waste is also a large contributor to GHG emissions. It is estimated to contribute to 8% to 10% of anthropogenic GHG emissions globally, with 11% of overall food waste coming from the household level (149). Much progress has been made in the UK in this area through the

Courtauld Commitment 2030 and Food Waste Action Week, although food waste is still associated with over 36 million tonnes of GHG emissions annually (150). Reducing food waste could benefit emission reductions as well as improving food security (151). Changes in dietary behaviours to reduce food waste can include reducing portion sizes, altering the way food is prepared within households, planned shopping and interventions such as food labelling (152).

Changing dietary habits will require considerable behaviour change across the population and it is likely that the level of change required to meet net zero targets will need multiple interventions (133, 152). For long-term dietary change, knowledge alone will not be sufficient, and it will require other interventions such as changing the food environments, how food is displayed on menus and increasing the prices of high-carbon food items (133). Novel plant-based foods (that is, vegan substitutes of meat, dairy, seafood and eggs that mimic the structure, taste and sensory profile of conventional animal-based products) (153) may be one example of foods to help in the transition of dietary change. Emerging evidence shows these foods can be healthier and more environmentally friendly than animal products, though nutrient content can vary significantly, and more research would be beneficial to ensure nutrient recommendations are met (153, 154).

3.5 Nature-based solutions

By 2035, the CCC's Sixth Carbon Budget scenarios to meet net zero involve planting of 440,000 hectares of mixed woodland to remove CO_2 from the atmosphere, along with growing energy crops, restoring peatlands, and improving land-based carbon sinks (19). Such measures may be considered nature-based solutions (NbS), which are "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (155). Some examples include afforestation (expanding or creating new forests), protecting existing forests and marine environments, and also green roofs and walls. NbS can support both climate mitigation and adaptation through positive impacts on ecosystems, biodiversity, and human health and well-being, with individual actions often intended as mainly a mitigation or adaptation action, with the other as a co-benefit. The Climate Assembly were highly supportive of nature-based removals of GHG, seen as 'natural' climate solutions and having significant co-benefits (19). The Environmental Improvement Plan 2023 for England highlights improving nature as an apex goal, and includes commitments to publish a Land Use Framework setting out how to balance multiple demands on our land including climate mitigation and adaptation (156).

Several key strategies for the role of nature enhancement as a contribution to net zero have been identified (127), including:

- creating new native broadleaved woodland and tree-planting, as native woodland is considered an effective carbon sink

- protecting semi-natural habitats, such as grasslands, with a decrease in grazing pressure and an increase in scrub vegetation to increase vegetation cover, thus increasing carbon stores
- protecting and restoring peatlands, through raising water levels or tables to allow re-wetting, reducing or stopping the burning of peatland, and a programme of removing planted trees on peatland
- protecting and restoring natural coastal processes, including the creation of saltmarsh habitats, which are known to sequester and store carbon (not covered here)

Using the current Greenhouse Gas Inventory methodology, the land use, land use-change and forestry sector (LULUCF) is a net carbon sink and sequestered 10.3MtCO_2e in 2018. However, the method accounts for only a small part of peatland emissions, and with updated methodology the LULUCF sector becomes a net source of around 11MtCO_2e in 2018 (19). Health effects relating to changes in the LULUCF sector are described below.

3.5.1 Forests and woodland

One of the NbS with the largest mitigation impact in a European context is protecting existing forest and afforestation. Trees sequester more carbon when they reach maturity, and new native woodlands sequester carbon faster than other semi-natural woodland (127). Sequestration rates remain high after 100 years (though fall over time), thus preserving existing forest can be a large contribution to reaching net zero. The UK has a low proportion of woodland compared to other European countries: 13% land cover in the UK compared to 43% for the EU-28 area, with over 30% in Germany which has a similar population to land area ratio as the UK (19). UK woodland cover needs to increase from the current 13% (10% of England) level to 17% to reach the 2050 net zero goal, requiring approximately 30,000 hectares (90 million to 120 million trees) to be planted annually, estimated to result in annual sequestration of 14MtCO_2e by 2050 (121). As tree-planting rates in England were only around 9,000 hectares per year from 2014 to 2017 (157), tree-planting rates will need to at least treble to meet this target (158).

Creating new woodlands could provide additional habitat for vectors such as ticks and their animal hosts including deer, and may connect previously isolated habitats, making woodlands more suitable to sustain ticks and less impacted by chance events and lack of hosts (159). Increased woodlands could facilitate deer movement, potentially moving ticks into new areas and impacting tick-borne pathogen transmission cycles. Although large-scale tree planting initiatives could alter tick densities and therefore tick-borne disease risk, passive surveillance data suggests that plantations such as the National Forest in central England have not led to increased reports of tick bites (160, 161). Planting trees to create wet woodlands, which are woods that are waterlogged at least seasonally, could provide habitat for nuisance woodland mosquitoes such as *Aedes cantans* (130). Restoration of bog (peatland) habitat from forestry reduces tick densities, and woodland removal from these habitats is likely to reduce suitability (162). The current plan is to restore approximately 280,000 hectares of peatland by 2050 to reach the required net zero contribution (156).

Urban and non-urban trees may indirectly affect health by reducing flood risk through sustainable drainage systems (SuDS) and being planted along rivers (163, 164). Around 3,000 hectares of new woodlands will be planted along England's rivers to improve water quality, biodiversity and provide flood defence (156). New wetlands as part of ecological mitigation and SuDS are a key part of increasing urban blue space; there is currently little evidence that they contribute to the presence of nuisance or vector mosquitoes (165, 166).

New forest habitats may present increased opportunities for time spent in nature, and evidence supports the benefits to health through increased physical activity opportunities as well as benefits to mental health (see section 3.5.2). Carbon storage and sequestration, particularly for urban trees, are highly dependent on biome (167), and will depend on the exposure, sensitivity and adaptive capacity of the ecosystem (168).

3.5.2 Urban greenspace

Urban greenspace includes parks, gardens, green roofs and walls, urban woodland and recreational areas. Though urban greenspaces sequester and store carbon, the mass of these are generally small relative to large-scale tree-planting. Urban parks often have large grassland areas instead of trees, and are estimated to sequester 0.2kg CO_2 per m^2 per year, and mowing and other landscape management activities often render these net GHG sources (169). Green walls and roofs are estimated to sequester 0.68 kg CO_2 per m^2 per year, though they may also help mitigate climate change by insulating the building, thus reducing energy use for heating and cooling (15% saving for living wall; 8% green walls; 6.7% green roofs) (169). The exception to the low mitigation impact is urban woodlands; whilst they are estimated to sequestrate around 1.4MtCO_2 per year (170), this is still only 10% of what is needed by 2050. Even though urban greenspace have a limited carbon storage potential, as most people live in urban areas (82% in the UK) and interventions like street trees can bring a wide range of ecosystem services (171), the potential health impacts of urban greening measures should be considered.

There is strong evidence that spending time in and around greenspace (particularly urban greenspace) has a positive impact on health and well-being (172). Research has linked greener neighbourhoods and greater greenspace exposure with better self-assessed general and mental health; reduced all-cause and cardiovascular mortality; reduced stress; reduced incidence of low-birth weight; maintaining a healthier weight; and mixed evidence for reaching the national physical activity recommendation (173). Besides impacts associated with increased exposure to light and UV radiation (discussed in section 3.2.3), the report concluded that greenspaces may link to positive health outcomes through 4 main pathways: promoting healthy behaviours; improving social contacts; supporting development of skills and capabilities; and mediating potential harm (173). Urban greenspace has been shown to provide a local cooling effect, with urban trees providing shading, improving thermal comfort and reducing building energy use in some cases (169), reducing the impact of hotter summer temperatures. A recent study of nearly 100 European cities found increasing tree coverage to 30% would cool cities by a mean of 0.4°C, reducing premature deaths attributable to the effects of urban heat islands by 40%, corresponding to 1.8% of all summer deaths (174).

Research on ticks in urban greenspace in southern England shows a strong link between the presence of woodland (or high woodland connectivity) and tick presence (175, 176). Although urban grassland has lower tick densities than urban woodland patches, densities are higher in areas with higher vegetation height (175).

Increasing the density of trees in urban spaces could potentially lead to enhanced allergenic pollen loads if the tree species are not chosen carefully (177). Birch (*Betula)* is the main cause of tree pollen allergy in the UK, although other species contribute as well (see Chapter 6). Urban trees could have a negative impact on health by producing VOCs, which can contribute to forming ground-level O_3 if there are substantial levels of NO_x present. This source is however very minor compared to anthropogenic VOCs (178). By avoiding highly allergenic and high VOC emission trees, these potential negative health impacts from increased urban greenspace can be avoided (177, 178).

In the UK, the greatest benefits from greenspace are generally seen for those living in the most deprived areas (173). Those living in more socio-economically deprived areas often have poorer access to greenspace, hence adjusting for income-deprivation in some studies can make the connection between greenspace and health non-significant (179 to 181). Despite the rapidly growing body of evidence, there are still some clear limitations, particularly the inconsistent definition of 'greenspace' and 'exposure' (173), rendering it difficult to compare studies. A further complication is that the perception of the quality or access to greenspace can be more important that an objective measure (182) and there is low agreement between perceived and objective access to greenspace (183). There is limited understanding of what constitutes 'quality greenspace' for health, and further studies are needed to establish the characteristics of greenspace that are perceived as higher quality, and connected with better health (184 to 186). However, improving the greenspace can lead to 'green gentrification' and improvements in health for only the more affluent population due to displacement or reduced sense of belonging for the more marginalised residents (187).

Green walls and roofs are another form of urban greenspace, and can contribute to several positive health effects by improving cooling of both indoor and outdoor temperatures (indoor air by 1.7°C to 4.4°C; outdoor air by 0.5°C to 3°C), and improve air quality, with a UK review study finding ambient PM_{10} reduced by 22% to 50% at street level for green walls, and by 7% to 14% above green roofs (169). Street trees can also have a positive impact on air pollution by providing a large surface area for potential deposition and acting as a barrier to the pollution source (such as a road), thereby creating areas in cities with reduced air pollution, but may limit dispersion in street canyons (street corridors) and increase pedestrian level pollution in some cases (171, 178).

3.5.3 Nature-based solutions and biodiversity

When considering the linkage between net zero and biodiversity, greenspace is the main overlapping area. Human health and well-being depend on the ecosystem we live in, providing essential services such as food, fresh water, pest and disease regulation and clean air.

Biodiversity underpins the functioning of the ecosystem and is therefore a key determinant of human health. In addition, new medical treatments and medicines are being discovered by better understanding of biodiversity, with losses risking extinction of species before we have discovered their health potential (172). At the latest UN Convention on Biological diversity (COP15, December 2022), the linw "biodiversity is fundamental to human well-being and a healthy planet" was included in the Kunming-Montreal Global Biodiversity Framework (188). Tree planting schemes can be both positive and negative for biodiversity, depending on location and mix of trees planted. For instance, bioenergy crops are often monoculture and therefore detrimental to plant and animal biodiversity (31). A recent study in China demonstrated a seasonally-varying positive correlation between tree species diversity in urban greenspaces and the cooling effect (189). Similar to greenspace studies, perceived amount of biodiversity is linked to psychological well-being, but not between actual species-richness and well-being (190).

Agro-forestry, when trees and hedgerows are planted next to agriculture land, may increase the carbon sink and biodiversity (191), and there is some indication that plant biodiversity can increase carbon storage in soil in both forests and grassland (192). Although increased biodiversity is likely to bring a wide range of health impacts, the most researched in the UK is the impact on ticks, which can be a health risk through transmission of vector-borne diseases. Hedgerows as part of agri-environment schemes can provide habitat for small mammals and thus contribute to tick habitats (193). A study in southern England found highly biodiverse deciduous woodlands were most suitable for supporting higher densities of ticks infected with the bacteria that causes Lyme disease (*Borrelia* spp.) compared with lower biodiverse non-native and monoculture woodlands (128). However, higher tree-species diversity has also been associated with lower tick abundance in Czechia (194). Therefore, more research on ecological drivers of transmission dynamics is required (see Chapter 8 for current and future UK climate suitability for vectors and vector-borne diseases).

Biodiversity and net zero can also overlap in renewable energy production. Wind turbines, and particularly offshore wind turbines, can increase biodiversity if correctly designed by providing a sheltered area for marine life and provide surfaces to grow on (191). However, any impact on fisheries, and thereby food supply, is not yet established (195). Hydro-electrical dams can negatively impact on fish and marine biodiversity by blocking migration paths, destroying habitats, and killing migratory fish such as eel and salmon (196) which can have a significant impact on the livelihoods of Scottish salmon fishermen (197). This however has a very small impact on food security in the UK.

3.6 Carbon capture and storage

Carbon capture and storage (CCS) will be necessary for meeting net zero commitments to offset emissions that can't be eliminated. All net zero trajectories for electricity generation considered by the CCC include components of generation provided by natural gas or biofuel combustion, coupled with CCS technologies from 2025 onwards.

Infrastructure associated with some mitigation measures may have short-term increases in air pollution associated with construction (section 3.1.2 and Chapter 4). CCS technologies may also increase pollution through the energy required for CO_2 capture, though how individual pollutants are affected depends on the fuel source and CCS approach (7).

Bioenergy with carbon capture and storage (BECCS) involves increasing energy crops for biofuel, including crop cultivation of *miscanthus* or short rotation coppice that requires only modest fertiliser. While detrimental impacts to health during the growing phase are expected to be minimal (though there may be land-use and biodiversity concerns – see section 3.5.3), there could be considerable air quality impacts when combusted without effective cleaning of flue gases (7).

Solvents are used to absorb CO_2 from gases emitted by industry and are currently the most well-tested and mature carbon capture technology available, so are likely to play a leading role for CCS at scale. At present, the use of organic amines has been most common, and there is some evidence of possible fugitive emissions from processes, potentially leading to atmospheric release of high-toxicity nitrosamines (carcinogenic) in exhaust gases. Though for overall VOC emissions masses, releases are insignificant, from a toxicity perspective they may be of concern (198). Thus, when scaling up this activity, less harmful solvents are currently the focus of research and development, and would need toxicological evaluation as part of the emission permitting process (7), and it is important to assess the risks of these technologies to see if processes that may be less polluting can be used.

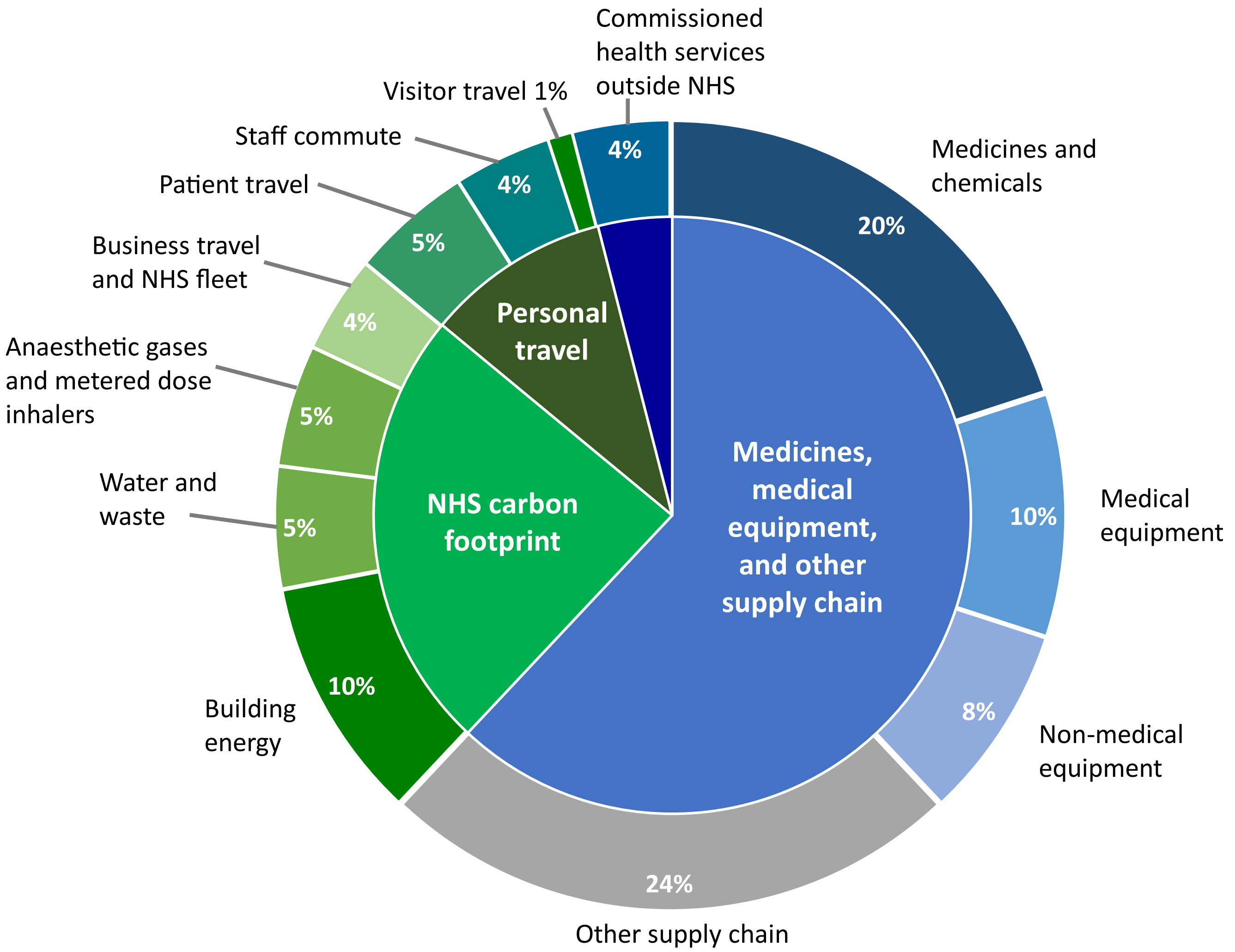
3.7 Net zero health care system

Global health care systems are significant contributors of GHG emissions, accounting for around 4% to 5% of global net CO_2 (199) and the NHS accounts for roughly 4% of England's emissions (14). As detailed in this report, both GHG emission itself and the resulting climate change have an impact on health, resulting in greater need for health care and thereby potentially even higher emissions from this sector. By reducing the sector's contribution to climate change, it can reduce the additional service required, and thereby reduce GHG emissions connected with delivering this service. Health co-benefits associated with mitigation actions outlined in this chapter will potentially amplify this.

All 4 UK national health care organisations have pledged to either become net zero or contribute their part in reaching net zero targets. Both NHS Scotland and NHS England (NHSE) aim to become net zero by 2040 for the emissions they can control directly (Scope 1 (onsite emissions), 2 (indirect emissions for example from electricity supplied to the site) and partly 3 (indirect such as water and metered dose inhalers), and by 2045 for the emissions they have influence over (supply chain, staff commuting and patient travel). An independent review by the Lancet Countdown confirmed that methods used to calculate the NHSE Carbon Footprint and NHSE Carbon Footprint Plus remain the most comprehensive and sophisticated of any health system to-date (14). As with other sectors, a significant part of reducing emissions will come from decarbonising the UK energy grid and improving energy efficiency of buildings (section

3.1), since building energy use is responsible for 10% of NHSE emissions (Figure 2). Where possible, this will also entail installing solar power, such as already achieved by Hull University Teaching Hospitals NHS Trust. From a global health care perspective, in countries with less reliable power grids, installing solar power locally increases quality of care by providing a more stable power supply for refrigeration (improving cold-chain storage of medicines, vaccines, and anti-venom), and lighting and medical equipment (200). However, the main contributor to NHS emissions are those associated with medicines, medical equipment and the supply chain, accounting for 64% of the NHSE Carbon Footprint Plus (Figure 2).

Figure 2. Sources of carbon emissions by proportion of NHSE Carbon Footprint Plus (14)



Text version of Figure 2.

Medicines, medical equipment and other supply chain:

- medicines and chemicals 20%
- medical equipment 10%
- non-medical equipment 8%
- other supply chain 24%

NHS carbon footprint:

- building energy 10%
- water and waste 5%
- anaesthetic gases and metered dose inhalers 5%
- business travel and NHS fleet 4%

Personal travel:

- patient travel 5%
- staff commute 4%
- visitor travel 1%

Commissioned services outside the NHS: 4%

End of text version of Figure 2.

Around 3.5% of all road travel in England is related to the NHSE (201) and make up 14% of NHS emissions (Figure 2). Reducing these emissions will require a combination of reducing unnecessary journeys, enabling more active travel by patients and staff and transition to zero-emission vehicles. Many NHS vehicles can be switched to electric without impacting delivery of care, however ambulances which must be operational at all times are more challenging to convert with currently available zero-emission technology. COVID-19 rapidly accelerated the implementation of virtual wards and video consultations, which are generally associated with a much lower footprint since travel is not required (202). Digital care can also provide better access to patients with limited mobility or living in remote areas, but the full health, health equity and sustainability implications of the shift still needs to be evaluated (14).

Around 6% of total NHSE emissions relate to food and catering. National Standards for Healthcare Food and Drink provides guidance for how to ensure the quality and sustainability of the food served to patients, visitors and staff and is part of the NHSE Standard Contract (203). Reducing emissions requires both cutting food waste and switching to a healthy, lower-GHG diet, while still serving food that patients can and want to eat to aid their recovery process. Together with the companies Mitie and Apetito, St George’s Hospital in Tooting is one of the first trusts in the country to decarbonise their patient menu by reducing red meat options and prioritising lower-carbon ingredients such as poultry, fish and vegan options (204).

The supply chain, on-site and point-of-use emission associated with medicines is the single largest contributor, accounting for around 25% of total NHSE emissions. A major source are anaesthetic gases and inhalers due to their generalised use and the high global warming potential of the gases used (14). To reduce emissions associated with medication, a combination of reducing the amount of medication prescribed, switching from high- to low-carbon alternatives and improvements in production and waste process is required. Low-carbon alternatives to anaesthetic gases exist and are clinically appropriate in many cases, and better management of the waste of N_2O could have a large impact on emissions without any impact on healthcare delivery (14). The UK has a significantly higher proportion of high-carbon metered-dose inhalers (MDI) compared to other European countries (70% versus 10% in Sweden) (205), hence switching to lower carbon options of dry powder inhalers in eligible patients should in many cases be possible without any negative impacts on patient health. A key barrier is often lack of awareness in both the public and clinicians of the emissions contribution of MDIs (206). The National Institute for Health and Care Excellence (NICE) Asthma Patient Decision aid therefore provides information to support a safe shift to low-carbon inhalers (207).

Reducing the amount of medication prescribed and switching to new forms of treatments is a key contributor to reducing healthcare system emissions. Green health prescribing aims to use the established link between spending time in greenspace and health (see section 3.5) to reduce the need for traditional health care by tackling physical inactivity, mental health issues and health inequalities. In Scotland, the Our Natural Health Service programme is demonstrating how this can work in practice, with 4 pilot NHS Greenspace for Health partnerships showcasing how to work with hospital staff and local organisations to encourage more people to use NHS greenspace, and 4 pilot Green Health Partnerships demonstrating how cross-sectoral working can increase physical activity and improve mental health through connecting with nature (208). In their 3-year evaluation report, 63 referral pathways were reported and spanned client groups such as cancer care, mental health and pain management (209). NHSE are also supporting the use of greenspace for health by planting trees and creating quality greenspace around NHS sites to improve air quality, mental health of staff and patients and store carbon (14). Another initiative to reduce the amount of prescribed medication, is the concept of 'realistic medicine', which aims to stop over-prescribing care. The primary goal is to improve patient care by reducing the risk and side-effects associated with medication and medical procedures but will also reduce the emissions from those services helping to reach net zero (206).

3.8 Economics of health and net zero

The significant changes in the economy expected by moving to net zero makes traditional cost-benefit analysis difficult, as technological change will affect the costs of actions and, according to the CCC, "the costs and benefits of deep decarbonisation are unknowable with any precision" (210). However, the economic case for net zero is certainly strengthened by the near-term gains from ancillary health benefits associated with carbon emission reduction. A study commissioned by the CCC in 2013 suggested that the value of the health benefits of moving to a low-carbon scenario amounted to 0.1% to 0.6% of gross domestic product (GDP), or half of the estimated resource cost of meeting the fifth carbon budget in 2030 (210).

The main examples of large benefits were (210):

- 5% shift in travel mode from cars to alternatives led to a benefit equivalent to 0.5% of GDP

- the health impacts of reducing meat consumption by 50% were estimated at 0.5% of GDP
- air quality and noise reduction benefits of a low carbon scenario would amount to 0.1% of GDP

An evaluation of the relative scale of co-benefits to the negative impacts on health and the environment of moves towards meeting carbon targets showed a net present value benefit from 2008 to 2030 in terms of these wider benefits of carbon reduction of £85 billion, with reduced congestion, reduced pollution, less noise, fewer road accidents and the health benefits of active travel being important elements (211).

If individual sectoral policies and strategies in the move to net zero are examined, it is possible to derive some lessons that may be useful. Table 1 summarises selected economic analyses of net zero-related projects and policies.

Table 1. Selected studies quantifying economic value of health co-benefits in appraisal of net zero measures

Study	Summary	Key findings
(212)	Assesses impact of 4 mitigation strategies (cleaner vehicles, active travel, food and agriculture, and energy efficiency) using a computable general equilibrium model.	For some strategies the health and other benefits (such as energy cost reductions) may significantly reduce the overall societal costs of actions.
(213)	Cost-benefit analysis of net zero retrofit for traditional tenement building in Glasgow.	Benefits for air quality and health improvements through better homes estimated and included in analysis. Overall, retrofitting to a reasonable standard is shown to be worthwhile.
(214)	Summarises evidence on cost-benefit analysis of sustainable travel interventions.	Shows that most interventions analysed have high to very high benefit-cost ratios.
(215)	Economic analysis of net zero land use scenarios.	Benefit-cost ratio of 3.3, with benefits being largely carbon reductions and recreation. Health benefits estimated for woodlands estimated at between £5,040 to £12,510 per hectare depending on type.
(27)	Uses modelling approach to estimate the health co-benefits and mitigation costs associated with Paris agreement.	Globally, the ratio of health benefits to mitigation cost ranges from 1.4 to 2.5. For Europe, 7% to 84% of mitigation costs are covered by health co-benefits.

4. Discussion

4.1 Policy review

Several policies relating to net zero actions have been highlighted throughout this chapter. Net zero policies fall under multiple branches of the government and cover many different economic sectors, with individual departments often having their own decarbonisation plans. In October 2021, the government released the 'Net Zero Strategy: Build Back Greener', outlining key policies and proposals for various economic sectors to meet the UK's commitments under the Climate Change Act 2008. Of note, the Health and Care Act (2022) embeds the NHS England net zero goal into legislation.

In January 2023, an independent review of net zero strategies was published by the government, considering a changing economic landscape (39). This analysis demonstrated that the decarbonisation pathway outlined in the Net Zero Strategy is still the most beneficial pathway to follow; however, areas will need to be accelerated to meet targets. The report also highlights that while wider benefits to society (including health) are likely to be great, much analysis does not quantify some critical factors which are difficult to model effectively or depend on how net zero is delivered (rather than whether it happens). As highlighted throughout section 3, how implementation of net zero occurs can be crucial for whether health impacts are positive or negative overall.

For many net zero actions, behaviour change will be required, and information alone will not be enough to fuel this. Policy interventions will play a critical part in driving this, particularly in enabling access to the right technologies and information to make informed choices and reducing inequalities in these (152). The CCC were commissioned by the Scottish Government to provide advice on the role of adaptation in a 'just transition' (216). A 'just transition' involves designing policies in a way that ensures the benefits of climate change action are shared widely, while the costs do not unfairly burden those least able to pay, or whose livelihoods are directly or indirectly at risk as the economy shifts and changes (217). The briefing highlights that for many climate impacts, it is the most vulnerable in society that will be most negatively affected and have the least ability to adapt, and that actions to address risks may have unequal impacts. It also highlights that effective and fair transition requires distributional effects to be considered throughout the policy cycle, and it is necessary to consider fairness and inequalities at implementation and evaluation stages (for example through effective regular engagement with stakeholders) to ensure a just transition (216).

The role of the health community in promoting climate action and policy is important; nurses and doctors remain among the most trusted professions when the public are asked if they would be trusted to tell the truth or not (218). At COP26, health professionals delivered a 'Healthy Climate Prescription' in Glasgow, UK, an open letter signed by more than 600 organisations representing over 46 million health workers, together with over 3,400 individuals from

102 different countries, calling for real action to address the climate crisis, and to make human health and equity central to all climate change mitigation and adaptation actions (219). The letter was delivered alongside the WHO special COP26 report, which provides 10 recommendations (developed through extensive consultations with health professionals, organizations and stakeholders globally) for governments on how to maximize the health benefits of tackling climate change in a variety of sectors, such as energy, transport, finance and food systems, to avoid the worst health impacts of the climate crisis.

4.2 Adaptation considerations

Adaptation and net zero may be viewed as speaking to different areas (adaptation versus mitigation). As warming of 1.1°C has already occurred at the global mean scale, with 1.5°C over land (220), some effects of climate change will be unavoidable, and adaptation needs to be considered. The level of climate change that we will need to adapt to is dependent on how successful mitigation policies are. For protecting health in the face of a changing climate, adaptation needs to be considered alongside mitigation, and should not be viewed as one or the other – it has been perceived that moving to adaptation may is seen a take emphasis away from mitigation, but this should not be the case, and both are important for protecting health. Therefore, it is important to identify and prioritise net zero actions that have adaptation benefits to maximise health co-benefits of actions. The importance of adaptation is being recognised and now forms part of some countries' nationally determined contributions (NDC) commitments (22, 23). Integration of health considerations into adaptation and mitigation policies and actions can help ensure benefits to the public are maximised, and any trade-offs or potential harms to health are mitigated; improving the scientific evidence base for health and climate adaptation and mitigation can help strengthen policies, identify synergies and avoid maladaptation. Where adaptation and mitigation measures have already been implemented, monitoring and evaluation (M&E) particularly from the health perspective is critical, though improvements in M&E are needed, including sharing data to inform improvement in interventions to maximise human health benefits.

5. Conclusions

5.1 Research priorities

Integrating health into climate policies and actions can help ensure benefits are maximised, and any trade-offs or potential harms to health are identified and mitigated. Scientific research that seeks to identify, understand, and where possible quantify these impacts is therefore important. Expansion of integrated modelling and quantitative studies of climate actions and outcomes for health and GHG emissions would help achieve this, as well as examining case studies relating to implemented intervention measures.

A major limitation in understanding health effects of mitigation policies is that data on the intervention, uptake, and health impacts are often not collected, or not widely available. Guidance to support evaluation of planetary health approaches including GHG mitigation would be beneficial (221). Research collaborations between policy-makers and researchers can ensure that when interventions are implemented, data collection and analysis is ready.

A One Health approach provides the best opportunity to assess risk and minimise impacts related to NbS, whilst enhancing the contribution of natural landscapes to achieve net zero – greening guidelines should consider health in an integrated manner. A Planetary Health approach considers other planetary boundaries, putting health and sustainability at the heart of economic policy (222).

Research into new technologies and processes (such as those related to built environment practices, new energy generation technology, farming and crop and livestock gene editing, CCS technology, flood management, and transport modal shifts and electric vehicles, among others) will help understand impacts to health. Strengthening evidence around health benefits of mitigation measures can support the international COP process by identifying co-benefits of net zero policies to support NDC commitments.

Understanding of how impacts of net zero policies are distributed across the population is not currently well known, and research to understand how actions may be targeted to help reduce inequalities would be beneficial, as well as ensuring that policies do not inadvertently lead to worsening inequality. Behaviour change will be a significant factor in meeting net zero targets – research to understand and support effective, accessible, and equitable choices for achieving net zero is critical.

5.2 Implications for public health practice

Net zero health systems should seek to also strengthen resilience through adaptation where possible and reduce the environmental impact of healthcare by for example opting for low-carbon treatments and technologies and use digital appointments to reduce staff and patient travel, where appropriate. The ‘NHS Net Zero Building Standard’ (applies in England) provides technical guidance to support the development of sustainable, resilient, and energy efficient buildings that meet the needs of patients now and in the future (223).

The health community can raise awareness of the significant health threats from climate change, and offer solutions informed by evidence to avoid the worst impacts (224) and highlight the health opportunities of climate actions. As health professionals are some of the most trusted members of society, they may use every opportunity to talk to patients and their families about ways they can improve their health which also have a positive impact on the environment, such as active travel and changes in diet, using the Make Every Contact Count (MECC) approach, as highlighted in the ‘Climate and health: applying All Our Health’ guidelines 2022 (224).

COP26 health programme commitments should be worked towards, including building sustainable, low carbon and resilient health systems, driving stronger domestic action to improve the resilience and sustainability of health and social care systems, raising the voice of health professionals as advocates for stronger ambition on climate change, and promoting stronger action-oriented adaptation and health research (for example through the Adaptation Research Alliance). There is opportunity for health professionals to communicate on health and climate to support the first Global Stocktake activities leading up to COP28 in 2023, with the stocktake being a major delivery item for this COP and every 5 years following.

Acronyms and abbreviations

Abbreviation	Meaning
CCC	Climate Change Committee
CCS	carbon capture and storage
CH_4	methane
CO_2	carbon dioxide
CO_{2e}	carbon dioxide equivalent
COP	Conference of the Parties
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gases
HECC	Health Effects of Climate Change in the UK report
LEZ	low emission zones
LULUCF	land use, land use change and forestry sector
M&E	monitoring and evaluation
MDI	metered dose inhalers
$MtCO_2e$	million tonnes of CO_2 equivalent
NbS	nature-based solutions
NDC	nationally determined contributions
NHSE	National Health Service England
NO	nitric oxide
NO_x	nitrogen oxides
N_2O	nitrous oxide
NO_2	nitrogen dioxide
O_3	ozone
PM	particulate matter
SuDS	sustainable drainage systems
TWh	terrawatt hour
ULEZ	ultra-low emission zones
UN	United Nations
UVR	ultraviolet radiation
VOC	volatile organic compounds

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