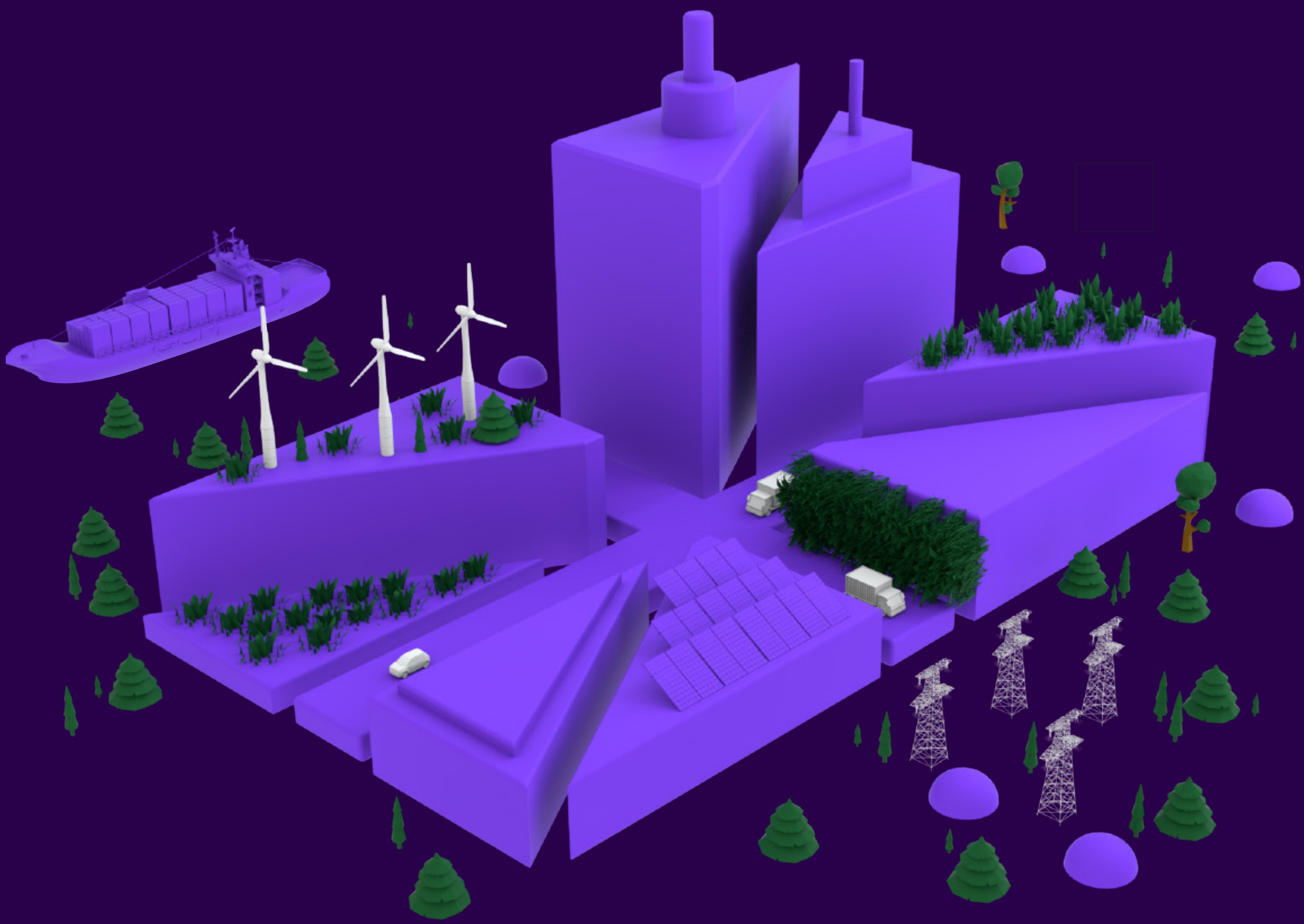
June 2021

Independent Assessment of UK Climate Risk

Advice to Government
For the UK's third Climate Change Risk Assessment (CCRA3)



Climate Change Committee

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Contents

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis and drafting for this report: Kathryn Brown, Brendan Freeman, Gemma Holmes, Diana Jelenova, Miriam Kennedy, Cara Labuschagne, Richard Millar, Simon Rayner, Andrew Russell, Chris Stark, David Style, and Mike Thompson.

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There have been hundreds of contributors to the Assessment from over 130 organisations. While they are too numerous to all name as individuals here, a full list of organisations is available on the UK Climate Risk website: www.ukclimaterisk.org

Foreword

The highest temperature recorded in Britain was in July 2019, 38.7°C at the Botanic Gardens in Cambridge. The World Meteorological Organisation (WMO) and the UK's Met Office have announced that there is now a 40% chance of the average annual global temperature reaching 1.5°C above pre-industrial levels in at least one of the next 5 years. Climate change is here, now.

Launching the announcement, the WMO General Secretary said: "increasing temperatures mean more melting ice, higher sea levels, more heatwaves and other extreme weather and greater impacts on food security, health, the environment and sustainable development…It underlines the need for climate adaptation."

There is a strong focus, globally and in the UK, as we approach COP26, on emissions reduction and achieving Net Zero. With good reason, reducing emissions is critical to reducing our climate change impacts, and is something we must do fast if we are to stay close to the Paris commitment of well below 2°C with an ambition to limit warming to 1.5°C.

But Net Zero alone is not enough. Reducing climate impacts requires both emissions reduction and adaptation. The UK will face significant further changes in climate to 2050 and beyond, even if the world is on a Paris-aligned emissions trajectory. By 2050 the heatwave summer of 2018 will be a typical summer, summer rainfall could fall by as much as 24% and winter rainfall increase by as much as 16%, changes that will impact our well-being, the natural environment and the economy.

The UK has a strong framework for emissions reduction and planning for climate risks set out in the Climate Change Act 2008. But adaptation remains the Cinderella of climate change, still sitting in rags by the stove: under-resourced, underfunded and often ignored. This Third UK Climate Change Risk Assessment (CCRA3) concludes that progress with adaptation policy and implementation is not keeping up with the rate of increase in climate risk and that the risks to all aspects of life in the UK have increased over the last 5 years.

Without action on adaptation we will struggle to deliver key Government and societal goals, including Net Zero itself. We cannot rely on nature to sequester carbon unless we ensure that our peat, our trees and our wetlands are healthy, not only today but under the climatic conditions we will experience in the future. Our advice to Government in this report sets out the risks the UK faces, highlights eight priority areas for urgent attention and identifies ten principles for good adaptation policy.

COVID-19 has been a tragedy, and it has shown us the importance of preparing for known risks. CCRA3 is an assessment of the known risks of climate change, and it is time for the UK to respond.

Baroness Brown
Chair of the Adaptation Committee, Climate Change Committee

The Committee

Baroness Brown of Cambridge DBE FRS
Chair, Adaptation Committee

Baroness Brown of Cambridge DBE FREng FRS (Julia King) is an engineer, with a career spanning senior engineering and leadership roles in industry and academia. She currently serves as Chair of the CCC's Adaptation Committee; non-executive director of the Offshore Renewable Energy Catapult; and Chair of the Carbon Trust.

Professor Michael Davies

Michael Davies is Professor of Building Physics and Environment at the UCL Institute for Environmental Design and Engineering (IEDE). At UCL his research interests relate to the complex relationship between the built environment and human wellbeing. He is also Director of the Complex Built Environment Systems Group at UCL and a member of the Scientific Advisory Committee of 'Healthy Polis'.

Professor Richard Dawson

Richard Dawson is Professor of Earth Systems Engineering and Head of Water in the School of Engineering at Newcastle University. Over the last two decades his research has focused on the analysis and management of climatic risks to civil engineering systems, including the development of systems modelling of risks to cities, catchments and infrastructure networks

Ece Özdemiroğlu

Ece Özdemiroğlu is an environmental economist and the founding director of eftec (Economics For the Environment Consultancy). Her work uses economic value evidence for natural capital and applies this evidence in accounting and appraisal. Ece is also the convenor of the British Standards Institution's Assessing and Valuing Natural Capital Committee who wrote the BSI8632 on Natural Capital Accounting for Organisations. She is Associate Editor of the Journal for Environmental Economics and Policy, and a Fellow of the RSA.

Rosalyn Schofield LLB

Rosalyn Schofield is a solicitor. She was Director of Company Secretariat at Associated British Foods plc, where she had global responsibility for the environmental sustainability and impact of the business. Rosalyn is also a Council Member of the University of Hull and Chair of the Audit and Risk Committee there as well as at the CCC. She has previously worked as Legal Director at JD Wetherspoon plc and was a commercial property lawyer in private practice.

Professor Piers Forster

Piers sits on the CCC's Mitigation Committee but has worked across both committees to help prepare this report. Piers is Director of the Priestley International Centre for Climate and Professor of Physical Climate Change at the University of Leeds. He has played a significant role authoring Intergovernmental Panel on Climate Change (IPCC) reports, and is a coordinating lead author role for the IPCC's sixth assessment report. Professor Forster established the forest protection and research charity, the United Bank of Carbon, and has a number of roles advising industry, including membership of the Rolls Royce Environment Advisory Board.

Professor Kate Jones
Expert Adviser to the Adaptation Committee

Kate is Professor of Ecology and Biodiversity at University College London. Her work focuses on crossing disciplinary boundaries to address critical global challenges, especially at the interface of ecological and human health. Prof Jones has made key advances in monitoring the status and trends in biodiversity and particularly in modelling and forecasting zoonotic disease outbreaks in humans (Ebola, SARS), breaking down traditional barriers between ecology, climate change and public health to inform global policy.

Dedication to Georgina Mace

This report is dedicated to the memory of Professor Dame Georgina Mace FRS, who led the Climate Change Committee's work on assessing the impacts of climate change on nature and responses to adaptation from January 2018 until her death in September 2019. We deeply miss our friend Georgina's intellectual fearlessness, leadership, integrity, humour and generosity of spirit.

During her time on the Committee, Georgina steered the analysis on the natural environment for major progress reports on adapting to climate change in England and Scotland. She also oversaw the work on a ground-breaking report on land use in 2018 and helped the Committee improve measurements of changes in the natural environment linked to climate change. She was a pivotal member of the team preparing this third landmark assessment of UK climate risk, reviewing the CCRA research projects, drafts of the Technical Report and this report.

Throughout her distinguished career Georgina led the way in assessing the global state of biodiversity, on how human actions have driven biodiversity loss, and on how society might change to deliver a sustainable future for both people and nature. She championed the idea that development and prosperity absolutely depended on protecting biodiversity, and not on accepting its destruction as necessary for economic growth. Georgina's research united biodiversity, economics and social justice to deliver evidence-based change, and her work underpins environmental laws and policies worldwide.

It is hard to think of another individual having such an impact on UK environmental policies. Her work on the UK National Ecosystem Assessment in 2011 established a 'natural capital' framework for decision-making, which viewed nature as an asset. This work started a snowball effect on UK policy, leading to the acknowledgement that addressing the decline in nature was first and foremost an economic problem with consequences for health and wellbeing. The world's first Natural Capital Committee (NCC) was established in 2012 with Georgina as a founding member, answering directly to the heart of UK government. One of the NCC's recommendation, an innovative 25-Year Environment Plan, was published by Defra in 2018. The same principles underpin the Agriculture Act, and the Environment Bill currently passing through UK Parliament.

Although one of the most distinguished and honoured scientists, Georgina was also one of the most supportive and generous. We will strive to not only deliver her legacy of a roadmap to a sustainable future for both people and nature, but also her legacy of immense kindness and leadership.

Executive summary

Climate change has arrived. The world is now experiencing the dangerous impacts of a rapidly heating climate. And further warming is inevitable, even on the most ambitious pathways for the reduction of global greenhouse gas emissions.

Only by preparing for the coming changes can the UK protect its people, its economy and its natural environment.

This is the third independent assessment of the UK's climate risks under the Climate Change Act, coordinated by the Climate Change Committee. Our advice draws on extensive new evidence gathered for the accompanying Climate Change Risk Assessment (CCRA3) Technical Report. Sixty-one risks and opportunities have been identified, fundamental to every aspect of life in the UK: our natural environment, our health, our homes, the infrastructure on which we rely, the economy.

Alarmingly, this new evidence shows that the gap between the level of risk we face and the level of adaptation underway has widened. Adaptation action has failed to keep pace with the worsening reality of climate risk.

The UK has the capacity and the resources to respond effectively to these risks, yet it has not done so. Acting now will be cheaper than waiting to deal with the consequences. Government must lead that action.

In this advice we identify eight risk areas that require the most urgent attention in the next two years. They have been selected on the basis of the urgency of additional action, the gap in UK adaptation planning, the opportunity to integrate adaptation into forthcoming policy commitments and the need to avoid locking in poor planning, especially as we recover from the COVID-19 pandemic.

We also report on the full set of 61 risks and opportunities. These must be considered in the next set of National Adaptation Plans, due from 2023.

We recommend ten principles for good adaptation planning that should form the basis for the next round of national adaptation plans. These are intended to bring adaptation into mainstream consideration by government* and business.

The UK Government and the administrations of Wales, Northern Ireland and Scotland must now set out a clear, measurable vision for a climate-prepared country, bringing forward policies to deliver it. This assessment provides them with the tools to do so, in a way that is compatible with the wider policies for Net Zero and other major government objectives. The benefits of coordinated action in this way are clear. It is time for a more effective response to climate change.

This executive summary steps through the challenge in four sections:

1. The UK's changing climate

2. Priority risks for urgent further action

3. Principles for effective risk assessment and adaptation planning

4. The benefits of adaptation action

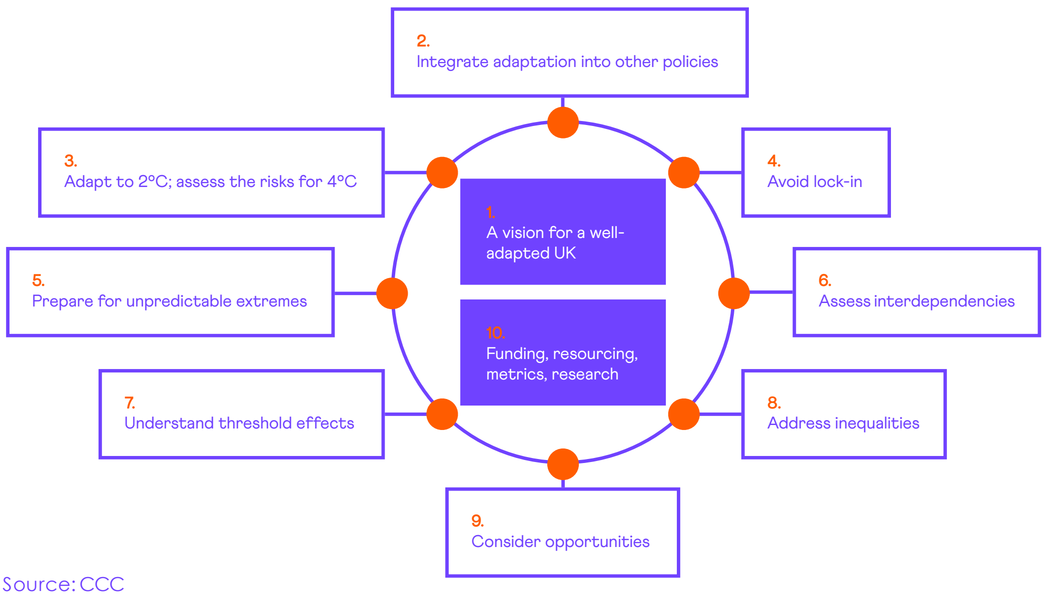
* Throughout this report, references to 'government' refers to both the UK Government and the devolved administrations.

Figure 1 Highest priorities for further adaptation in the next two years

Source: CCC

Notes: Figure shows the changing magnitude over time of the risk areas that require the most urgent action in the next two years. Change in magnitude is shown up to 2100 for the highest scenario assessed in the Technical Report for the relevant risks for that theme. Details are set out in an accompanying Annex to this report.

Figure 2 Ten principles for good adaptation



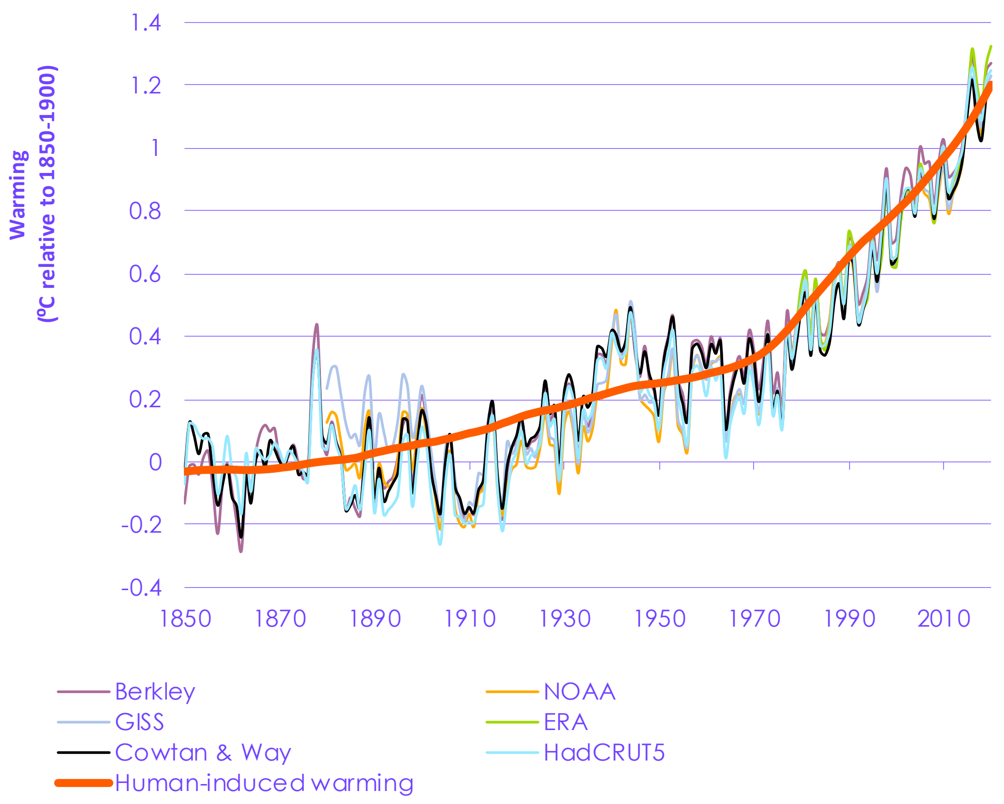
Source: CCC

1. The UK's changing climate

The climate is changing, with further warming inevitable.

Human activity is now causing changes to the climate that have long been predicted. Global and UK average land temperatures have risen by around 1.2°C since the 1850-1900 period (Figure 3). UK sea levels have risen by 16cm since 1900. Episodes of extreme heat are becoming more frequent, with the chance of a hot summer like 2018 now up to 25% per year compared to less than 10% a few decades ago. People, nature, infrastructure and business are already vulnerable to a range of climate impacts. These will increase.

Figure 3 Global average surface air temperature change



Source: CCC analysis; full sources listed in Chapter 1
Notes: Each thin line represents a different global temperature dataset. The NOAA, GISS and ERA datasets are expressed relative to 1850 - 1900 using the offset over the 1961 - 1990 period from the HadCRUT5 dataset. Human-induced warming is taken from globalwarmingindex.org.

The UK is likely to experience around an additional 0.5°C increase in annual average temperature by 2050, even under ambitious global scenarios for cutting greenhouse gas emissions. The general pattern of change in the UK is towards warmer and wetter winters, hotter and drier summers, with high variability. These changes will increase our exposure to weather-related hazards:

- Increases in average and extreme temperatures, in winter and summer.
- Changes to rainfall patterns, leading to flooding in some places, at some times, and water scarcity in others.
- Increased coastal flooding and erosion, alongside increasing sea temperatures and ocean acidification.

- Increased frequency and intensity of wildfire.

- Potential changes to other weather variables including wind strength and direction, sunshine and UV levels, cloudiness, and sea conditions such as wave height.

After 2050, the extent of further climate change will depend on future global emissions of greenhouse gases. If the world cuts emissions rapidly to Net Zero, there is a good chance of limiting global temperature increase below 2°C. If not, we will see higher levels of warming and much more extreme impacts. Uncertainties over the response of the climate system add further risks of very high temperature increases.

The UK's third climate change risk assessment

This report updates the latest evidence of how the risks and opportunities from the changing climate for the UK are changing and their implications for the way we live and work, and for our natural environment. We set out where further action to adapt to climate change is most urgently needed in England, Northern Ireland, Scotland and Wales.

Sixty-one risks and opportunities have been studied in detail. Several hundred experts from across the UK have contributed over the past three years to the technical assessment that underpins this work. Their work is presented in the 1,500 page CCRA3 Technical Report and supporting research that is published alongside this report.

Growing risks of climate change

The overall level of risk facing the UK from climate change has increased since the Committee's last assessment. The gap between the level of risk and level of adaptation underway is growing.

We are falling behind on adapting to climate change. The need for additional adaptation, above what is already planned, has increased in the last five years. New evidence has revealed a greater degree of risk:

- 56% of the risks and opportunities assessed in the Technical Report have received the highest urgency score, compared to 36% for the last assessment in 2016.

- Fourteen comparable risks have increased in future magnitude compared to the last assessment in 2016. None have decreased.

- The magnitude of risks is also increasing faster than earlier assessments predicted. Fifteen of today's risks are now at a higher magnitude than the first CCRA, in 2012, predicted for the 2020s.

In the absence of further adaptation, the number of risks with annual impacts costing of the order of £billions per year is likely to triple by the 2080s, even if the global effort is successful in reducing greenhouse gases and limiting warming to 2°C above 1850-1900 temperatures.

Where climate change creates opportunities for the UK, action must still be taken to deliver benefits. Overall, the limited opportunities from climate change in the UK do not offset the substantial and pressing risks.

2. Priority risks for urgent further action

Risk areas requiring the most urgent action in the next two years

Eight risk areas are critical for adaptation action in the next two years.

We identify eight risk areas that must be tackled with new action from Government in the next two years (Figure 1). The Committee's assessment is based on the urgency of additional action, the gap in adaptation planning across the UK, imminent opportunities for integrating adaptation action into upcoming major policy commitments, and the opportunity to avoid lock in where major developments are taking place now.

Key risks to the UK such as flooding and water scarcity also remain significant and are assessed as needing more action in the CCRA3 Technical Report. However, well-developed policies are in place for managing these hazards so they have relatively smaller gaps in adaptation planning.

1. **Risks to the viability and diversity of terrestrial and freshwater habitats and species from multiple hazards.**

Nature supports all economic activity and human wellbeing. Many of the services that the natural environment provides, such as CO_2 removal, water supply, flood mitigation and cooling are also key adaptation services for people. Climate change poses a major threat to UK biodiversity, at a time when it is already degrading rapidly. Overall, the abundance and distribution of UK terrestrial and freshwater species has declined by 13% since 1970. Climate change has the potential to cause irreversible losses in some species and habitats. Increased temperatures and extreme events such as drought and wildfire pose the biggest threats.

Upland areas face particularly acute risks, with 75% of present-day upland species potentially facing a decline in climate suitability by the end of the century under a medium level of warming. The UK's uplands also account for a high percentage of the UK's agricultural land and national parks. When in good condition, they provide essential ecosystem services for the rest of the country, including carbon sequestration and water regulation.

For terrestrial and freshwater species and habitats, adaptation requires reducing pollution and creating suitable conditions for existing species to persist, for example through increased shading of rivers using trees. We can help species to move, installing fish passages for example, and we can manage habitats actively to improve their resilience, for example through mixed planting and the removal of lying dead wood and other fuel loads that risk wildfire. These actions must be underpinned by enhanced monitoring and surveillance.

Over the next two years, through the wholesale review of environmental policy following EU Exit, there is a time-limited opportunity to build adaptation explicitly into policies to protect terrestrial and freshwater habitats and species. Opportunities to integrate adaptation into major current and forthcoming policies include:

- England – Environment Bill, Nature Recovery Network, Environmental Land Management Scheme, Nature for Climate Fund, National Pollinator Strategy, Nature Strategy, Soil Health Action Plan, Green Finance Strategy, updated to River Basin Management Plans, England Trees Action Plan, England Peat Action Plan.

- Northern Ireland – All-Ireland Pollinator Plan, NI Environment Strategy, NI Peatland Strategy, NI Biodiversity Strategy review.

- Scotland – Forest Strategy, Environment Strategy outcome pathways and monitoring framework.

- Wales – National Peatland Action Programme, Natural Resources Policy.

2. **Risks to soil health from increased flooding and drought**

Soils are a key natural asset. Well-functioning, fertile soils maintain our food and timber supply, they store carbon, and they support a diverse range of organisms that form part of the terrestrial food chain for wildlife.

Climate threats to UK soils exacerbate existing human pressures. Heavier rainfall causes erosion and compaction. Drier conditions lead to loss of soil organisms and organic matter. Present day compaction costs are already £470 million per year in England and Wales, while the costs from soil erosion in terms of loss of soil depth and nutrients and off-site impacts to water quality, are estimated to be in the region of £150 million per year.

Reducing UK greenhouse gas emissions to Net Zero will require healthier soils, to support increases in agricultural productivity. Productivity improvement frees up agricultural land for carbon sequestration, for example through tree planting, growing forest cover from 13% today to around 18% by 2050. The Committee's recommended Net Zero pathway requires a 10% per decade improvement in crop yields to achieve this.

Soil health features in all of the current national adaptation plans across the UK, but the necessary adaptation responses are not yet commensurate with the level of risk. There is not yet a comprehensive soil monitoring strategy to understand and measure progress on climate change adaptation, nor are there targeted interventions and land management strategies to improve soil health, locally or at national scale.

Beneficial adaptation actions involve soil-friendly farming practices, including no-till and precision farming, to minimise erosion and pollution, and good water management on agricultural and forested land to keep soil moisture in balance. More investment in soil monitoring is essential to understand the current condition of soils and the future success of adaptation actions.

The overhaul of UK environmental policies presents a unique opportunity to define better targets, monitor condition and encourage more widespread soil conservation to address the impacts of climate change while maintaining and improving productivity. Opportunities to integrate adaptation include:

- England – Environment Bill, Environmental Land Management Scheme, Soil Health Action Plan, England Peat Action Plan.

- Northern Ireland – Sustainable Agricultural Land Management Strategy.

- Scotland – Soil and Nutrient Network, Farm Advisory Strategy.

- Wales – Sustainable Farming and Our Land Strategy.

3. Risks to natural carbon stores and sequestration from multiple hazards, leading to increased emissions

There are extensive stores of carbon throughout the UK's terrestrial and marine habitats – in soils and sediments, trees, saltmarsh and kelp forests. Human activity is exerting pressures on all of them through pollution, erosion, degradation and loss, and through damaging practices such as peat extraction and rotational burning.

Climate change is exacerbating these pressures. Hotter, drier conditions reduce the functioning of peatlands and forests and threaten their existence. These habitats face erosion from wind and rain, and increased risk of fire damage. Blue carbon stocks are also at risk from warming seas, ocean acidification and the loss of coastal habitats.

UK peatlands are one of the most important terrestrial natural stores for carbon, estimated to store the equivalent of around 11,700 (± 1,100) $MtCO_2$ – over 25 times larger than the UK's total current annual emissions and an order of magnitude higher than the carbon stored in trees. However, the area of land suitable for peat-forming vegetation in the uplands could decline by between 50% and 65% by the 2050s through the effects of climate change alone, potentially dramatically increasing UK emissions. Blue carbon stored in coastal and marine habitats is also thought to be a critical store, with a baseline assessment of the total stock urgently needed.

Maintaining these carbon stores is critical to delivering the net removal of CO_2 from the atmosphere required for Net Zero by 2050. The Committee's scenarios involve annual CO_2 removals based on UK nature-based solutions of around 50 $MtCO_2$ per year by 2050. Even a small loss from existing stores could entirely offset this. Although there will be a mix of risks and opportunities to natural carbon stores from warmer conditions and changing rainfall patterns, the risks are much more significant to address and require the most urgent adaptation responses.

The critical role of CO_2 removals from tree planting and growth, peatland restoration, wetlands, bioenergy production and other nature-based solutions in delivering Net Zero make this risk a high priority. There is a high chance of lock-in leading to permanent losses if action is not started now to plant suitable trees for the future climate in appropriate locations and to restore and restore peatlands and other wetlands.

Critical adaptation actions include spatial targeting of land use policies to match changing conditions, including better species choice in tree planting programmes (i.e. the right trees in the right places), the restoration of degraded peatlands and soil carbon monitoring. Opportunities to integrate adaptation into major current and forthcoming policies include:

- England – Net Zero Strategy, Environmental Land Management Scheme, Soil Health Action Plan, Green Finance Strategy and funding measures (e.g. Sovereign Green Bond), England Trees Action Plan, England Peat Action Plan.
- Northern Ireland – Sustainable Agricultural Land Management Strategy.
- Scotland – Soil and Nutrient Network, Farm Advisory Strategy.
- Wales – Sustainable Farming and Our Land Strategy.

4. **Risks to crops, livestock and commercial trees from multiple climate hazards**

Productive agriculture and forestry sectors are essential for future domestic food security and for the UK's land to contribute fully to delivering Net Zero emissions by 2050. To maintain and enhance agricultural and forestry productivity, the health and diversity of terrestrial and freshwater ecosystems need to be protected and enhanced. Climate change poses a direct risk to crops, livestock and commercial trees through increased exposure to heat stress, drought risk, waterlogging, flooding, fire, and pests, diseases and invasive non-native species.

An effective adaptation response will require different and new varieties of crops, livestock and trees that are more climate resilient. Changes to land management practices are also needed, including better technologies for managing water and nutrient input, and improved soil conservation. The lead times to develop and establish new crops and technologies can be significant, so action now to address future risks is especially important to avoid lock-in. Other actions identified as beneficial in the next five years include better long-term seasonal forecasts for land managers, assessment of land use options given changing water availability and land use strategies that bring climate change mitigation and adaptation together, particularly when considering potential future agronomy and bioenergy production in the UK.

There is no clear evidence that climate risks or opportunities for agriculture and forestry are being strategically planned for or managed. Risk assessment and planning is more evident in the forestry sector than in agriculture, although we note that much of the impetus for this is provided by Net Zero, rather than adaptation. There is an opportunity to improve climate resilience in forthcoming national and devolved policies for land management, Net Zero and nature protection, as well as using these new policies to support training and skills. But this opportunity is not being taken; the signs so far are that specific actions in these policy areas are not yet being introduced.

Opportunities to integrate adaptation into major current and forthcoming policies include:

- England – Net Zero Strategy, Environmental Land Management Scheme, Soil Health Action Plan, England Trees Action Plan, England Peat Action Plan.
- Northern Ireland – Sustainable Agricultural Land Management Strategy.
- Scotland – Future rural support schemes
- Wales – Sustainable Farming and Our Land Strategy, Natural Resources Policy

5. **Risks to supply of food, goods and vital services due to climate-related collapse of supply chains and distribution networks**

Most products, including food, finished goods, components and materials, have complex – often international – supply chains. Extreme weather is already causing supply chain disruption and exposure to climate hazards is set to increase. The impacts of disruption can be extensive. Severe flooding in Thailand in 2011 disrupted five major manufacturers of hard disk drives, output declined by up to 30% compared to the previous quarter, and the shortage of hard disk drives increased global prices by 80 - 190%.

The World Bank estimated that the total economic cost from this one event was US$45.7 billion, equivalent to around 13% of Thailand's GDP at the time.

Climate hazards can affect the supplies, the infrastructure and routes by which goods are transported. Businesses report that heavy rainfall, surface water flooding and high temperatures dominate their current weather-related supply chain risks, but coastal and river flooding and water scarcity will become more significant drivers in the future.

Adaptation actions involve the provision of better information, diversification of supply chain risks and building better capacity to manage, share and transfer risk. There is an important role for new technology and infrastructure. These actions fall mostly to business, but government can support them by ensuring information and advice is available, especially for smaller businesses, and by implementing stronger reporting requirements for businesses and infrastructure providers, such as ports and airports.

Some action has already been taken by businesses and there are opportunities to learn from the lessons on supply chain resilience during the COVID-19 pandemic. However, it is unclear whether action will keep pace with the increasing risk or how effective it will be specifically in managing climate or weather-related disruption. Enhancing supply chain resilience should be a priority for post-COVID recovery planning and should also be a factor in the development of new trade agreements as trade patterns change following EU-Exit.

Opportunities to integrate adaptation into major current and forthcoming policies include:

- UK – HM Treasury's Plan for Growth; Green Finance Strategy including TCFD and TNFD reporting; the developing global reporting system led by major sustainability reporting organisations (CDP, CDSB, GRI, IIRC and SASB); FCA's Sustainable Finance Strategy and the Climate Financial Risk Forum.

- In addition, increasing awareness of guidance or tools through channels such as the SME Climate Hub; Transforming public procurement programme and public procurement guidance; Department for International Trade's Business of Resilience campaign.

6. **Risks to people and the economy from climate-related failure of the power system**

The UK will become more dependent on electricity as we reduce our greenhouse gas emissions to Net Zero and it becomes our dominant energy source. Electricity provides about 15 - 20% of our energy today. By 2050 it could account for around 65%, as we transition to the use of electricity for heat, transport and across industry, as well as light, communications and delivery of other critical services such as water. People and the economy will be increasingly exposed and vulnerable to electricity system failures.

Different parts of the power sector can be impacted by each of the major climate hazards: flooding, water shortages, increased temperatures and wildfire, sea level rise and potential increases in storms, swells and wave heights. While the power sector generally has good plans in place for the risks of 2°C and 4°C warming scenarios, weather-related problems still occur. For example, a lightning strike on an electricity circuit between Cambridgeshire and Hertfordshire in August 2019 led to a cascade of impacts on other generators, interrupting supply to over 1 million people and stranding affected trains for hours.

Risks from climate-related hazards will become more common and more damaging as our dependence on electricity grows and the variability of our weather increases. Within a Net Zero power system, weather-dependent renewables like offshore wind are expected to play a dominant role. We strongly recommend that the Government works with the regulator (Ofgem) and the industry to review the approach to electricity system design and risk assessment in the context of the more central role of electricity in the UK's future energy system.

The risks can be managed, but ensuring the UK has a power system that is resilient to future climate impacts is now an urgent issue. The next 10 years will see a huge growth in investment in both electricity generation and expansion of the distribution grid. For example, the UK Government plans a four-fold increase to 40 GW of offshore wind by 2030, alongside significant electrification of transport, heat and industry.

The implementation of the 2020 Energy White Paper and of the National Infrastructure Strategy provide opportunities to embed climate resilience in the power system. Climate resilience must also be reflected in the wider energy system governance (e.g. by Ofgem, and in considering the possible role for an independent Energy System Operator) and in planning conditions for new infrastructure. The Government should implement stronger approaches to systemic risk assessments and resilience for critical infrastructure, especially where the interdependencies are so ubiquitous.

Opportunities to integrate adaptation into major current and forthcoming policies include:

- UK – the Implementation of the Energy White Paper 2020 and National Infrastructure Strategy 2020, the next National Infrastructure Assessment in 2023, the Offshore Transmission Network Review (and wider network plans), and the upcoming Net Zero Strategy, including any plans to phase out unabated gas power generation by 2035 (as recommended by the Committee).

- England – Review of public procurement rules and guidance, TCFD reporting, implementation of National Flood and Coastal Erosion Risk Management Strategy and Policy Statement.

- Northern Ireland – second round of Flood Risk Management Plans for Northern Ireland.

- Scotland – implementation of Scottish Government Infrastructure Investment Plan, The final tranche of the Low Carbon Fund investment in Emerging Energy Technology, key energy infrastructure considerations in the fourth National Planning Framework.

- Wales – future Welsh Climate Change Adaptation Plan.

7. Risks to human health, wellbeing and productivity from increased exposure to heat in homes and other buildings

People in the UK are already at risk of illness and death from high temperatures, particularly those with existing heart and respiratory conditions. There were more than 2,500 heat-related deaths during the 2020 heatwave in England, higher than at any time since records began in 2003.

The latest UK Climate Projections show a hot summer like 2018 is likely to occur every other year by 2050, by which time the number of heat-related deaths could more than triple from today's level in the absence of additional adaptation; from around 2,000 per year to around 7,000.

As well as a risk to life, high temperatures will lead to productivity losses for UK workers. Analysis across 11 UK city regions estimated the benefits of urban greening was nearly £300 million in a single year for these regions alone, through avoided productivity losses and reduced cooling costs.

The ways in which people work may also change. In 2019 only 5% of people worked exclusively from home, but at points during the COVID-19 pandemic it has been closer to 30%. Exposure to heat in homes will increase if some businesses and workers choose to adopt this style of working on a permanent basis. Overheating in homes also has implications for the future delivery of health and social care as trends indicate a move to more home-based care rather than in hospitals.

Building designs and technology are available that can greatly reduce occupant exposure to heat while ensuring high levels of thermal efficiency – staying warm in winter, while cool in summer, alongside being moisture safe and maintaining high indoor air quality. Beneficial adaptation actions include the updating of building regulations and other policy measures to address overheating in new and refurbished homes through passive cooling measures like better shading, reflective surfaces and green cover. Regional and local risk assessments can be made by health and social care organisations, and there can be more widespread monitoring of indoor temperatures throughout the country.

Policies to address overheating risks in buildings are still missing despite it being one of the top risks in all UK climate risk assessments published to date. Little preventative action is being taken to address health risks from overheating in buildings, and in homes in particular. More than 300,000 homes are due to be built each year across the UK and there is a major risk of lock-in if they are not planned and built to address overheating alongside energy efficiency and low-carbon heating. Inaction now will create unnecessary retrofit costs later and could even leave many existing and new homes uninhabitable as temperatures rise.

Opportunities to integrate adaptation into major current and forthcoming policies include:

- England and UK – Building Regulations review; review of the National Planning Policy Framework; revision of the Heat and Cold weather plans; NHS Green Plans; Heat and Buildings Strategy, including any replacement for the Green Homes Grants or similar schemes, Homes England requirements, new Building Safety Regulator.

- Northern Ireland – New Housing Strategy; review of Building Regulations; expand Northern Ireland Climate Change Adaptation Programme to include actions to address heat hazards in health and social care settings.

- Scotland – Review of energy standards and supporting guidance; use of Green Infrastructure Fund and Green Infrastructure Community Engagement Fund to support urban greening; creation of NHS Boards' adaptation plans; NHS Scotland Sustainability Strategy.

- Wales – Introduce overheating standards into Building Regulations; PHW extreme weather strategy review; PHW climate change Health Impact Assessment; commitment to address climate risks to health and social care delivery and update of contingency plans.

8. Multiple risks to the UK from climate change impacts overseas

Extreme weather events in the UK and globally can create cascading risks that spread across sectors and countries, with impacts an order of magnitude higher than impacts that occur within a single sector. The COVID-19 pandemic is a shocking example of a cascading global impact, albeit not a climate-driven event, which has resulted in terrible impacts to society and huge costs to Government.

There is growing potential for weather-related hazards, such as floods, hurricanes, or drought, to spark these kinds of cascading impacts globally. The current model of conventional risk governance in the UK, which focuses on single events, single sectors and characterisation of reasonable worst-case scenarios, should be updated to address cascading climate risks.

Opportunities to integrate adaptation include:

- Increased capacity building by FCDO programmes overseas to improve global capacity for climate resilience, including supply chains, health systems and early warning systems. Overseas programmes should work to reduce underlying vulnerabilities and not just respond to disasters. This ties in with the UK Government's 'levelling up' agenda and its aims for global leadership, including through presidencies of the G7 and upcoming UN climate talks (COP26).

- Increased research and capacity building by BEIS via its International Climate Finance work overseas to ensure that low-carbon development and delivery of Net Zero include co-benefits of adaptation and are not undermined by climate risks.

- Increased research through the BEIS Global Challenges Research Fund (GCRF) that is delivered through UKRI, UK Academies and the UK Space Agency, to improve understanding of interacting risks, which regions and sectors are most fragile and how to improve resilience.

- Development of a UK Resilience strategy by the Cabinet Office.

- Clear commitments at COP26 to leverage increased adaptation financing and support developing countries with capacity building for implementing national adaptation actions.

3. Principles for effective risk assessment and adaptation planning

Principles for good adaptation

Implementing the ten principles will improve understanding of risk and enable effective adaptation to climate change.

The Government has an essential role to enable and enforce good adaptation planning across the UK. It can do this by addressing market failures, providing better information on risks, supporting the coordination of local action, implementing a framework of targets, incentives and reporting, and directly funding adaptation action. It should also provide a strong governance framework for adaptation to ensure that it is integrated more widely into relevant policies.

The Government has not heeded our past advice on the importance of setting this framework and resourcing it adequately. Adaptation governance has weakened over the past ten years at the same time as the evidence of climate risk has grown. This must change.

Integrating the ten principles set out in this section and in Figure 3 into the next set of national adaptation plans will strengthen the framework for risk assessments and adaptation action.

1. **Set out a vision for a well-adapted UK**

Previous iterations of the UK's national adaptation plans have not articulated a positive vision for a resilient UK. The next set of national plans should be inspired by a clear vision for a well-adapted UK, where adaptation is integrated as standard into policies and business operations, and implications are clear for people, places and sectors throughout the UK. It is essential that new plans include measurable outcomes that can be achieved by the end of the next reporting period (2023 – 2029).

2. **Integrate adaptation into policies, including for Net Zero**

A host of government and societal goals will be undermined by the effects of climate change, including the provision of reliable and safe supplies of food and water; infrastructure services such as transport, energy and digital; biodiversity; public health; natural and cultural heritage; and the achievement of Net Zero. A more realistic appraisal of climate risk must be embedded in the policies, investments and decisions that relate to these goals.

Integrating measures for adaptation and emissions reduction is especially important – addressing adaptation and mitigation together. In the past three years, the opportunity was missed in 11 of 15 relevant major UK Government announcements to include integrated plans to adapt to climate change alongside those for reducing emissions. Where adaptation was mentioned, it often lacked specific actions or was not viewed as necessary to meeting the goal of that particular policy. In others it was simply absent.

The best way to address climate change and to avoid unintended consequences is to ensure adaptation and mitigation are considered together in those areas where there are the major interactions: especially across policies for infrastructure, buildings and the natural environment.

3. Adapt to 2°C; assess the risks up to 4°C

Recent global Net Zero pledges and commitments to reduce emissions by 2030 have improved the prospect of limiting global warming to 2°C by 2100, but they must be delivered in full and extended further. Even if warming is limited to 2°C, significant alterations to the UK's climate will still take place.

But global emissions are yet to fall, and effective new policies must still be implemented globally to deliver the new commitments. If global emissions do not fall, it is possible that the UK will experience much higher temperatures, possibly as high as 4°C between 2080 and 2100 if the climate response to emissions is on the high end of current uncertainty ranges.

This has fundamental implications for adaptation planning. The UK must adapt to a minimum average global temperature rise of between 1.5 and 2°C for the period 2050 – 2100 and consider the risks up to a 4°C warming scenario. Warming at this level would substantially limit the effectiveness of adaptation, leading to widespread threats to life and wellbeing, economic damage and systemic changes to the natural environment. Very high levels of adaptation could reduce some of the resulting impacts compared to what they would otherwise be, but would likely not stop them from rising.

4. Avoid lock-in

Early adaptation action – before impacts actually occur – reduces vulnerability to current climatic variability and builds in resilience where decisions have long lifetimes or long planning processes, such as with major infrastructure projects.

Early action is also needed to prevent, as far as possible, irreversible changes such as loss of species or ecosystems. Failing to do this leads to 'lock-in', where delayed decisions, or decisions that don't consider the long-term risks, result in irreversible changes, increased climate change damages, or higher costs when larger and faster action is required later.

The current practice of building new homes without designing in adaptations to future conditions such as extreme heat is one example of 'lock-in'. Retrofitting windows and shutters is around four times more expensive than including them at design stage.

5. Prepare for unpredictable extremes

Adaptation planning needs to accommodate unpredictability and the potential for sudden shifts in the climate, even at lower levels of warming.

The risk assessment has identified evidence on low likelihood, high impact changes that fall outside of the 'likely range' used in the assessment. This includes global warming higher than 4°C by 2100, but also earth system instabilities that could happen at a range of warming levels, such as significant shifts in the jet stream, leading to more extreme weather. These changes are subject to deep uncertainty.

At present there is no UK early warning system to consider such changes, or any assessment of what adaptation actions could be undertaken to reduce the resulting impact. Undertaking storyline approaches or use of 'what if' scenarios for national risk planning would be beneficial, as would planning in more headroom to policies and operations to account for sudden extreme changes.

6. Assess interdependencies

Interacting risks pose one of the biggest challenges when assessing climate risks. A single hazard, such as a flood, will often have knock-on impacts across a range of sectors, amplifying the resulting risk. Similarly, risks can interact across very different sectors; impacts on infrastructure can cascade through to the built environment and natural environment, and vice versa.

The Committee has identified risks to people and the economy from climate-related failure of the power system as one of the top priorities for Government, given the potentially far-reaching consequences of a power failure across society and the growing importance of electricity in the whole infrastructure system in the transition to a Net Zero economy.

Siloed thinking remains a problem for addressing climate change risks or opportunities that interact or are subject to cascading impacts, or where adaptation responsibility falls across more than one Government department.

7. Understand threshold effects

A threshold is the point at which a 'non-linear' change in a system occurs because of change in a climate variable, such as temperature. Algal blooms start to emerge when water temperatures exceed 17˚C for example. Understanding where these thresholds exist and how often they may occur in the future is important for understanding the size of a given risk, and at what point new action, or a different approach to adaptation might be required. Understanding thresholds can mean knowing when action is not needed, as well as when it is, leading to more efficient investment.

There is a general absence of consideration of thresholds in the literature on adaptation. Risk assessments that look at average changes over time assume a gradual increase in risk, so by their nature miss specific points that 'tip' the system or asset into a different state. Emphasis in future national adaptation plans should be placed on how threshold effects can be accounted for.

8. Address inequalities

Climate change is likely to widen existing inequalities through its disproportionate effects on socially and economically disadvantaged groups. For example, lower income households are relatively more exposed to flood risk in the UK. People living in Scotland, Wales and Northern Ireland are also exposed to higher annual damages from flooding per person than those living in England. Lack of action today stores up negative impacts for future generations, creating inter-generational inequalities.

To avoid unfairly disadvantaging future generations, especially with significant and irreversible impacts of environmental damage and climate change, the discount rate used in standard economic appraisal related to these impacts should be lowered.

Actions to address climate change could also exacerbate existing inequalities if not carefully planned. Inequalities have been identified in the risk assessment in relation to where people live, their income level and assets, and characteristics such as age and ethnic background, that can correlate to current vulnerabilities and capacity to adapt to climate change. The next set of national adaptation plans should map these effects and include actions to deliver positive distributional effects, in line with updated guidance in the Treasury Green Book.

The UK Government should address the inequal impacts of climate change as part of its levelling up agenda so that no community is left behind.

9. Consider opportunities from climate change

There will be some potential benefits to the UK from climate change, such as longer growing seasons, new species arriving in the UK or benefits to health from warmer temperatures in winter. But evidence on the extent of these opportunities is limited.

There are potentially large economic benefits from reduced winter heating costs, which need to be factored into future energy policy. The changing climate can also bring opportunities to businesses from new markets for goods and services, better growing conditions or an increased need for financial solutions. UK businesses have a potential for market leadership, competitive advantage through early adaptation and being first movers, attracting clients and talent aligned to climate objectives and improved reputation.

10. Support the implementation of adaptation through funding, resources, indicators, and research to link adaptation actions to reductions in risk

Sufficient funding and resourcing are a pre-requisite for effective adaptation. There are several financial barriers to taking action, varying by sector. For example, there may be less investment in projects that contribute to the health and resilience of natural assets than is socially optimal, due to investors being unable to capture the full benefits of their investment, unless new revenue streams are created.

New initiatives and financial products are helping to address some of the funding barriers, but they need to be scaled up to meet the extent of action required. Reporting initiatives such as the Taskforces on Climate-Related and Nature-Related Financial Disclosure are helping to provide investors with better information. Green, Climate Resilience and other similar bonds or financial products can help to raise capital.

These are promising developments, but they are still recent and there is a need to foster the continued growth of 'green' financing like this at the national and local level. Government has a primary role to play in helping to integrate adaptation and resilience into the financial system and existing economic plans such as financing Net Zero and a green recovery, reducing policy uncertainty, as well as other actions which can leverage private sector investment.

One of the biggest gaps to supporting more investment in adaptation is a lack of understanding of the effectiveness of different adaptation actions in different settings. Improved understanding of how adaptation actions are leading to risk reduction and better outcomes is needed urgently, following the approach set out in the UK Government's Magenta Book (Guidance for Evaluation) and using indicators to monitor change over time.

4. The benefits of adaptation action

There are strong economic and societal benefits from taking further adaptation action.

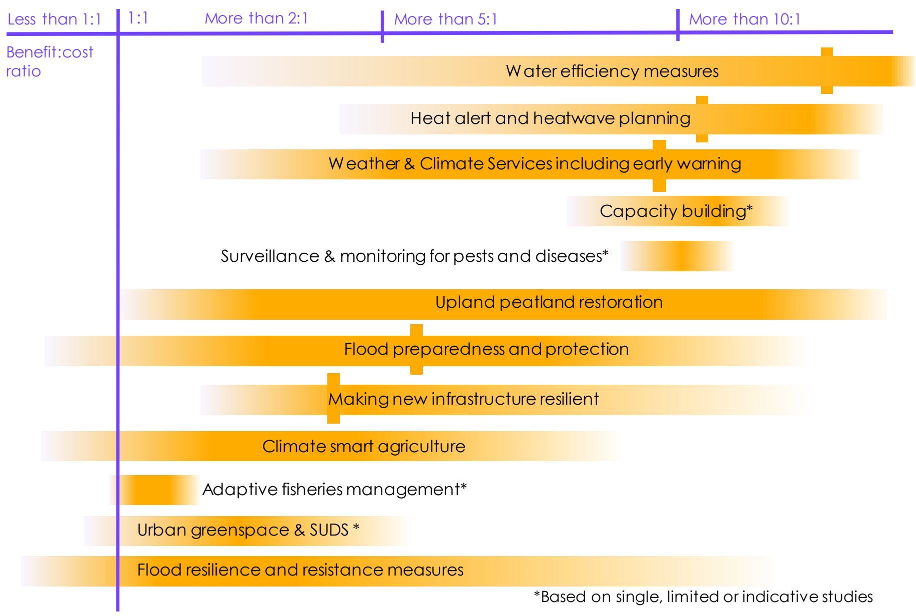
Adaptation can lead to large-scale reductions in damages from climate risks as well as providing a range of co-benefits to health, to the natural environment and to the economy. Table 1 shows seven categories of beneficial adaptation action identified in the assessment.

Table 1
Categories of beneficial adaptation actions for the next five years for the UK

Type of adaptation action	Examples
Engineered solutions	Improved building design and retrofit, road resurfacing, flood defence investment, drainage
Nature-based solutions	Increasing plant diversity, habitat creation, peatland restoration, soil conservation, increased blue carbon (coastal and marine vegetation), green sustainable urban drainage, urban greening
New or emerging technologies	Precision farming, using new crop and livestock varieties, remote sensing, new designs for infrastructure assets, use of digitisation and big data for monitoring, evaluation and management
Behavioural	Changing timing of agricultural practices, information sharing, public engagement, skills development in adaptation
Institutional	Adaptation standards, supply chain diversification, regulation, advisory services
Financial	Insurance, risk disclosure, adaptation finance
Data, R&D	Monitoring and surveillance, inspections, forecasting, research, decision support tools

More evidence is becoming available on the returns from adaptation actions, showing that for many their benefits substantially outweigh their costs (Figure 4). Some actions have extremely high net benefits (benefit-to-cost ratios of 10:1 or more). These estimates only include benefits that are easy to quantify, so ratios are likely to be even higher.

Figure 4 Benefit-cost ratios of adaptation measures included in CCRA3



Source: Watkiss, P. and Brown, K.A (2021)
Notes: Figure shows the indicative benefit-to-cost ratios and ranges for a number of adaptation measures. It is based on the evidence review undertaken in the CCRA3 Valuation study, which was co-funded by the EU's Horizon 2020 RTD COACCH project (CO-designing the Assessment of Climate Change costs). Vertical bars show where an average BCR is available, either from multiple studies or reviews. It is stressed that BCRs of adaptation measures are highly site- and context-specific and there is future uncertainty about the scale of climate change: actual BCRs will depend on these factors.

However, there are often barriers or constraints to their uptake, including appropriate availability of funding, as in the case for installing passive cooling in homes, or delay in implementing enabling policies like the environmental land management schemes, post EU-Exit.

Future national adaptation programmes must identify the barriers and constraints more accurately – and seek solutions to overcome these – particularly with better financing mechanisms for adaptation.

Can the UK wait to adapt?

Urgent adaptation cannot wait for another year, or another five years. It is needed now.

The UK is not prepared for unprecedented extreme weather events that could occur now. There is already a 1% risk each year that monthly winter UK rainfall could be 20-30% higher than the maximum ever observed. The chance of daily maximum temperatures exceeding 40°C is also growing.

Lack of adaptation over the past five years has also led to lock-in, irreversible changes and higher future costs for the Government:

- **Lock-in.** Since CCRA2 was published, over 570,000 new homes have been built in England alone that are not resilient to future high temperatures. These will require costly retrofit to make them safe, habitable and water efficient in the future. In the next five years, at least another 1.5 million homes are due to be built across the UK; these will also lock in increased climate vulnerability unless planning and building policy is changed now.

- **Irreversible impacts.** Since 2018, over 4,000 heat-related deaths have been recorded in England. Three major wildfires at Saddleworth Moor, the Flow Country and the Mourne Mountains reportedly burned between 70-140km^2, an area of a medium to large city, though there are uncertainties about the extent of the damage. Wildlife has been lost and emissions have increased as a result. It will take decades for those areas of peatland, heathland, forest and moorland to recover.

- **Increasing costs.** Both the size of current and future risks, and the urgency of action has increased compared to five years ago. The future costs from climate change over the century are estimated to be higher now than they were five or ten years ago. The longer action is delayed, the higher the costs the Government will face as the insurer of last resort. The costs of adaptation will also increase.

While the principles of urgent action are clear, the costs of adaptation inaction have still not been quantified for specific risks, nor all of the benefits of further action. A new Defra-funded project on the economics of adaptation, linked to this CCRA assessment, will be completed in 2022.[*] It will consider the case for further action for a set of priority CCRA3 risks, including the costs of inaction, and then assess the economic benefits and costs of further adaptation.

But adaptation is a pressing priority now. It cannot wait for another year, or the next five-yearly assessment of risk. The next two years are critical in raising the profile of adaptation in government policymaking and acting on the priorities identified in this report.

[*] The Economic Case for Climate Change Adaptation project is being led by Frontier Economics and Paul Watkiss Associates

The requirement for a Climate Change Risk Assessment

The Climate Change Committee provides advice to Government on climate change risks and opportunities to inform the CCRA.

The UK Government is required to conduct a UK Climate Change Risk Assessment (CCRA) every five years as set out in the UK Climate Change Act (2008). The Climate Change Act requires that the Climate Change Committee provide advice on the CCRA to the UK Government six months before the Government's UK Climate Change Risk Assessment is laid in Parliament. Two previous CCRAs have been published in 2012 (CCRA1) and 2017 (CCRA2). For this third CCRA, due in 2022, the UK Government requested the Climate Change Committee to prepare an Independent Assessment setting out the risks and opportunities to the UK from climate change up to 2100, including the Committee's advice on priorities for adaptation for the coming five-year period.

Following the UK Government's publication in 2022, each UK nation then must prepare a National Adaptation Plan to address those risks and opportunities as soon as practicable.*

Structure of the CCRA3 Independent Assessment

The CCRA3 Independent Assessment is made up of the Committee's Advice Report; an accompanying independent Technical Report, and summaries of the Technical Report.

Our independent assessment is made up of a series of reports (Figure 5):

- **The Technical Report**† provides the full analysis for 61 climate change risks and opportunities for the UK. Chapters 0 to 2 cover an introduction, the wider climate change context and method. Chapters 3 to 7 cover the risk assessment split by sector – natural environment; infrastructure; health, communities and built environment; business; and international dimensions. The Technical Report has been produced by a consortium of expert technical authors, led by the University of Exeter in partnership with the Met Office.

- The Technical Report is underpinned by a wider range of reports prepared specifically to support CCRA3, including a **Valuation Report** and other supporting **research reports.** Three **calls for evidence** were also carried out to identify additional evidence from the public, private and third sector stakeholders.

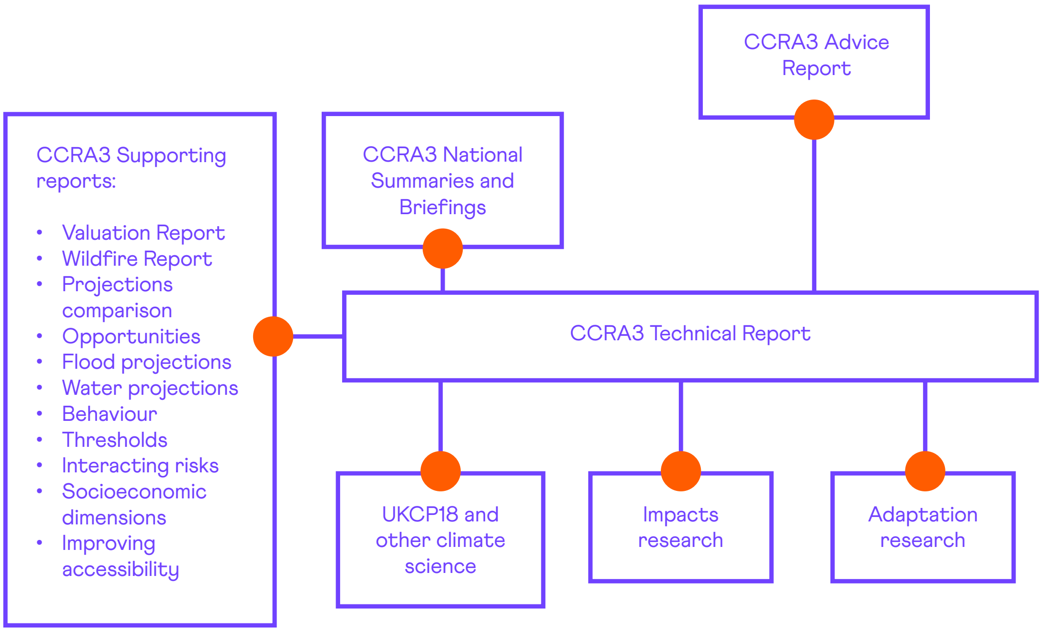
- **The Summaries** provide an accessible, shorter introduction and signposting of the risk assessment presented in the Technical Report. There are two types of summary: 17 factsheets that summarise the assessment for different themes chosen by government; and four national summaries that give an overview of the risk assessment for each UK nation. The summaries have been produced by a consortium led by Sustainability West Midlands.

* The evidence and policy cycle is set out in more detail in Betts, R.A and Brown, K.A. (2021) CCRA3 Technical Report – Introduction.

† The CCRA3 Technical Report Chapters are referenced where appropriate in footnotes throughout this report; this is to distinguish the Technical Report from other sources of evidence, which are shown in Endnotes.

- **The Advice Report (this report)** provides the Adaptation Committee's statutory advice to government on the priorities for the forthcoming national adaptation plans and wider action, drawing on the analysis in the Technical Report. This report does not summarise all 61 risks and opportunities in detail as this is done elsewhere, but it does provide a synthesis of the cross-cutting issues that emerge from the Technical Report, alongside the Committee's recommendations.

Figure 5 Components of the CCRA3 Independent Assessment



Source: CCC
Notes: This schematic shows the various components of the CCRA3 Independent Assessment. The bulk of the risk assessment is set out in the Technical Report, with the assessment for each set of relevant risks and results by UK nation set out in the accompanying summaries. There are also a range of supporting reports that have been completed specifically to inform the Independent Assessment, and those are also available on the Climate Risk website.

The wider context for this assessment

The UK is very different now to five years ago. The COVID-19 pandemic, EU-Exit and the commitment to Net Zero have altered the socioeconomic context underpinning how climate risk is assessed.

The background social, economic and technological conditions have been very different during the period that this assessment has been prepared, compared to the previous two CCRAs.

The work for the CCRA3 Independent Assessment took place between 2017 – 2021. During this period, the world's population has been affected severely by the COVID-19 pandemic (2020 - ongoing), bringing widespread global disruption. The pandemic has in some cases increased people's vulnerability and exposure to climate hazards, and the linkages and interactions between COVID-19 and climate change have been mentioned where relevant in the Technical Report.*

* See Betts, R.A and Brown, K.A. (2021) CCRA3 Technical Report - Introduction

The pandemic has also provided insights into globally complex and cascading risks, and tested how risk planning operates across departments, governments and countries. This Advice Report includes reflections from the Technical Report authors and the Adaptation Committee on what can be learned for future risk planning in the context of climate change.

The UK also left the European Union in 2020. These changes have altered the context for adaptation policy for many of the risks and opportunities, particularly in the natural environment, business and international dimensions themes. These changes and associated uncertainty in future policy are also discussed in the Technical Report.

In 2019, the UK passed into law a target to reduce UK greenhouse gas emissions to Net Zero by 2050 (with associated devolved targets), setting in train a process for a rapid decarbonisation of many of the sectors considered in this report. Again, this has created a significant shift in our assumptions about the future conditions in which climate change risks and opportunities will be experienced; for example, because the UK's energy production and distribution system will look very different by 2050. In preparing this set of reports it has been possible to say more than in previous assessments about the synergies and trade-offs between mitigation and adaptation measures in addressing climate change. This analysis is also presented for each risk and opportunity in the Technical Report and summarised in this report.

The UK remains in a period of rapid change, and this has made assessing the magnitude of future risks more challenging than in previous assessments due to greater uncertainty about future geopolitical conditions.

Our understanding of current and future climate change has also changed for this assessment.

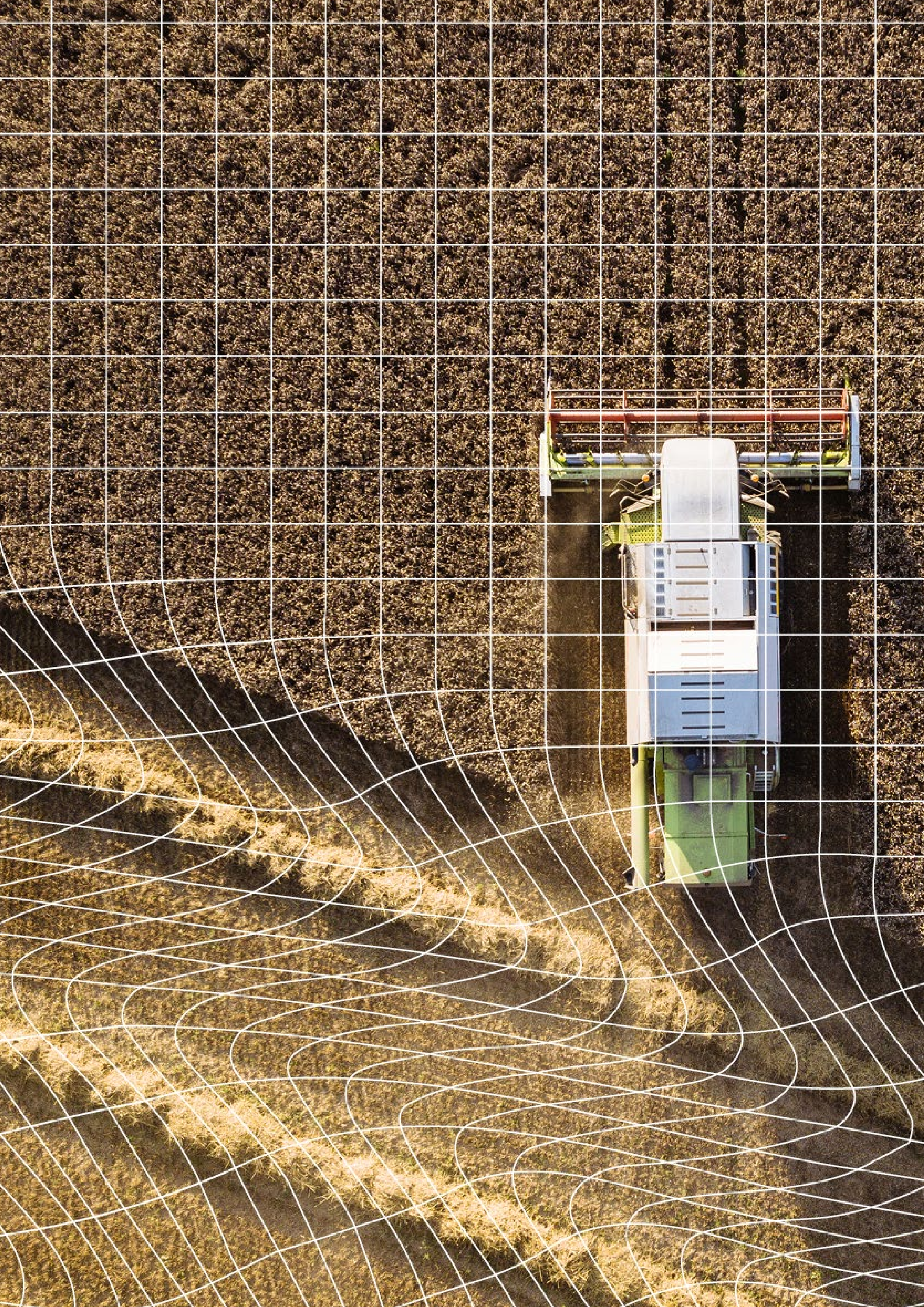
Scientific understanding of the likely level of future climate change has improved since earlier risk assessments.

Scientific understanding of the likely level of future climate change has developed since earlier risk assessments, and the range of global warming that the world might experience above 1850 - 1900 levels by 2100 has narrowed, from between 1°C to 6°C considered in CCRA1, to a range between 2°C to 4°C used in CCRA3. In part this reflects advances in climate science, which have ruled out some more extreme low or high values for climate sensitivity. It also reflects the path of global emissions of greenhouse gases: these have continued to rise in recent years, though advances in low-carbon technologies (especially falls in the costs of renewable energy) and pledges to the Paris Agreement should hopefully lead to a levelling off in emissions. Recent commitments for 2030 and to Net Zero targets in the longer-term imply emissions could fall rapidly in future, if those targets are delivered. We explore this further in Chapter 1.

Since CCRA2 was published in 2017, even more sophisticated projections of future changes in the UK's climate and associated hazards (such as heatwaves) has become available, including through the Met Office's UKCP18 climate projections and improved high-resolution modelling. Uncertainties in future climate projections remain however, and estimating the precise changes in the resulting impacts (such as number of deaths due to extreme heat) remains challenging. These impacts are driven not just by the change in climate but also through complex interactions with socioeconomic drivers such as population, economic growth and the UK's future transition to Net Zero. The risk assessment considers both climate and socioeconomic change as far as possible and in particular highlights for each risk and opportunity the interactions with a Net Zero future in the UK.

Chapter 1

The UK's changing climate



Introduction and key messages

This chapter summarises observed and possible future changes in the UK's weather and climate.

This Chapter gives an overview of how the UK's climate has changed and may continue to change in the future. It summarises the aspects of climate change that will drive the direct climate risks to the UK considered in this report. It builds on the analysis in Chapter 1 of the CCRA Technical Report.[1] Our conclusions are:

- **The UK's climate has already changed over recent decades.** Over recent decades the UK's annual average temperature has warmed at nearly 0.3°C per decade. Heatwaves are now more common and intense across the country and cold extremes significantly less likely. Sea levels are over 5 cm higher than in 1990 and continue to rise. A signal of climate change is also being detected in some extreme heavy rainfall events.

- **Further changes in the UK's climate is expected by mid-century.** Changes in UK climate by 2050 are largely insensitive to the trajectory of global emissions over the next few decades. The UK is more likely to experience warmer and wetter winters in future together with hotter and drier summers. Rainfall and temperature extremes will become more intense and frequent. Sea levels will continue to rise around the UK.

- **A wide range of future UK climates remains possible in the second half of the century.** UK climate after 2050 depends on global efforts to reduce global greenhouse gas emissions. If the world successfully reduces emissions to limit global warming to the temperature goal of the Paris Agreement, only limited changes would occur in many aspects of UK climate beyond those expected by 2050 (however, sea levels would continue to rise). If global emissions remain high, summers will continue to become even hotter and drier, and winters warmer and wetter. Considering a range of global warming levels (e.g. 2ºC to 4ºC above preindustrial levels by 2100) can help to assess risks over the long-term.

- **The UK's weather and climate will continue to be highly variable.** In the future, summers will still occur that are cooler and wetter than typical over the recent past (as well as winters that are cooler and drier) despite trends in the opposite direction expected on average. The future variability of the UK climate needs to be considered in risk assessments to be fully resilient to the full range of weather and climate conditions expected.

- **Low-likelihood, high-impact climate changes outside the envelope considered in current projections could still be possible.** These changes include global warming higher than 4°C by 2100, and potential instabilities such as collapse of the Atlantic Ocean currents. These changes could have a large impact on UK climate. At present there are no monitoring systems to consider whether many of these changes are imminent. Storyline approaches or the use of 'what if' scenarios could be useful to help consider these low-likelihood impacts in risk assessments.

We set out our analysis in three sections:

1. Observed climate changes

2. Projected future changes in UK climate

3. Climate variability, extremes, and low-probability outcomes

Changes in the global and UK climate have been observed over recent decades. These changes demonstrate the emerging signal of climate change that is now clear in many aspects of weather and climate. There is no 'safe' level of warming in which climate change impacts in can be avoided entirely. Future warming will bring additional increases in the climate-related risks already present as well as the emergence of new ones.

Observed global climate change since the mid-19th century

Global temperatures continue to rise rapidly – with human influence the driver.

The earth is warming, with clear evidence linking this warming to human activities:

- The last six years have been the six warmest on record globally (Figure 1.1).
- Estimated human-induced global warming has now reached around 1.2ºC above 1850 - 1900 (which has been regularly used as an approximation for preindustrial levels) when disentangled from the effects of natural climate variability.[2] Human-induced warming is estimated to explain 100% (+/- 20% uncertainty) of the observed warming since 1850-1900.[3]
- Human-induced warming is increasing at around 0.25ºC per decade, leading to further increases in global and UK climate hazards into the future.*

Rising global temperatures have much wider effects on climate around the world – impacting people and ecosystems today.

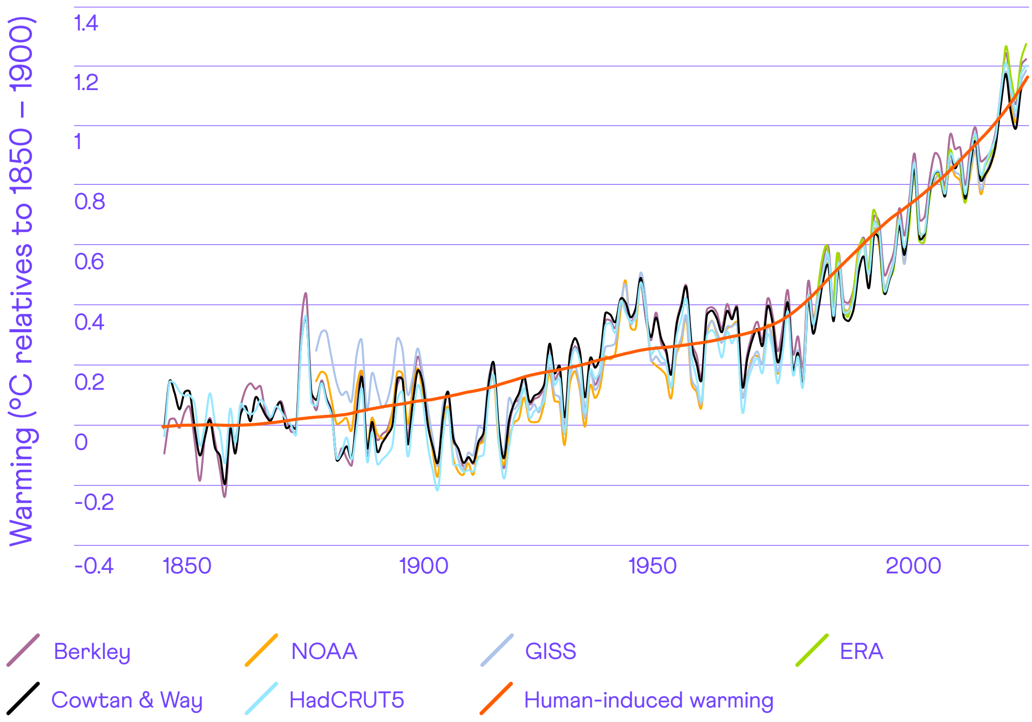
This observed increase in global average temperature is also driving wider changes in the climate around the world:

- Global sea-level has risen by about 20 cm since the start of the 20th century and the oceans are becoming more acidic. These ocean conditions are unprecedented in at least the last 65 million years.[4]
- The heat stored in the planet's oceans continues to rise. Temperatures are rising in the deep ocean (below 2 km depth) with more than 90% of the extra energy trapped by greenhouse gases ending up in the oceans.
- Around the globe, more frequent heatwaves are occurring in most land regions, global-scale extreme precipitation has intensified, and climate change has increased heat-related mortality.[5]
- Patterns of water availability are changing due to melting land-ice and shifting rainfall in some parts of the world. Glaciers have been melting across the world due to climate change, affecting runoff and downstream glacier-fed water availability.[6]

Impacts from these changes in global climate are becoming clearer and their consequences for people and ecosystems more apparent. This is particularly so in the tropics where the climate is less variable and climate change more rapidly leads to unprecedented weather conditions.[7]

* Based on the linear trend in human-induced warming over the last decade (2011-2020) and rounded to nearest 0.05ºC per decade.

Figure 1.1 Global average surface air temperature change



Source: CCC analysis
Notes: Each thin line represents a different global temperature dataset. The NOAA, GISS and ERA datasets are expressed relative to 1850 - 1900 using the anomaly over the 1961-1990 period from the HadCRUT5 dataset. Human-induced warming is taken from globalwarmingindex.org.

Observed climate change in the UK over recent decades

Changes in aspects of the UK's weather and climate are already being seen.

Observations document several clear recent trends in different aspects of the UK's weather and climate (Figure 1.2):

- **Warmer average temperature.** The UK's annual average temperature has risen by around 0.6°C above the average of the 1981-2000 period, consistent with a trend of around nearly 0.3°C per decade since the 1980s. The signal of human-induced warming above 1850 -1900 in the UK is estimated to be similar to the global average.[8]

- **Higher average sea levels.** The level of the seas around the UK has risen by around 6.5 cm since 1981-2000. They are currently estimated to be rising at around 2.5 cm per decade.*

Temperature extremes in the UK have changed. Heatwaves and warm summers are now significantly more likely than a few decades ago.

- **Changed temperature extremes.** The average duration of heatwaves (periods in which there are more than three days in excess of 25°C) has increased over time.[9] For the UK as a whole, summers as hot as in 2018 (the joint warmest summer on record) are currently expected to occur in up to

* Based on a linear trend over the past 20 years.

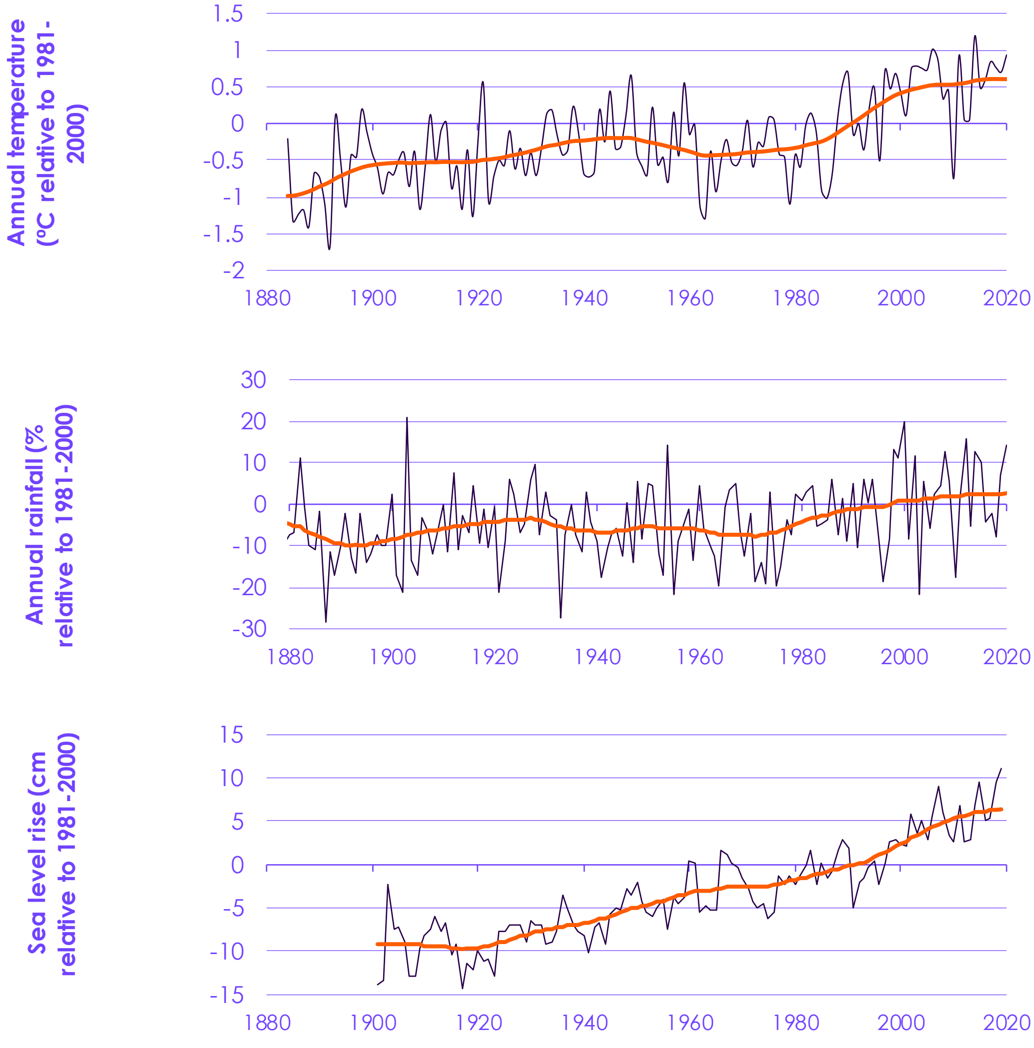
25% of years, whereas they would be expected in less than 10% of years only a few decades ago.[10] Cold extremes have also decreased in frequency and intensity.

- **Changed precipitation extremes:** Metrics for heavy rainfall generally show an increase in very wet days across the UK. However the expected signal associated with human-induced climate change remains hard to distinguish from the large interannual variability in the observational record at a UK-wide scale.[11] Extreme event attribution studies indicate that human-induced climate change has increased the likelihood of some observed UK precipitation extremes linked to significant flooding impacts.[12]

Further changes in the UK's climate linked with global climate change will emerge over coming years.

Evidence of the effects of global climate change in these and other aspects of the UK's weather and climate is expected to grow over the coming years as human-induced warming continues to increase and as observational records get longer.

Figure 1.2 Observed changes in aspects of UK climate



Source: CCC analysis; HadUK-Grid dataset, Kendon, M. et al. (2020) State of UK Climate 2019. *International Journal of Climatology*, 40 (S1), 1-69.
Notes: Annual data is shown in all panels. The orange line is a moving 29-year triangular averaging window (reflecting at ends of timeseries) in all panels.

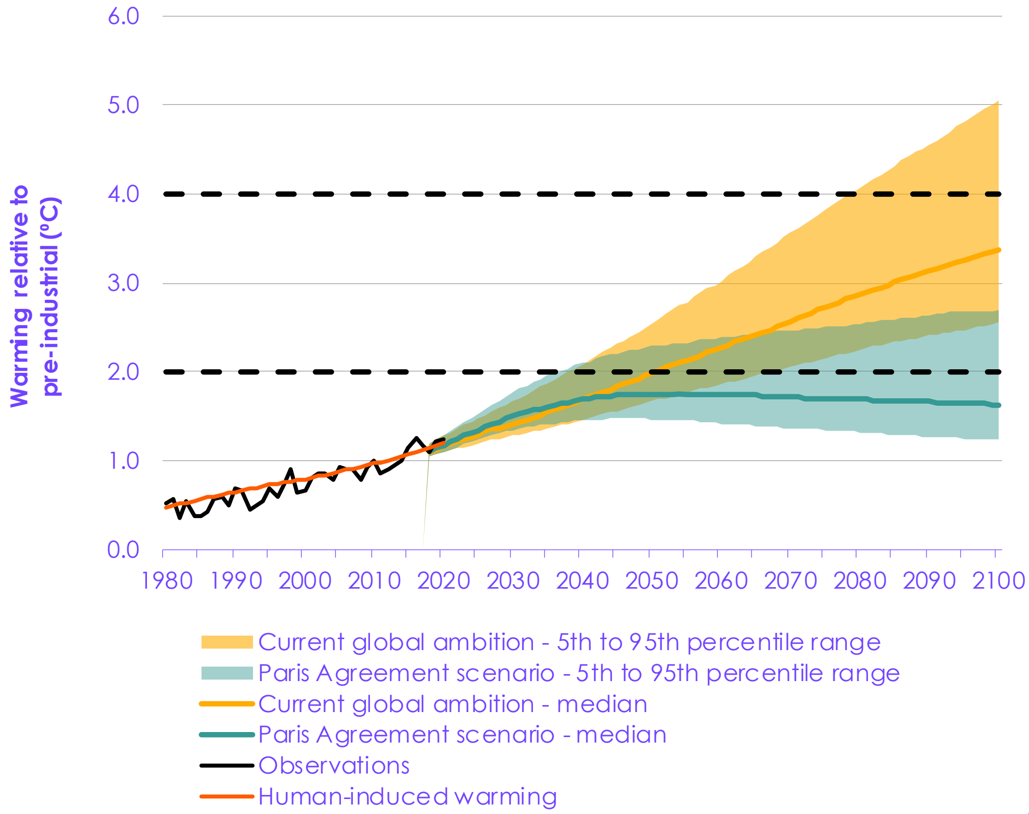
Further change in aspects of the UK's climate is inevitable – no matter how global greenhouse gas emissions change in future.

Future changes in UK weather and climate depend on both the amount of future global greenhouse gas (GHG) emissions and on how the climate responds to these emissions. Although the latest evidence indicates that there is expected to be no significant future global warming 'locked-in' from past emissions, further changes in the global and UK's climate by 2050 is inevitable as the world will take several decades, at the very least, to reach Net Zero emissions.[13] Longer-term (post-2050), changes in the UK's climate will largely depend on how rapidly global emissions are reduced and then brought toward Net Zero.

Changes in global temperature over the next few decades do not significantly differ across the range of possible global emissions pathways. Countries around the world are currently strengthening their commitments to reduce emissions ahead of the next UN climate change conference, COP26, scheduled for November 2021. A similar range of possible levels of global warming over the next several decades is expected, irrespective of whether global decarbonisation ambition continues at current levels or is successfully strengthened to align with global emissions pathways expected to achieve the Paris Agreement (Figure 1.3).

There is little difference between different pathways for global emissions for the range of global temperature changes expected in the near-term.

Figure 1.3 Global temperature projections under a range of global emissions reduction ambition



Source: CCC (2020) The Sixth Carbon Budget: The UK's path to Net Zero.
Notes: This 'current global ambition' scenario is one in which current global commitments for emission reductions in 2030 are achieved with a similar decarbonisation effort maintained over the rest of the century. Pledged Net Zero targets are not assumed to be met in this scenario. The Paris Agreement scenario sees global emissions fall rapidly from 2020 with Net Zero CO2 emissions reached around 2060 and is estimated to be consistent with keeping (central estimate) warming 'well-below' 2°C above preindustrial levels. The range of climate outcomes shown here are based on the recent World Climate Research Programme estimate and include a median estimate of additional climate feedbacks not typically included in current climate models (e.g. permafrost thawing).

Changes in the UK's climate by mid-century

Expected changes in the UK's climate by 2050 are also (largely) independent of the pathway of global emissions.

Expected changes in the UK's climate by 2050 are also (largely) independent of the pathway of global emissions. Across a range of possible future pathways for global emissions a consistent picture of expected changes in UK weather and climate emerges:*

- **Warmer and wetter winters:** By 2050 the UK's average winter could be around 1ºC warmer (0.5ºC cooler – 2.5ºC warmer uncertainty range) than it was on average over 1981-2000 and around 5% wetter (10% drier – 20% wetter uncertainty range). An increase in both the intensity of winter rainfall and the number of wet days is expected.

- **Hotter and drier summers:** By 2050 the UK's average summer could be around 1.5ºC warmer (0ºC – 3ºC uncertainty range) than it was on average over 1981-2000 and around 10% drier (30% drier – 5% wetter uncertainty range). A summer as hot as in 2018 (the joint hottest summer on record) for the UK as whole could be normal summer conditions by 2050. The temperature of the hottest days each year are expected to increase more than the average summer temperature increase. The intensity of summer rainfall (when it occurs) is expected to increase.

- **Continued sea-level rise:** The seas around the UK will continue to rise over the next three decades to 2050. By 2050 sea levels could be around 10 – 30 cm higher than over 1981-2000, depending on the specific location in the UK.†

These changes in aspects of the UK's weather and climate over the next three decades will create additional weather and climate risks. For example, wetter winters will drive up the risk of flooding whilst drier summers increase the risks of water shortages, hotter summers come with more intense heatwaves that can affect farming and human health, and higher sea levels increase the risk of coastal erosion and coastal flooding from high tides and storm surges. The risks these climate changes create are summarised in Chapter 2.

* Quantitative changes are taken across the RCP2.6, RCP4.5 and RCP6.0 scenarios from UKCP18 results, with uncertainty ranges based on the 5th – 95th percentiles given there. Changes are rounded.

† Range (in 50th percentile) outcomes across UK capital cities is given here. Climate uncertainties means that changes could range from 30 – 40 cm above 1981 – 2000 levels across capital cities under a high climate response (95th percentile).

Possible changes in the UK's climate after 2050

In the second half of the century the level of global warming is strongly dependent on the success of global efforts to reduce emissions, with a wide range of global warming levels possible.

Levels of global warming of 2ºC and 4ºC above preindustrial levels by 2100 are used as indicative of the range of possible long-term changes that could occur for this risk assessment. Beyond 2050, changes in global and UK climate strongly depend on the future trajectory of global GHG emissions (Figure 1.3). If large reductions in global emissions have been achieved by 2050 (on the pathway to Net Zero soon after) only relatively minimal changes in global temperature would occur above the level reached by 2050.* If however global emissions remain significantly above Net Zero after 2050 then continued increases in global temperature would occur. This leads to a wide range of possible levels of global warming by 2100.

The 2ºC to 4ºC range is a useful indicator of the spread of possible 2100 climate outcomes that can inform adaptation strategies for the second half of the century (whilst acknowledging that they do not represent the full range of possible changes).†

Reaching a global warming level of 4ºC by 2100 would bring significant additional climate changes in the UK.

Global warming reaching 4°C above preindustrial levels by 2100 would see significant further changes to the UK's climate beyond the changes by 2050:‡

- **Much warmer and wetter winters:** the UK's average winter could be around 1 - 3ºC warmer (depending on the location across the UK) than it was on average over 1981- 2000 and around 10 - 30% wetter. Wetter winters are expected due to both an increase in the number of wet days and the intensity of rainfall when it is raining.

- **Much drier and hotter summers with frequent and intense heatwaves:** the UK's average summer could be around 3 – 5ºC warmer (depending on the part of the UK considered) than it was on average over 1981- 2000 and around 20 - 40% drier. A summer as hot as in 2018 (the joint hottest summer on record) for the UK as whole would now be significantly cooler than the average summer. Over 50% of days could have 'very high' fire risk in the peak months of the summer.[14]

- **Much higher sea levels:** UK sea levels could continue to rise reaching around 55 – 80 cm above their levels in 1981-2000 (depending on the location across the UK).§

These changes would see an increase in the rate of climate change compared to the recent decades. The faster rates of climate change can also create additional risks in of themselves, particularly on ecosystems.

* In the most ambitious global emission pathways global net negative CO_2 emissions are achieved after 2050, reducing the level of global warming in 2100 below that in 2050. However, the plausibility of the very large levels of net negative emissions needed to achieve this is uncertain.

† Global average warming can be kept below 2°C above 1850 - 1900 levels if global emissions can be cut sufficiently rapidly on a path to reaching global net-zero CO_2 emissions around 2050. Similarly, the worst cases of high climate and Earth System feedbacks under continued high global emissions could see warming exceed 4ºC above 1850-1900 levels by 2100. The falling costs of low-carbon technologies, and increasing global commitment to addressing climate change, is making these high-warming outcomes less likely over time but they remain possible and relevant for consideration in climate risks assessments.

‡ Quantitative changes are taken from Gohar, L. et al. (2018) *UKCP18 Derived Projections of Future Climate over the UK*.

§ Sea level rise could be significantly higher (>1 metre in the south of the UK) at the high end of climate response.

Changes in UK climate beyond 2050 would be much less if global warming is kept to below 2ºC above preindustrial levels by 2100.

A 2°C rise in global temperature above preindustrial levels by 2100 would see relatively small additional changes in many (but not all) aspects of UK climate beyond those already expected by 2050. Further changes in summer and winter temperature and precipitation would be relatively limited (Table 1.1) – however UK sea levels would continue to rise through to 2100 (and beyond) even under a stabilisation of global warming at 2°C above preindustrial levels or below.

Table 1.1
Observed and projected changes in UK hazards due to climate change

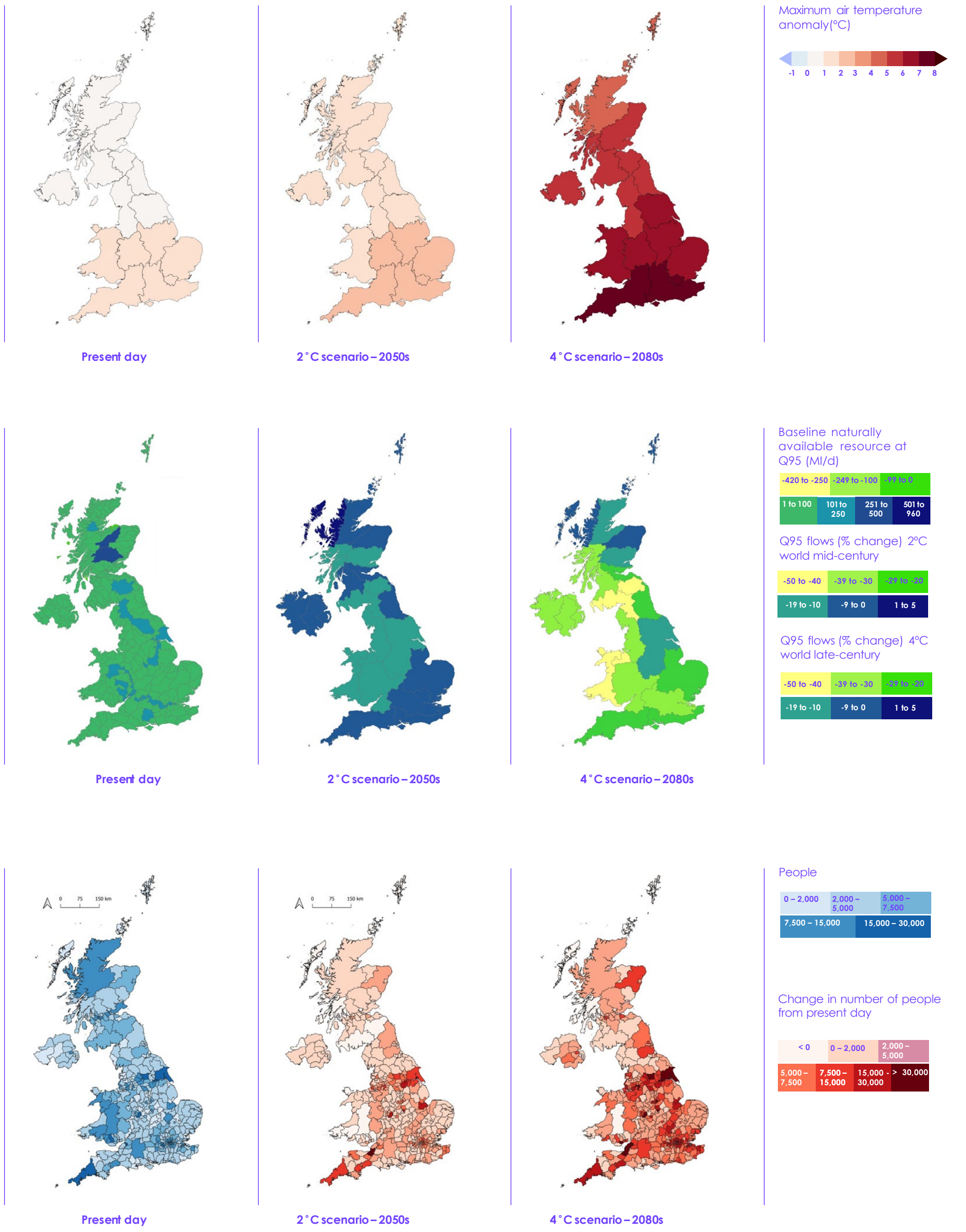
Observed change	Expected change by mid-century	Global warming of 2°C above preindustrial levels by 2100	Global warming of 4°C above preindustrial levels by 2100
0.6°C from 1981 – 2000	**~1.3°C** from 1981 – 2000	**~1.5°C** from 1981 – 2000	**~3°C** from 1981 – 2000
10 – 25% chance of a '2018 summer', up from <10% a few decades ago	**~50%** chance each year	**~50%** chance each year	**>>50%** chance each year
0 no significant long term trend	**~10%** drier than over 1981 – 2000	**~15%** drier than over 1981 – 2000	**~30%** drier than over 1981- 2000
0 no significant long term trend	**~5%** wetter than over 1981 – 2000	**~5%** wetter than over 1981 – 2000	**~20%** wetter than over 1981 – 2000
0 Some increase, but no significant long-term trend	**~10%** increase	**~20%** increase	**~50%** increase
~6.5cm above 1981-2000	**10 – 30cm** above 1981-2000	**25 – 45cm** above 1981-2000	**55 – 80 cm** above 1981-2000

- Average annual UK temperatures
- 'Hot summer' occurrence
- Average summer rainfall
- Average winter rainfall
- Heavy rainfall
- Sea level rise

Notes:
* Changes to mid-century are taken from across RCP2.6, 4.5 and 6.0 scenarios for UKCP18 probabilistic projections (50th percentiles).
** Changes are taken from the 50th percentile of the RCP2.6 probabilistic projections from UKCP18 averaged over 2081 – 2100 (approximately consistent with a global warming level of 2°C above preindustrial levels.
*** Estimated from the UKCP18 Derived Projections for a global warming level of 4°C above preindustrial levels using the median model realisation. Values given are indicative of the middle of the range of local changes expected across most of the UK.
Heavy rainfall is here defined as the mean of the wettest 5% in the distribution of hourly rainfall over winter. Future projections taken from Sayers et al. (2015) Projections of future flood risk for the UK.
Future sea level changes are given as a range across UK capital cities (50th percentile of projections). Future projections are taken from the UKCP18 Marine Projections for the RCP2.6 and RCP8.5 scenarios which correspond to global warming levels of 2°C and 4°C by 2100 respectively (50th percentiles). Change to 2050 are the range of 50th percentile change across UK capital cities and the RCP2.6 – RCP8.5 scenarios.
Throughout this table values are rounded. Climate response uncertainty means that a broader range of changes are possible around the central estimates presented in this table.

These changes in aspects of the UK's weather and climate are the fundamental drivers of the direct climate risks that the UK will face in future. Throughout this independent assessment, the framing of global warming levels of 2°C and 4°C above preindustrial levels by 2100 has been used to turn these projected changes in aspects of weather and climate (e.g. reduced summer average rainfall) into the climate hazards (e.g. low river flows) that create risks to people and ecosystems (Figure 1.4).

Figure 1.4 Projections of UK climate hazards



Source: a) Maximum summer temperature - UKCP18 user interface, b) Low flows - HR Wallingford et al. (2020), c) Flooding (all source) provided by Sayers et al. (2020)
Notes: a) Probabilistic projections for the 1-year average change in summer maximum air temperature from 1981-2000 baseline for 2021, 2050 (RCP2.6 50th percentile) and 2080 (RCP6.0 90th percentile) b) maps of changes in low flows (Q95 indicator) for the present day, and then % change in the 2050s (2C scenario) and 2080s (4C scenario). Note that a larger area around Northern Ireland has been included in the future projections as the analysis has used the UKCP18 river basin areas for the future projections but not for the baseline. c) Present day number of people exposed to significant flood risk (river, coastal and surface water flooding combined), and then the absolute change in number of people from the present day for 2050 (2C scenario) and 2080 (4C scenario).

Implications for adaptation policy

Several principles relevant to adaptation policy can be identified from our current understanding regarding possible future UK climate.

Several conclusions relevant to climate adaptation can be drawn from the current understanding of how the UK's weather and climate may change over the coming decades:

- **Continued change in the UK's climate should be expected.** In all scenarios for global emissions the UK's climate continues to change over the coming decades. Only under the very lowest possible values for climate sensitivity is there close to no future change in UK climate. Assuming a static UK climate at today's levels does not provide a good basis for decision making.

- **Changes in the UK's climate out to 2050 are largely insensitive to the trajectory of global greenhouse gas emissions.** Changes in the UK's climate to 2050 are not strongly sensitive to how successful the world is in cutting emissions. This means that there is significantly more certainty in the range of UK climates that could occur by 2050 than over longer time horizons (e.g. by 2100). This can help focus decision making for policy, assets and infrastructure that have a lifetime of only a few decades on a more constrained set of expected UK climates than for the assets and infrastructure that will also need to be robust to weather and climate significantly beyond 2050.

- **Very long-lasting policy and investment decisions being made today need to consider a wide range of changes in climate for the second half of the century.** Some investments being made today (e.g. housing new build) is expected to still be around in 2100. Future pathways of global emissions have a strong effect on the range of possible climates after 2050. Using a range of outcomes spanning at least 2°C to 4°C above preindustrial levels by 2100 (as in this Independent Assessment) can help to assess adaptation needs over these time horizons. Building-in flexibility mechanisms to enable the targeted long-term level of global warming resilience to be adjusted over time as more is learnt about plausible futures of global emissions and climate response can support effective decision making for these longer time horizons.

These principles can help guide effective decision making over different timescales despite the uncertainty regarding the magnitude of changes that will be experienced in the UK's future weather and climate.

Considering climate variability, changes in weather extremes and low-probability climate outcomes are important for risk assessments.

The previous section described the expected changes in the average climate conditions of the UK under different possible futures for global emissions and different time horizons. This section considers three additional aspects, climate variability, climate extremes, and low-probability outcomes that are also important for assessing future UK weather and climate risks.

Climate variability and climate extremes

Variability in weather from year-to-year will continue to be very important for future weather and climate risks.

The UK's weather and climate are naturally variable today and will continue to be in the future. Individual years and seasons can be significantly warmer or colder than the average climate conditions as well as significantly wetter or drier. Cycles of average conditions of the Jet Stream over the North Atlantic can also drive large variations in the UK's climate over multi-year periods. Adequately preparing for future climate and weather hazards means building resilience to the expected year-to-year fluctuations in the UK's weather and climate as well as to the range of possible average conditions.

Maintaining resilience to individual years that could be very different from the expected future average is important for climate adaptation.

Incorporating climate variability and climate extremes into adaptation planning is important for multiple reasons:

- **Individual years could still see conditions opposing the long-term average trend.** Climate variability in the UK means that, for example, total rainfall in an individual future UK summer could still be significantly greater than typical over the recent past despite drier summers expected on average (Figure 1.5). Whilst preparing for more hotter and drier summers on average, it is therefore important that resilience to individual summers that are significantly wetter and cooler than the recent average is maintained.*

- **The frequency of damaging UK weather patterns may shift due to global climate change.** Evidence from new modelling produced for the latest UK climate projections indicates future UK winter weather may be dominated more often by weather patterns associated with wetter, wilder and windier winter weather, particularly over western parts of the UK. This would bring increases in flooding risks as well as strong winds and waves.† Possible shifts in the frequency of different patterns of UK weather should be factored into effective adaptation planning as this evidence base becomes more robust.

- **Changes in climate extremes may look different to changes in the average climate conditions.** Many climate risks are driven by changes in weather extremes (e.g. flash flooding is driven by the intensity of rainfall over the period of a few hours). At the UK-wide scale the chance of a summer as hot as in 2018 (the joint warmest UK summer) rises to around one in every two years by 2050 from up to one in every four today.

* This also applies to other aspects of the UK's weather and climate, such as winter temperature and precipitation, where individual winters in future could still be colder and drier than over the recent past despite a shift to wetter and warmer winters on average.

† Detail is provided in Chapter 1 of the CCRA3 Technical Report. Slingo, J. (2021) Latest Scientific Evidence for Observed and Projected Climate Change. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

The temperature of hot summer days is also expected to warm more than the summer average temperature. Although summers are expected to be drier on average, the intensity of rainfall when it does rain is expected to increase significantly in summer, with the possibility of intense localised rainfall extending into the autumn – raising the risks of flash flooding and extending the duration of the year in which it could occur.

Insights from high-resolution modelling suggest that increases in climate extremes might be larger than in coarser resolution models.

It is necessary to go beyond average changes to fully understand the extent of the hazards and the range of outcomes that resilience needs to be built for. Important new insights on the extent of this variability is now available from new high-resolution projections for the UK that suggest that some aspects changes in UK extremes may be larger than expected from coarser-resolution modelling (Box 1.1).

Box 1.1
Insights from high-resolution modelling for future UK climate

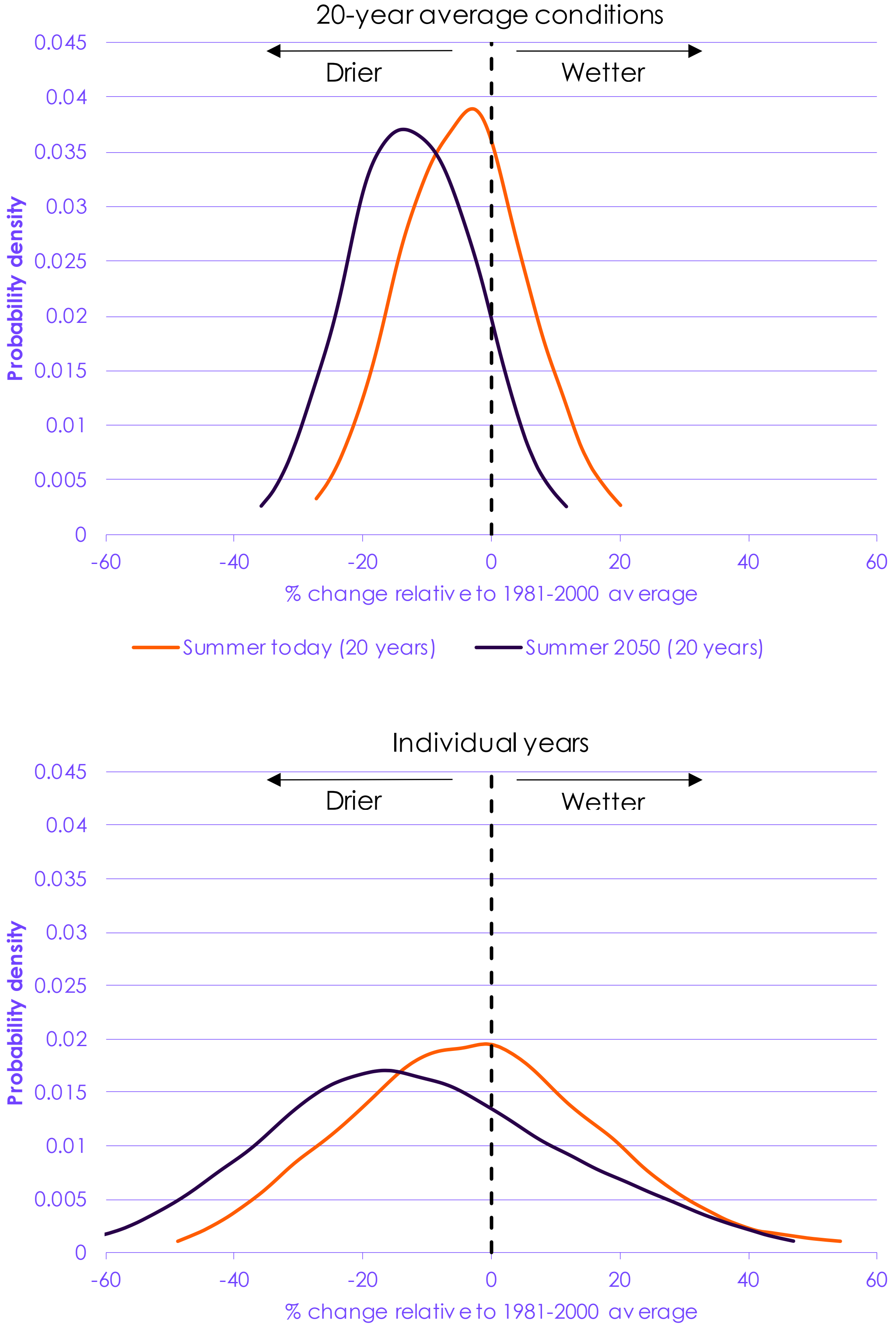
The latest UK climate projections (UKCP18) include, for the first time, a new set of high-resolution projections produced using a climate model with a resolution of 2.2 km over the UK. This resolution is the same used in weather forecast models and allows convection (the vertical movement of air) processes relevant to the formation of clouds to be resolved within the model. These processes are particularly important for representing intense rainfall events that occur over just a few hours and can lead to flash-flooding. These simulations improve the ability to represent how rainfall varies day-to-day and hour-by-hour across the UK as well as the representation of the UK's average climate today. This high-resolution modelling has been used to explore possible changes in the UK's climate under a very high global emissions future. There are a number of relevant differences to lower-resolution models:

- **Increases in winter rainfall are significantly larger than in lower resolution models:** Changes in winter total rainfall in convective-permitting models can nearly twice as large as in modelling with a resolution of around 10 km. This occurs due to a larger increase in the number of days with rainfall than in the lower resolution models, and possibly due to better representation of convective rainfall moving inland.
- **Larger increases in intense summer rainfall:** Both convection-permitting and coarser resolution models project summers to be drier overall in future, but project heavier rainfall when summer rainfall does occur (wet days are projected to become less frequent overall). The increase in the intensity of summer rainfall is more pronounced in the convection-permitting models – with potentially increased risks of summer flash-flooding.
- **More intense temperature extremes:** The higher-resolution projections from the convection-permitting model show that it is more likely to exceed high temperature thresholds in summer (e.g. 40ºC) than in lower-resolution projections. This is due to the improved representation of urban heat island effects within the higher resolution models. More frequent exceedance of these high-temperature thresholds can increase the risks of heat-related mortality.

These new high-resolution projections are an important new resource for understanding future UK weather and climate risks. The differences outlined above provide a compelling case that higher resolution projections may offer a more accurate estimate of how UK climate extremes may change in the future, with larger changes than in more conventional resolution climate models. These projections do however need to be set within the context of other strands of UKCP18 which consider a broader range of uncertainties, for example a range of global simulations providing boundary conditions to the UK model covering a wide range of climate sensitivities.

Source: Kendon E. et al. (2019) UKCP Convection-permitting model projections: Science report; Slingo, J. (2021) Latest Scientific Evidence for Observed and Projected Climate Change. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

Figure 1.5 Probability density functions for future and current UK summer total precipitation for 20-year averages (top) and individual years (bottom)



Source: UKCP18

Notes: Future conditions (for 2050) are shown under the RCP4.5 scenario. A similar qualitative picture is expected for other possible futures for global greenhouse gas emissions and for other climate variables (e.g. temperature) and seasons.

Low-likelihood, high-impact outcomes

Low-probability climate changes outside of the main envelope of climate projections could still occur and may have a large impact in the UK.

'Low-likelihood high-impact' outcomes are weather and climate changes that, whilst possible, are thought to be sufficiently unlikely that they don't feature within the standard range of projections for the UK's future weather and climate, but nonetheless can have large impacts if they were to occur. For examples, an abrupt collapse in the Atlantic Ocean currents this century is thought unlikely but would have a large impact on the climate of Western Europe including the UK. The CCRA Technical Report has considered the low-likelihood, high-impact events that may occur over the course of the rest of the century and the climate risks they could create in the UK.*

Low-likelihood, high-impact outcomes can be classified into three groups:

- Changes that have a direct effect on the UK's local weather and climate – for example: collapse in the Atlantic Overturning Circulation, or large shifts in the position of the North Atlantic Jetstream.
- Changes involving melting of land ice, affecting sea level rise impacts in the UK and worldwide – for example collapse of the Greenland or West Antarctic ice sheets.
- Changes that provide a large feedback on carbon or other biogeochemical cycles that would act to significantly amplify global warming – for example significant and rapid greenhouse gas release from thawing permafrost.

Considering possible low-probability outcomes through 'what-if' scenarios can help understand the risks they pose to the UK and what actions could be taken to reduce risks.

If these low-likelihood high-impact outcomes were to occur, there would be significant implications for the climate and weather risks that the UK would face (Table 1.2). For many of these low-likelihood high-impact events further research is required to better understand the mechanisms underlying these changes, their plausibility, and the effects they would have if they were to occur. 'Storyline' or 'what-if' scenarios (which consider the implications of a particular event occurring without trying to assess how likely this would be) can be useful ways to help understand the risks that low-likelihood high-impact events would pose to the UK. Monitoring systems that may be able to identify early signals of these events occurring could be a useful part of understanding and addressing these risks.

* These low-likelihood high-impact outcomes (also known as earth-system tipping points, and sometimes as climate tipping elements) are described in Chapter 1 of the Technical Report and where evidence is available, summarised in relation to each risk and opportunity in Chapters 3 – 7. A special report on 'Effects of Potential Climate Tipping Points on UK Impacts' has also been produced for CCRA3 Technical report.

Table 1.2
Risks arising from low likelihood, high impact events

	Types of climate change that could occur	Resulting risks
Extreme changes to regional and UK climate	• Abrupt collapse of the Atlantic Meridional Overturning Circulation (AMOC), leading to reduced European warming, reduced summer rainfall, increased winter storminess over and above projected trends in Europe • Changes to the Jet Stream due to Arctic warming, leading to persistent and amplified 'waviness', leading to changes to UK weather patterns	• Widespread and large reductions in arable farming output • Severe depletion of groundwater reserves and severe summer drought
Land ice melt-accelerated sea level rise	• Accelerated loss of Antarctic and Greenland Ice Sheets, leading to sea level rise of over 1 m and up to 2 m by 2100 (and much more beyond)	• Extreme coastal flooding and widespread loss of viable coastal communities
Carbon and biogeochemical feedback cycles – accelerated global warming	• Large and rapid release of carbon from permafrost thawing significantly amplifying the level of global warming so that it reaches above 4°C from preindustrial levels by 2100 • Large reduction in the carbon uptake by the biosphere (oceans, Amazon, northern boreal forests), leading to abrupt ecosystem collapse and accelerated warming	• Major increases in heat-related deaths and losses to well-being and productivity • Major increases in cooling demand

High-impact events can also occur within the standard range of climate outcomes.

The CCRA3 Technical Report also highlights potential extreme events that could 'tip' particular systems into severe impacts. These outcomes could be possible even within the standard range of UK climate changes outlined in the Technical Report. Some examples of these changes are:

- Consecutive seasons with stable atmospheric circulation patterns driving a very dry summer followed by a dry winter; this could lead to severe drought and soil moisture deficits, drought orders, major impacts on biodiversity, agriculture and forestry, with consequent disruptions and economic losses to agriculture, water supply and the natural environment.

- A warm autumn followed by a wet spring, leading to severe drops in agricultural harvests (as was seen in France in 2016). The East of England is at particular risk from such events.

- Changes in atmospheric circulation patterns leading to increased UK storminess with severe impacts on the coast, such as experienced in winter 2013/14 leading to extreme flooding and erosion.

- Successive storms (e.g. Storm Ciara and Dennis in 2020) where the second storm hampers recovery from the first and leads to even greater human health, environmental and economic impacts.

- The risk of novel vector-borne diseases reaching the UK and spreading rapidly even in the current climate with related human health costs and productivity impacts.

These examples highlight the potential for instances of climate variability within the current and expected envelope of possible UK climate changes, to drive potentially very high impact events on specific systems.

Endnotes

[1] The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

[2] Based on human-induced warming estimated at globalwarmingindex.org.

[3] IPCC (2018) Special Report on Global Warming of 1.5ºC - Chapter 1: Framing and context.

[4] IPCC (2019) Special Report on the Ocean and Cryosphere in a Changing Climate.

[5] IPCC (2018) Special Report on Global Warming of 1.5ºC - Chapter 3 - Impacts of 1.5°C of Global Warming on Natural and Human systems.

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[7] Frame, D. et al. (2017) Population-based emergence of unfamiliar climates. *Nature Climate Change*, 7, 407 – 411.

[8] Based on method in Hawkins, E. et al. (2020) Observed Emergence of the Climate Change Signal: From the Familiar to the Unknown. *Geophysical Research Letters*, 47, 6.

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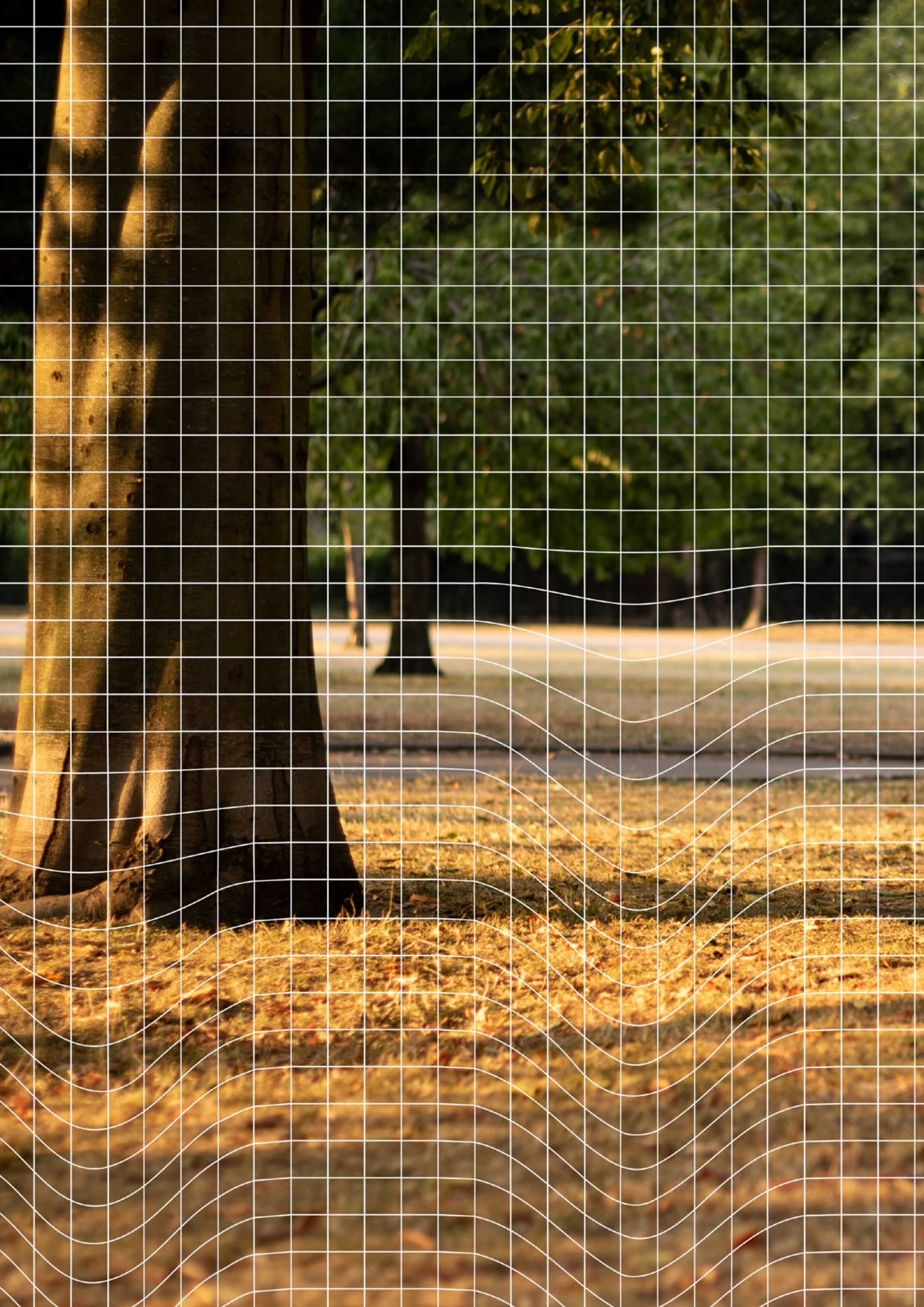
[13] MacDougall, A. et al. (2020) Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO2. Biogeosciences, 17, 2987–3016.

[14] Belcher, C. et al. (2021) *UK Wildfires and their Climate Challenges*.

Chapter 2

Assessing UK climate risk



Introduction and key messages

This chapter synthesises the assessment from the CCRA3 Technical Report on the risks and opportunities that climate change will bring to the UK and what issues need to be considered in effective risk assessments.

The Technical Report has assessed both the magnitude (size) and the degree of urgency of further adaptation action for 61 risks and opportunities. It considers climate change from the present day to 2100. It also considers a series of cross-cutting issues that relate to understanding risk, including how the costs from climate change alter in the future in different scenarios, the importance of understanding thresholds and interactions between risks, and to what extent there are opportunities from climate change for the UK.

We set out a summary of this information from the Technical Report in this chapter, alongside our analysis of how climate risks are likely to affect societal goals, how climate risks need to be integrated into policy making, and how the assessment of risk has changed since the last CCRA in 2017.

Our conclusions are:

- **The UK faces risks from climate change to its natural environment, its food and water supplies, its infrastructure, the health and wellbeing of its population and disruption to its business.** The risk assessment considers different impacts across these sectors. Many of the risks are already material and all are expected to worsen under warming of 2°C, with escalating impacts in a 4°C scenario even with high levels of adaptation.

- **The assessment shows an increase in high magnitude risks between today and 2100.** The percentage of 'high' magnitude risks increases from 26% of the total in the present day, to 79% in the 4°C pathway in the 2080s. There is also a noticeable increase in the number of high magnitude risks compared to similar risks assessed in CCRA2; 14 risks in this assessment have higher future risk scores than in CCRA2, whereas none have lower scores. A key evidence gap that must be filled for CCRA4 is to develop better quantitative estimates of impacts across all of the risks and opportunities in a 2°C and 4°C scenario.

- **There are significant economic costs from negative impacts under all future scenarios in the absence of further adaptation.** While it was not possible to calculate a total economic cost of climate change for the UK in this assessment, the valuation analysis suggests that the number of individual risks with very high annual damage costs (£billions/year) could triple in the 2°C scenario compared to the present day.

- **Key Government and societal goals will be harder to meet because of climate change.** These include ensuring a healthy and safe society with natural and cultural heritage protected; having a reliable and safe supply of food, water, transport, energy and digital services; sustainable businesses; thriving plants, wildlife and ecosystems that underlie human life and economic activity; and reducing UK emissions of greenhouse gases to Net Zero. Without further adaptation even in a 2°C scenario, these goals will become more expensive to achieve at best, and impossible to achieve at worst.

- **Effective risk assessments need to consider interacting risks and threshold effects.** Interacting risks pose one of the biggest challenges when assessing climate risks. A single hazard, such as a flood, will often have knock-on impacts across a range of sectors, amplifying the resulting risk. Siloed thinking remains a problem for addressing climate change risks or opportunities that interact, that are subject to cascading impacts, or where adaptation responsibility falls across more than one government department. Another component of risk planning that is often missed out is understanding threshold effects. A threshold is the point at which a 'non-linear' change in a system occurs as a result of change in a climate driver – such as temperature. For example, algal blooms can start to occur when water temperatures exceed 17°C. Understanding where these thresholds exist and how likely they may be in the future is important for understanding the size of a given risk and its economic costs, as well as at what point a different approach to adaptation might be required.

- **Climate change may also present some opportunities for the UK,** including for new species and longer growing seasons in agriculture and forestry, benefits from warmer temperatures for health and energy bills, and opportunities for adaptation goods and services. While many opportunities will not require government action, there are cases where intervention could help fully realise benefits (such as through finance), but there is little evidence of such action being taken. Most of the opportunities will not be realised unless the corresponding risk is also addressed; increased agricultural productivity will not happen without adequate soil and water quantity and quality, for example.

- **The UK is less well prepared for climate change now than it was five years ago.** This largely reflects that the pace of change in risk has outstripped the pace of adaptation; only four of the 61 risks and opportunities have been scored as not having an adaptation gap. At the UK level, 56% of the risks and opportunities assessed have been given the highest 'urgency score' in the CCRA3 Technical Report, compared to 36% for the last assessment in 2016. More of the risks are now classed as 'high magnitude' in the future, meaning that the assessment of the impact of the risks in the absence of additional adaptation has increased.

We set out our analysis in the following sections:

1. Introduction to the risk assessment
2. Impacts of climate change for 2°C and 4°C warming scenarios
3. Costs of climate impacts in the UK
4. Impact on societal goals
5. Threshold effects
6. Interacting risks
7. Opportunities from climate change
8. How risks and opportunities have changed since CCRA1 and CCRA2

The CCRA3 Technical Report follows a three step method, based on assessing the magnitude of current and future risks or opportunities, the extent of adaptation planned, and the benefits of further action in the next five years.

The CCRA3 Technical Report provides a detailed assessment and scoring for the risks and opportunities to the UK from climate change.
The CCRA3 Technical Report provides a detailed description of the assessment of each risk and opportunity, including a) the current and future magnitude of impact* under different climate and socioeconomic scenarios, b) an assessment of current and planned adaptation, and c) an assessment of the benefits of further adaptation in the next five years. We do not summarise all of the detailed analysis for each risk and opportunity in this Advice Report but encourage readers to use the Technical Report and accompanying Summaries (see Figure 5 in the 'About this Report' section) to see the full analysis for specific risks and opportunities. The Technical Report runs to nearly 1,500 pages, with further evidence presented in a series of accompanying research reports. In total, the independent assessment consists of 3,500 pages of analysis.

The risk assessment has identified 61 key risks and opportunities to the UK from climate change.
The Technical Report authors consulted with government, external stakeholders and the CCC on which risks and opportunities to consider in the risk assessment, resulting in a shortlist of 61 risks and opportunities to assess in detail for this CCRA. For each risk and opportunity, an assessment of the urgency of further action has been conducted. This assessment includes three questions:

1. What is the current and future level of risk or opportunity?

2. Is the risk or opportunity being managed, taking account of government action and other adaptation?

3. Are there benefits of further action in the next five years, over and above what is already planned?

Using the answers to these three questions, each risk and opportunity has ultimately been awarded an 'urgency score' using one of four categories as shown in Table 2.1.

61 risks and opportunities have been assessed related to the natural environment; infrastructure; health and built environment; business; and international dimensions.

The scores are split out in the Technical Report by UK nation. Although 'more action needed' and 'further investigation' are deemed the higher urgency categories, adaptation action is needed across all four categories of urgency; what varies is the type of action and how far it diverges from current adaptation. 'Sustain current action' and 'watching brief' are categories that suggest a continuation of current adaptation effort and monitoring, but there will still be costs associated with these actions as they continue. In addition, further research and monitoring are needed across all of the risks and opportunities in the assessment. This need for research does not just apply to the 'further investigation' category.

* See Annex for criteria for magnitude categories

Table 2.1
CCRA3 urgency categories

Urgency category	Definition of urgency category
More Action Needed	New, stronger or different Government action, whether policies, implementation activities, capacity building or enabling environment for adaptation – over and above those already planned – are beneficial in the next five years to reduce climate risks or take advantage of opportunities. This will include different responses according to the nature of the risks and the type of adaptation, but include: • Addressing current and near-term risks or opportunities with low and no-regret options (implementing activities or building capacity). • Integrating climate change in near-term decisions with a long life-time or lock-in. Early adaptation for decisions with long lead-times or where early planning is needed as part of adaptive management.
Further Investigation	On the basis of available information, it is not known if more action is needed or not. More evidence is urgently needed to fill significant gaps or reduce the uncertainty in the current level of understanding in order to assess the need for additional action.
Sustain Current Action	Current or planned levels of activity are appropriate, but continued implementation of these policies or plans is needed to ensure that the risk or opportunity continues to be managed in the future.
Watching Brief	The evidence in these areas should be kept under review, with continuous monitoring of risk levels and adaptation activity (or the potential for opportunities and adaptation) so that further action can be taken if necessary.

Source: Watkiss, P. and Betts, R.A. (2021) Method. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London

Table 2.2 sets out the urgency scores for each risk and opportunity, using the highest score awarded across the UK to derive a 'UK-wide' urgency table. These denote the primary results of the assessment and direct government to how it should approach adaptation action for each risk and opportunity in the next iterations of the National Adaptation Plans for England, Northern Ireland, Scotland and Wales (full urgency scores by UK nation are provided in the CCRA3 National Summaries and Technical Report).

Table 2.2
CCRA3 Risks and Opportunities by Urgency Score (UK-wide scores)

N1 Risks to terrestrial species and habitats	N2 Risks to terrestrial species and habitats from pests, pathogens and INNS	N4 Risk to soils from changing conditions, including seasonal aridity and wetness	N5 Risks to natural carbon stores and sequestration from changing conditions	N6 Risks to and opportunities for agricultural and forestry productivity
N7 Risks to agriculture from pests, pathogens and INNS	N8 Risks to forestry from pests, pathogens and INNS	N11 Risks to freshwater species and habitats	N12 Risks to freshwater species and habitats from pests, pathogens and INNS	N14 Risks to marine species, habitats and fisheries
N16 Risks to marine species and habitats from pests, pathogens and INNS	N17 Risks and opportunities to coastal species and habitats	I1 Risks to infrastructure networks from cascading failures	I2 Risks to infrastructure services from river and surface water flooding	I5 Risks to transport networks from slope and embankment failure
I8 Risks to public water supplies from reduced water availability	I12 Risks to transport from high and low temperatures, high winds, lightning	H1 Risks to health and wellbeing from high temperatures	H3 Risks to people, communities and buildings from flooding	H4 Risks to people, communities and buildings from sea level rise
H6 Risks and opportunities from summer and winter household energy demand	H8 Risks to health from vector-borne diseases	H11 Risks to cultural heritage	H12 Risks to health and social care delivery	H13 Risks to education and prison services
B1 Risks to business sites from flooding	B2 Risks to business locations and infrastructure from coastal change	B6 Risks to business from disruption to supply chains and distribution networks	ID1 Risks to UK food availability, safety, and quality from climate change overseas	ID5 Risks to international law and governance from climate change overseas that will impact the UK
ID4 Risks to the UK from international violent conflict resulting from climate change	ID9 Risk to UK public health from climate change overseas	ID7 Risks from climate change on international trade routes	ID10 Risk multiplication from the interactions and cascades of named risks across systems and geographies	N3 Opportunities from new species colonisations in terrestrial habitats
N9 Opportunities for agricultural and forestry productivity from new species	N10 Risks to aquifers and agricultural land from sea level rise, saltwater intrusion	N15 Opportunities for marine species, habitats and fisheries	N18 Risks and opportunities from climate change to landscape character	I3 - Risks to infrastructure services from coastal flooding and erosion
I4 Risks to bridges and pipelines from flooding and erosion	I6 Risks to hydroelectric generation from low or high river flows	I7 Risks to subterranean and surface infrastructure from subsidence	I9 Risks to energy generation from reduced water availability	I10 Risks to energy from high and low temperatures, high winds, lightning
I13 Risks to digital from high and low temperatures, high winds, lightning	H2 Opportunities for health and wellbeing from higher temperatures	H5 Risks to building fabric	H7 Risks to health and wellbeing from changes in air quality	H9 Risks to food safety and food security
H10 Risks to health from poor water quality and household water supply interruptions	B3 Risks to businesses from water scarcity	B5 Risks to business from reduced employee productivity – infrastructure disruption and higher temperatures	B7 Opportunities for business - changing demand for goods and services	N13 Opportunities to marine species, habitats and fisheries
I11 Risks to offshore infrastructure from storms and high waves	B4 Risks to finance, investment, insurance, access to capital	ID8 Risk to the UK finance sector from climate change overseas	ID2 Opportunities for UK food availability and exports	ID3 Risks to the UK from climate-related international human mobility
ID6 Opportunities (including Arctic ice melt) on international trade routes				

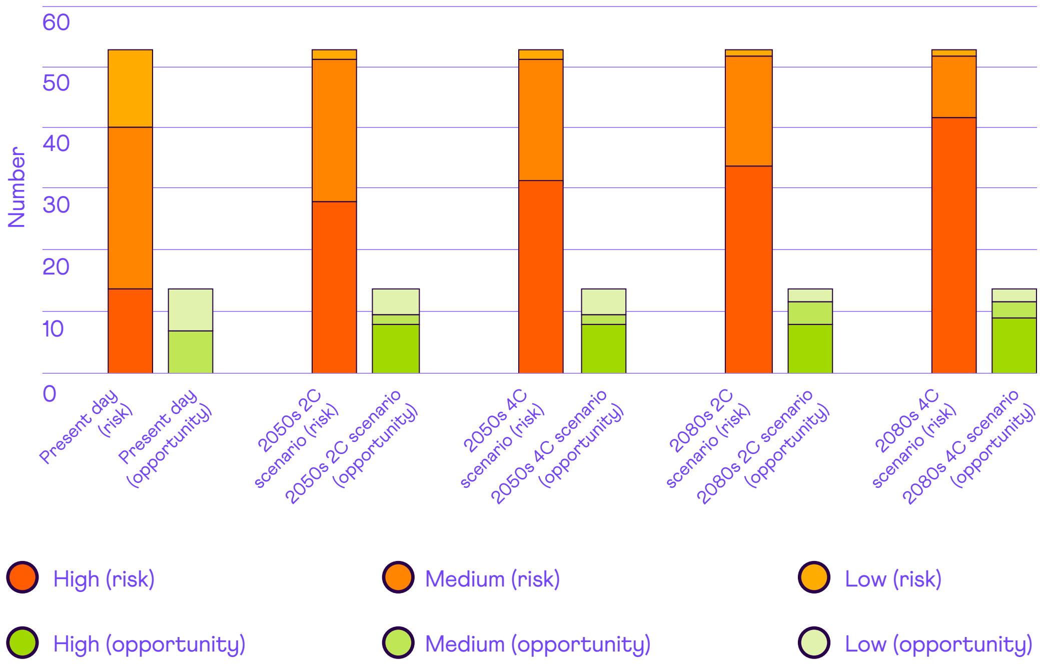
- More Action Needed
- Further Investigation
- Sustain Current Action, Watching Brief

Source: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London
Notes: A UK-wide score has been derived using the highest urgency score awarded across the four UK nations for each risk or opportunity.

The percentage of 'high' magnitude risks (red bar) increases from 26% of the total in the present day, to 79% in the 4°C scenario in the 2080s.

The proportion of high magnitude risks increases significantly in the future. The risk assessment has assigned magnitude categories (low, medium, high or unknown*) for each risk and opportunity for the present day, and the 2050s and 2080s for both a 2°C and 4°C scenario. Figure 2.1 shows the changes in magnitude of the risks and opportunities. The percentage of 'high' magnitude risks increases from 26% of the total in the present day (14 risks), to 79% in the 4°C scenario in the 2080s (42 risks). Even in the 2°C pathway there is still a significant proportion of high magnitude risks by the 2080s (64%, or 34 risks).† There is a large increase in the magnitude of risk compared to the present day in all future scenarios.

Figure 2.1 Changing magnitude of risks and opportunities



Source: Based on The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.
Notes: Figure shows how the number of low, medium and high magnitude risks and opportunities changes from the present day to the 2080s, in both 2°C and 4°C scenarios. See Annex for the criteria for the different magnitude scores. The highest magnitude across the four UK nations has been used. For risk numbers that are listed as both a risk and opportunity (e.g. N5 – risks and opportunities for natural carbon stores) the magnitude has been counted under both the risk column and the opportunity column.

While the Technical Report has used magnitude categories to assess the size of impact for each risk and opportunity, this semi-quantitative scoring needs to be improved in future assessments.

* See Annex for the criteria used for each magnitude category. At the UK level, monetised impact categories are a) high (£hundreds of millions in annual damages), b) medium (£tens of millions in annual damages), c) low (<£10 million in annual damages).

† Some of the difference in actual impact between the 2°C and 4°C scenarios is masked due to the high category including every risk with an impact over the equivalent of £hundreds of millions in annual costs.

In almost no cases has it been possible for the Technical Report to give quantified estimates of annual impact for the future 2°C and 4°C scenarios. There are three reasons for this lack of quantification:

- For many of the risks, the literature available provides only qualitative descriptions of changing risk, which the authors have then used to assign a magnitude score based on expert judgement. This is particularly the case for the business and international dimensions chapters.

- Some of the risk evidence is based on specific emissions scenarios that are not easily comparable with global warming levels. For example, the SRES A1B* scenario has been a popular scenario of choice in studies prior to 2017, but this scenario spans a global temperature rise of between 2.6°C and 4.2°C by the 2080s.[1] Often, a range of regional projections within such a scenario have been used that then each represent a different warming level. This issue is frequently seen in the natural environment, health and infrastructure chapters.

- Some studies where it is possible to translate an emissions scenario into a warming level provide results that either fall between, or outside of the 2°C - 4°C pathway range.

In most cases, the only quantitative information for specific warming levels of 2°C and 4°C scenarios is from the CCRA3 water availability and flooding projects, where the methods were specifically designed to assign risk magnitudes in these scenarios.

These gaps in the evidence base highlight an important area of consideration for CCRA4 and beyond; further work is needed to quantify estimates of risk for the likely range of future warming levels on the basis of current and planned global emissions reduction pathways.

* The 'medium' scenario used in 2009 UK Climate Projections

The UK is already experiencing significant weather-related damages in the current climate.
The UK is vulnerable to a large range of risks from climate change, and these are projected to grow in the future. Table 2.3 shows some single-event, local or regional examples of the monetised and non-monetised impacts from extreme weather events in the UK over the past 10 years.

Table 2.3
Examples of impacts from extreme weather in the UK, 2017 - 2020

	Economic damages	Deaths	Other environmental impacts
Summer heatwaves	£770 million[2] - total estimated productivity loss in the 2010 heatwave	2,500+ heat-related deaths were recorded during the summer of 2020 in England; the highest number since 2003	Localised fish die-offs due to de-oxygenation of streams and rivers were observed during the 2018 heatwave
Flooding	£1.6 billion - overall cost of the 2015-16 winter floods	10 – 15 deaths recorded as a direct result of flooding in 2007	30% increase in topsoil degradation during winter 2015/16 floods in a sample of Scottish catchments
Drought	Economic costs of the 2012 drought were estimated at £165 million in revenues and £96 million in profit.	None recorded due to drought in the last 10 years	A net reduction in carbon uptake of ecosystems was observed during the 2018 drought across Europe
Wildfire	£32 million - agriculture sector losses from wildfire in 2020	No direct deaths caused by wildfire in the last 10 years	174,000 tonnes of carbon estimated to have been lost from the Flow Country wildfire in Scotland in 2019[3]

Source: The Third UK Climate Change Risk Assessment Technical Report. [Betts, R.A., Haward, A.B., Pearson, K.V. (eds)] Prepared for the Climate Change Committee, London

The summer of 2018 in the UK illustrates how multiple sectors can be impacted by a single extreme weather event (Figure 2.2). It is expected that a summer heatwave like that experienced in 2018 will occur on average one year in two by 2050, and in a 4°C scenario, would occur in every nine years in ten by 2100 (see Chapter 1).

Figure 2.2 2018 heatwave in numbers

1053%
increase in gorse fires compared to 2017 in Northern Ireland

84%
reduction in export value of UK wheat due to yield losses

137%
increase in farm fire costs from 2017 (£32 million)

Net reduction
in carbon uptake of natural ecosystems across Europe

864
heat-related deaths

28°C
overheating threshold exceeded in hospitals

500
emergency call-outs from private water supply failures

10,000
subsidence claims costing £64 million

40– 50%
increase in rail asset failure

7%
reduction in hydroelectric generation compared to 2017 (costing £tens of millions)

Natural environment

Health and built environment

Infrastructure

Source: The Third UK Climate Change Risk Assessment Technical Report. [Betts, R.A., Haward, A.B., Pearson, K.V. (eds)] Prepared for the Climate Change Committee, London.

A standalone valuation report has been prepared as part of the CCRA3 Independent Assessment.

Estimates of current and future monetised impacts from climate change have been included in the CCRA3 magnitude scoring.
CCRA1 included a detailed monetary valuation that estimated the effects of climate change on the market economy, human health and wellbeing, and environmental costs or benefits. A valuation analysis was not undertaken for CCRA2 due to lack of resources. In CCRA3, a separate Valuation Report has been prepared as an accompanying document to the Technical Report, synthesising the evidence on economic costs (market and non-market) of climate change impacts. The valuation fed into the magnitude scoring for each risk and opportunity.

The number of risks with very high annual damage costs could triple by the 2080s even in the 2°C scenario.

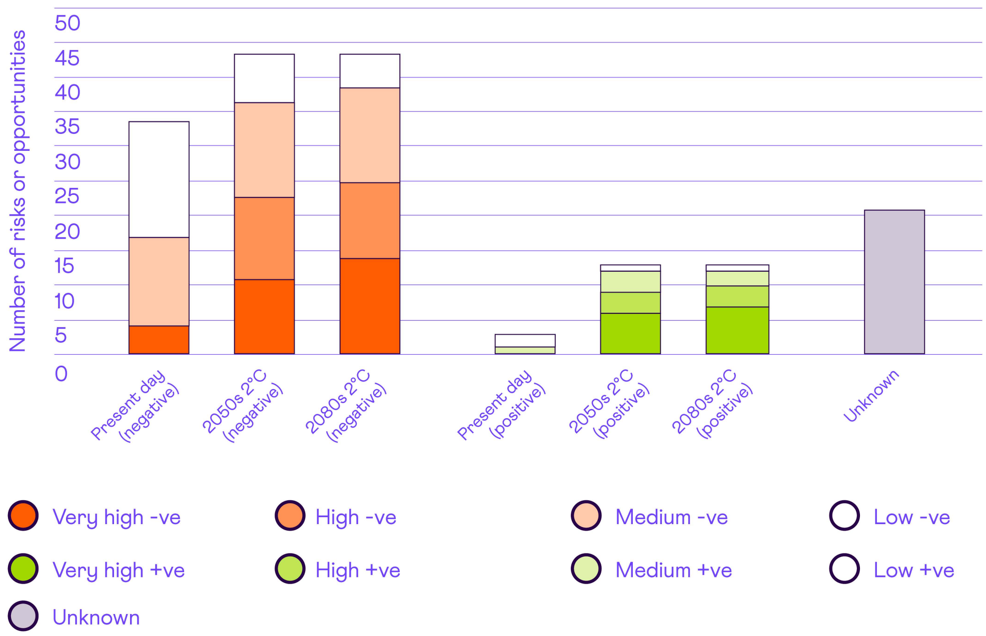
The analysis of economic costs to the UK from climate change suggests that the number of individual risks with very high annual damage costs (£billions/year) could triple in the 2°C scenario compared to the present day.
In the Valuation Report, an order of magnitude of the economic cost (or benefit) has been assigned to each risk (and opportunity) where possible. The categories used are low (<£10 million per year), medium (£tens of millions per year), high (£hundreds of millions per year) and very high (£billions per year).

Figure 2.3 shows the range of categories of monetised negative or positive impacts for the present day, 2050s and 2080s in a 2°C scenario, giving a sense of the scale of increase in costs without additional adaptation at the low end of the possible range of future climate change.

The number of risks with very high estimated damage costs increases significantly in the future; from four in the present day to 14 in the 2080s 2°C scenario. The estimated damage costs from these risks alone, assuming they are mutually exclusive would be at least in the £tens of billions per year. A significant number of the risks also have very high projected costs by 2050. These include the impacts to communities from all types of flooding (coastal, river and surface water), extreme heat risks to human life and productivity, risks to the natural environment from both slow-onset climate change and extreme events, and risks to financial services.

Indirect risks and cascading impacts all have potentially very high damage costs, but the evidence base for quantifying these effects remains limited. Chapter 3 looks at the benefits that adaptation brings in reducing these costs.

Figure 2.3 Change in monetised costs or benefits for CCRA3 risks and opportunities



Source: Based on Watkiss, P., Cimato, F., Hunt, A. (2021). Monetary Valuation of Risks and Opportunities in CCRA3. Supplementary Report for UK Climate Change Risk Assessment 3, prepared for the Climate Change Committee, London.
Notes: Values denote the number of risks and opportunities categorised by low, medium, high or very high costs (-ve and +ve) Low - <£10 million per year loss (negative) or gain (positive) Medium - £tens of millions per year in losses (negative) or gains (positive) High - £hundreds of millions per year in losses (negative) or gains (positive) Very high - £billions per year in losses (negative) or gains (positive).

It is important to consider any opportunities to the UK from climate change, alongside the risks.

Alongside the risks, there are potentially large opportunities from climate change, including a growing adaptation goods and services sector.
The Valuation Report also quantified benefits from climate change opportunities as well as the risks.

Some examples of potentially high benefits have been identified from warmer winters leading to reduced winter heating demand (and potentially a reduction in associated inequalities from winter fuel poverty), and opportunities for the adaptation goods and services industry.

However, potential positive economic effects from direct climate impacts do not 'cancel out' negative impacts because they affect different geographical areas and groups of people. In addition, negative climate impacts may mean the benefits are not realised (or that they are not deliverable) as they act as a barrier to realising the opportunity. An example is reduced water availability and soil erosion blocking potential opportunities for increased agricultural productivity due to longer growing seasons. Adaptation is needed both to take advantage of opportunities, but also to reduce the risks in order to make these opportunities feasible in the first place.

While CCRA3 provides a wide range of examples of damage costs from climate change, it does not estimate the effect of climate change risks on the UK economy as a whole.

It has not been possible to calculate a total cost of climate change to the UK, but cost estimates for specific hazards are provided in the Valuation Report, reaching £tens of billions per year by the 2080s.

Because CCRA3 is a synthesis exercise of the available literature, it draws upon a very diverse evidence base for different risks and opportunities. The different methods, scenarios, time periods, and assumptions used in the primary studies cannot be combined to provide an aggregate monetised value for the UK, i.e. a total cost of climate change (£) or a % of GDP, or to estimate the total benefit of adaptation actions. Much of the evidence available for assessing risks and opportunities is qualitative, and often risks are not quantified in a comprehensive way.

Some risk areas are also particularly challenging for valuation, making it difficult to derive a single national estimate of climate change cost to the UK. For example, for five of the 18 natural environment risks, it was not possible to derive valuation estimates from the literature. There are also very large uncertainties in the evidence on the magnitude of the costs to the UK from systemic global changes, such as changing food availability, conflict or migration. Finally, there are very few cost estimates to the UK of low-likelihood, high impact events (see Chapter 1). Understanding more about the risks from these events is critical to understand the full implications to the UK of climate change, including the benefits of mitigation in the long-term.

Instead of UK-wide coverage of costs and benefits, examples from specific events are given in the Technical Report to highlight the existing evidence and encourage further work by potentially impacted policy areas and economic sectors. The Valuation Report shows that annual damage costs for selected hazards increases ten-fold by the 2080s from today in the 4°C scenario, reaching £tens of billions for eight selected risks where quantified estimates are available.

Research work by the 'Co-designing the Assessment of Climate Change Costs' (COACCH) project, which has supported the CCRA3 valuation analysis, has assessed the potential economic costs of climate change in the UK using economic models. These models indicate very large potential costs to the UK, with a very large increase in higher warming scenarios (most notably in the 4°C scenario as would be expected). It is stressed that these numbers do not include all climate risks (especially non-market impacts) and do not consider the potential for low-likelihood, high impact outcomes.

Climate change does not just affect the current 'business as usual'. It also affects the achievement of government and societal ambitions, now and in the future, and what kind of a country is left to future generations.

Climate change affects all parts of society and economy, albeit in different ways, to different extent and in different times. Thus, it poses challenges to delivering on a large number of Government and wider societal goals. The Committee has identified 11 key societal goals that map against priority government policies and the UN Sustainable Development Goals to illustrate this point. Table 2.4 exemplifies how climate change risks and opportunities could affect these goals.

Climate change affects every part of UK society and the natural environment.

Impacts from climate change on natural assets (soil, water, biodiversity) and the services they provide will have effects on all of the goals listed, from food supply to health protection to reliable services to Net Zero. Impacts on infrastructure assets and services also have a significant number of (largely negative) impacts across the goals. Policies and plans related to health, sustainable businesses and social stability need to consider a large number of risks across different sectors (and different government departments). Importantly, many of the risks are not 'owned' by the departments that will be affected, such as the risks to health from overheating in homes, where health departments own the impact (mortality and morbidity), but planning and business departments own the policy response (building regulations and planning). Cross-departmental working is critical to ensuring the Government can achieve its aims in the face of climate change.

Table 2.4
Examples of how climate change risks and opportunities will affect societal goals

Risks	Risks to natural assets (soil, water, biodiversity)	Risk to ecosystem services (agriculture, forestry, fisheries, cultural services)	Risks to physical infrastructure assets and services	Risks to health, wellbeing and community viability	Risks to supply chains and trade routes	Risks from conflict, governance breakdown or economic shocks	Opportunities from new species, supply chains, trade routes	Opportunities for health from warmer temperatures
Goal: Reliable Food and Fibre Supply	N1, N2, N4, N11, N12. N14, N16, N17 Example: Productivity losses from soil and water degradation are estimated to be £150 million per year [N1]	N6, N7, N8, N10 Example: the 2018 hot dry summer led to 20-40% losses of yields for onions, carrots and potatoes [N6, N14]		H9	B6, ID1, ID2 Example: Price rises of 45-132% for imported vegetable crops in 2016/17 due to severe weather across Europe [B6]	ID5, ID10	N3, N9, N13, N15 Example: 160% increase in area of vineyards over last ten years in England and Wales [N9]	

Goal: Reliable Water Quantity and Quality	N4, N11, I8 Example: 16.7 million people live in water scarce regions across the UK [I8]	N10	I1, I2, I3, I4, I7, I8 Example: Around 650 clean water sites and 1,400 sewage treatment works are located in areas at significant flood risk [I2]	H10		ID10		
Goal: Reliable Energy Supply	I7 Example: One-third of high voltage subterranean electricity cables and 12% of high pressure natural gas pipelines in England are located in areas of high susceptibility to shrink-swell subsidence [I7]		I1, I2, I3, I4, I6, I9, I10, I11, H6 Example: 178 power stations and 575 substations across the UK in areas of significant surface water flood risk [I2]		ID7 Example: renewable energy generation e.g. PV relies on sourcing minerals such as cobalt from overseas supply chains [ID7]	ID10		H6
Goal: Reliable ICT Supply	I7 Example: 15% of small telecomm-unications masts are located in areas of high susceptibility to shrink swell subsidence [I7]		I1, I2, I3, I4, I6, I9, I10, I11, Example: loss of electrical power in Birmingham in 2011 led to the loss of broadband connection to hundreds of thousands of customers in the UK [I1]			ID10		
Goal: Safe and Reliable Transport	I7 Example: 22% of category 1 rail lines and 29% of major train		I1, I2, I3, I4, I5, I7, I12 Example: over 3,500km of rail length in areas at		I1 Example: Storm Desmond in 2015 left Lancaster with no	ID10	ID6, ID7 Example: Opening of Arctic trade routes could increase	

	stations are located in areas of high susceptibility to shrink swell subsidence. Network Rail reported £40million in costs from subsidence between 2006-2016 [I7]		significant risk of surface water flooding [I2]. Network Rail reported £15 million in annual payments to passengers for delays from flooding for 2006-2016 [I2]		power for >30 hours, leading to loss of traffic lights and closure of petrol stations [I1]		importance of UK ports, but also lead to an increase in global tensions on access and ownership [ID6, ID7]	
Goal: Thriving Plants and Wildlife	N1, N2, N4, N11, N12, N14, N16, N17 Example: Present day: annual control costs for invasive signal crayfish are about £9 million, and for zebra mussels are about £19 million [N12]	N1, N5, N6				ID10	N3, N13, N15 Example: Warmer winters likely to be leading to increased over-wintering survival of Dartford warblers, great tits, robins, dunnocks and wrens [N3]	
Goal: Public Health Protection	H1 Example: 'Cool roofs' (green roofs) installed in the West Midlands estimated to offset 25% of heat-related mortality [H1]		H12, H13 Example: Up to 90% of hospital wards at risk of overheating, and around 10% of hospitals are located in areas at significant flood risk [H12]	H1, H3, H4, H7, H8, ID9 Example: In summer 2020, a record 2,500 heat-related deaths were recorded during the summer heatwave [H1]	H9 Example: Emergency food parcels distributed by the Trussel Trust to families struggling to afford food rose from 500,000 in 2014 to more than 800,000 in 2019. Future climate change likely to affect food prices [H9]	ID4, ID10 Example: Food riots more likely to occur globally when the Food Price Index exceeds 140 (e.g. as happened in 2008, 2010 and 2012) [ID4]		H2, H6 Example: Future reductions in cold-related mortality [H2] and winter fuel poverty [H6] due to warmer winters
Goal: Protecting Natural and Cultural Heritage	N18, H11 Example: Coastal erosion is affecting	N1 Example: Severe impacts on survival	H11 Example: 23% of listed buildings and 18% of					H7 Example: Present day - warmer days

	15% of the Northern Ireland coastline including Strangford Lough, the Foyle Estuary and dune system at Murlough [H11]	beech and oak from summer drought stress in a high emissions scenario in the SE of the UK [N1]	scheduled monuments in England are at risk of flooding [H11]					encourage greater engagement with cultural heritage [H7]
Goal: Sustainable Businesses	B3 Example: Projected changes in incidence of low flows of up to 50% by 2080 are projected in a 4C pathway [B3]	N6 Example: Reduction in the area of grades 1 and 2 (excellent and very good quality agricultural land), by 2050, downgraded primarily to grade 3a/3b [N6]	B2 Example: Expected annual damages for UK-wide non-residential properties from coastal flooding is expected to increase by 30% by 2050 in a 2C scenario [B2]	H3, H4, H5, B5 Example: global studies show up to 80% reductions in labour capacity in peak months by 2050 [B5]	B6 Example: Over half of businesses reported productivity losses in the previous year due to supply chain disruption [B6]	ID4, ID5, ID10	N9, B7, ID2, Example: UK vineyards now cover over 2500 hectares, representing a 160% increase in 10 years [N9]	
Goal: Net Zero	N1, N2, N4, N5, N17 Example: In 2018, a net reduction in carbon uptake of global ecosystems was detected due to drought [N1]	N6, N8	I1, I2, I3, I4, I5, I6, I7, I8, I9, I10, I11, I12, I13 Example: Increases in maximum storm wave of up to 2 metres by 2070-2100 (RCP8.5) could reduce stability and increase degradation of offshore wind turbines [I11]		ID7 Example: Net Zero targets are resulting in greater dependence on narrow supply chains of rare earth metals e.g. cobalt [ID7]	ID5	N9 Example: CO_2 fertilisation effects suggest annual biomass increments could increase by 15-25% by 2050, but only if water and nutrients are not limiting [N9]	

Source: Based on The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

Notes: Table shows which risks and opportunities (columns) will affect the different societal goals identified by the Committee (rows). Risk numbers and some examples are provided to show the specific risks and opportunities that are relevant; see Table 2.2 for a key to the different risks and opportunities. Unless stated otherwise, examples are UK-wide.

Threshold effects can change the level of impact from climate change but are usually ignored by risk assessments that rely on linear models of change. A threshold is the point at which a 'non-linear' change in a system occurs as a result of change in a climate driver – such as temperature. For example, algal blooms in rivers start to occur above temperatures of 17°C.

There is a lack of consideration of thresholds in adaptation planning.

Understanding where these thresholds exist and how likely they may be in the future is important for understanding the size of a given risk, and at what point a different approach to adaptation might be required. The Technical Report has demonstrated a general absence of consideration of thresholds in the literature on adaptation. Risk assessments that look at average changes over time give a gradual increase in risk, and by their nature miss specific points that 'tip' the system or asset into a different state. This should change and emphasis be given in future national adaptation plans on how threshold effects be accounted for.

The assessment for each risk and opportunity in the risk assessment has considered the potential for key threshold points to be crossed between the present day and 2100. Such threshold effects can be of different types. The Technical Report has mainly considered biophysical thresholds where an impact occurs or increases significantly following an exceedance of a temperature or rainfall level. But other thresholds have also been identified. Engineering or design thresholds represent chosen points that infrastructure and built assets are designed to perform up to (for example, critical national infrastructure tends to be designed to withstand a 1 in 200-year flood). Policy or social thresholds are those beyond which a human-derived unacceptable limit is reached. These can include public-defined or business-defined thresholds of acceptable risk (e.g. numbers of deaths, profit losses) or behavioural changes that occur beyond a threshold, for example rioting has been observed to increase globally when the Food Price Index (FPI) exceeds 140.

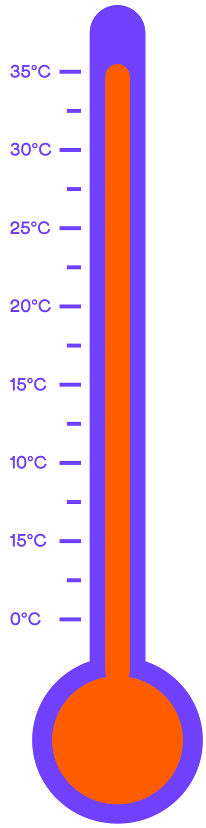
Most of the evidence that has been collected from the literature for the assessment involves biophysical thresholds. Some of these, in relation to temperature, are illustrated in Figure 2.4, as well as the quantified impacts in a 2°C and 4°C scenario where these are available.

Figure 2.4 Biophysical thresholds identified in CCRA3 Technical Chapters

27°C
Increased risk of rail buckling

18°C
Declines in vendace (cold water fish species). No change to today (2°C), tripling of risk of loss (4°C)

14.5°C
(average temperature of warmest month per year). Peatland degradation. Annual economic losses £318million (2°C), £1.3 billion (4°C



35°C
(3 days or more exceedance). Winter wheat grain filling declines. No change to today (2°C), annual economic damages of £42 million (4°C)

23°C
Increased heat stress in cattle. Annual economics damages of £3.8 million (2°C), £15.9 million (4°C)

17°C
(Daily max). Algal blooms in lakes and rivers. Annual economic losses of £295 million (2°C), £481 million (4°C)

9°C
(daily mean) Increases in sheep parasite *Haemonchus contortus*. Increase in development season by 30 days (2°C), 60 days (4°C)

Sources: UKCEH (2020) Climate driven threshold effects in the natural environment; Jaroszweski, D., Wood, R., and Chapman, L. (2021) Infrastructure. In: The Third UK Climate Change Risk Assessment Technical Report. [Betts, R.A., Haward, A.B., Pearson, K.V. (eds)] Prepared for the Climate Change Committee, London.
Notes: While a number of potential threshold effects have been identified throughout the CCRA, only those with a specified temperature value are presented here for illustrative purposes.

Interacting risks pose one of the biggest challenges when assessing climate risks and climate change impacts can have significant, far-reaching consequences. System resilience to climate change goes beyond individual risks and opportunities. All infrastructure sectors are connected, meaning that vulnerabilities on one network can cause problems for others, and impact beyond the infrastructure system itself, affecting the economy, health and wellbeing. The Committee has identified risks to people and the economy from climate-related failure of the power system as one of the top priorities for Government, given the potentially far reaching consequences of a power failure across society and the growing importance of electricity in the whole infrastructure system in the transition to a Net Zero economy.

We highlight cascading impacts from the power sector as one of the Committee's eight priority areas for urgent action.

All of the major climate hazards considered in CCRA3 could trigger a cascade effect from the power sector to other sectors; flooding, reduced water availability, increased temperatures and wildfire, as well as potential increases in storms. Interactions with other risks within and across sectors have been considered for each of the 61 risks and opportunities in the Technical Report. Given the wide-ranging nature of the linkages within and across sectors, a full understanding of the impacts of cascading failures is difficult to ascertain and the Technical Report concludes that the vulnerability of interconnected systems may be significantly underestimated. To support the assessment of interdependent risks in the Technical Report, a project was commissioned to assess how climate change affects the interaction of risks across the infrastructure, built environment and natural environment sectors (WSP, 2020).[4] The project developed baseline 2020 scenario pathways and then considered how the risk levels within pathways and the drivers of overall risk changed under 2050 and 2080 2°C and 4°C climate scenarios. Table 2.5 shows the most significant risk pathways modelled for CCRA3. In 4°C climate scenarios, several cross-sector interactions become significant drivers of overall risk in the mid and late century.

Table 2.5
Summary of the most significant risk pathways modelled in the CCRA3 Interacting Risks project, by climate driver with risk ratings in 2020 and 2080

Hazardous events	Main impact cascades		2020	2080
Climate driver: Increase in summer temperatures and reduction in summer mean rainfall				
Heatwaves and very hot days	Building overheating leading to building productivity loss		Medium	High
	Transport infrastructure overheating, or disruption to IT and comms services	Travel and freight delays	Low	Medium
		Transport infrastructure damage	Medium	Medium
Low summer river flows, and increase in river water temperatures	Environmental water shortages, more algal	Habitat degradation	Medium	High
	Reduction in water quality		N/A	Medium
Increase in soil desiccation	Soil condition and quality impact			Medium
Climate driver: Extreme winter rainfall events and increase in winter mean rainfall				
River, surface and groundwater flooding	Power supply disvding		Low	Low
	Water/sewerage infrastructure flooded, reduced water quality or power supply disrupted	Water supply disrupted	Low	Medium
		Sewer flooding	Low	Medium
	Transport hubs or infrastructure flooded or damaged, or power supply disrupted	Travel and freight delayed	Medium	High
	Damaging water flows, slope or embankment failure	Transport infrastructure damaged	Medium	High
	Building flooded	Building productivity loss	Medium	High
		Building damaged	Medium	High
	Increase in run-off	Reduced water quality	Low	Low
Climate driver: Sea level rise and storms				
Coastal flooding and erosion damage	Loss of natural flood defence		N/A	Medium
	Coastal squeeze		N/A	High
	Saline intrusion		N/A	High
	Near shore environmental impact		N/A	High
	Coastal building flooded/eroded	Coastal building productivity loss	N/A	Medium
		Coastal building damage	N/A	High

Source: WSP et al. (2020). Interacting risks in infrastructure and the built and natural environments: research in support of the UK's third Climate Change Risk Assessment Independent Assessment.
Notes: Shows the most significant risk pathways and the magnitude of risk in 2020 and 2080, considering the impact and probability of the interaction occurring.

A better understanding of interacting risks and incorporation into adaptation planning will help reduce the impacts of these interactions on UK citizens and business.

Interruptions to power supply and disruptions to IT and communication services were identified by the Interacting Risks project as having the highest number of knock-on impacts across sectors. Most business functions depend on reliable infrastructure, with disruptions being a key risk for site operations, access to markets, supply chain and distribution networks, and employee productivity.

The impact of flooding on infrastructure can have several significant cascading impacts to all infrastructure assets, including buildings, and all the sectors they serve. For example, power or IT outages caused by extreme weather can affect the ability to provide health and social care in hospitals and care facilities, and disruption to transport infrastructure (for example roads being flooded) can cause transport delays impacting ambulance and emergency vehicles.

The combined effect of increased winter rainfall and extreme rainfall events leads to ground saturation and slope or embankment failures. A passenger train derailment in Scotland in 2020, caused by embankment failure following a period of heavy rainfall, tragically led to a loss of life and subsequently the closure of the railway line between Aberdeen and Dundee for almost 3 months. Interaction between climate hazards adds further complexity, for example combinations of drought and periods of intense rainfall can exacerbate embankment stability issues.

Increased drought stress in the natural environment can lead to soil desiccation impacting soil condition and quality. This can lead to structural stability issues and pipeline movement. Soil condition is also crucial for a range of related ecosystem services including plant growth, water quality and greenhouse gas mitigation.

There are implications for water supply from drought, reduced water quality in the natural environment and sewer infrastructure flooding which will all increase the likelihood of water supply disruptions, though changes in drought frequency are highly uncertain.

These are just some examples of the types of interactions and potential impacts on society that will be exacerbated by climate change. There is a need for a systematic assessment of interdependency risk across the UK, to complement the many examples of best practice adaptation within individual infrastructure sectors and improve resilience across society more generally. Major businesses also have an important role to play, being responsible for infrastructure resilience in key sectors including energy and water.

The natural environment plays an important role in moderating many climate change risks.

The natural environment is central to understanding and reducing the effects of cascading climate change impacts across all sectors.

The natural environment is the source of the majority (54%) of knock-on impacts on other sectors, followed by infrastructure (32%) and the built environment (14%).[5] This is not surprising given how dependent human life, society and the economy are on nature. It also leads to the conclusion that being highly connected, a well-managed natural environment could contribute significantly to systems resilience across the UK. The assumption that nature is freely available, will recover from pressures, or is someone else's responsibility to fix was never valid and is increasingly being replaced by placing nature in the heart of business and policy activity.

Acknowledging natural assets as capital that can keep on giving, only if properly maintained, is the basis of a natural capital approach. It encourages all business and policy decision makers to assess their impacts and dependencies on nature and take the necessary steps to maintain natural assets and be prepared for risks like those from climate change. This is reflected in recommendations for business and investors from the Task Force on Climate-related Financial Disclosures and the ongoing Task Force on Nature-related Financial Disclosures.[6]

Many of the services the natural environment provides are also key to climate change resilience. For example, water purification and regulation, fluvial/pluvial flood hazard alleviation, coastal flood and erosion hazard alleviation and natural control of pests, pathogens and Invasive Non-Native Species.

Ecosystem-based adaptation and nature-based solutions aim to recognise and work with the natural resilience and adaptability of the natural environment to preserve natural assets and ecosystem services, and in doing so, maintain the resilience of the core underpinning services they provide. To be effective, these solutions require the reduction other current pressures on the natural environment, such as over-extraction and pollution – in addition to reducing the pressures from climate change.

The direct benefits from adaptation action in the context of nature-based solutions are set out in Chapter 3.

Action to minimise the risks from climate change is also important for realising any potential opportunities, such as longer growing seasons.

Although climate change for the UK is associated mainly with risks, there may be opportunities, if appropriate adaptation action is taken in time to minimise the risks and to put in place any necessary support to take advantage of the benefits from warmer temperatures, in particular.
This section summarises the direct opportunities from climate change identified within the Technical Report. Chapter 3 discusses the benefits from further adaptation action.

Figure 2.5 summarises the different opportunities identified in the Technical Report, followed below by a summary for each.

Figure 2.5 Opportunities from climate change identified in the CCRA3 Technical Report

Source: Based on The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London
Notes: Figure shows the changing magnitude score of opportunities according to the Technical Report. Magnitude is shown as a colour gradation from today (left) to 2100 (right) for the highest scenario assessed in the Technical Report (reaching 4°C increase in annual average global temperature from 1850-1900 levels by 2100). Opportunities for energy supply and demand show magnitude for demand only, as the opportunity for supply has not been assessed individually.

Opportunities for biodiversity, agriculture and forestry from changing climatic suitability and new species

Climate change, especially increasing temperatures, could lead to some increasing populations of different species of plants and animals, as well as leading to species movement and expansion of their ranges.

New species could enhance species richness and contribute to community adaptation to climate change, if they do not pose negative impacts to existing ecosystems as is the case for invasive species:

- **Fish.** New opportunities are developing for fish species such as Atlantic bonito, jack, bluefin tuna, sardines and Northern hake, which has been largely absent from the northern North Sea for the past 50 years.

- **Crops.** Climate change provides potential benefits for both arable agriculture and horticulture, through reduced incidence of frost damage for vulnerable crops, CO_2 fertilization, and increasing the intensity and speed of the growing season, assuming sufficient water and fertile soil are available. It can open a range of opportunities for growing new crops such as chickpeas, quinoa, vines, soya, lentils, peaches, apricots, tea, sunflowers, sweet potatoes, watermelons, walnuts, and truffles. In addition, for some crops, reduced times to reach maturity may be providing new opportunities for increased production by enabling multiple crops in a year, such as for lettuce and an increasing variety of salad crops. While climate change could open a range of opportunities for growing different varieties of grapes, which are currently cultivated in Europe, the level of warming will affect the type of opportunity. However, water scarcity and poor state of soil can be the limiting factors for this opportunity.

- **Livestock.** Warmer temperatures throughout the year also imply opportunities for livestock to be outdoors more during winter months, though high rainfall could prevent this due to an increased risk of soil erosion and soil poaching from livestock.

At present, it is likely that most of this benefit will not be realised in the absence of additional government intervention. This intervention could be in the form of: grants providing support to overcome potential technological barriers; provision of information about suitable crops; enabling knowledge exchange; co-ordination of initiatives; and outreach activities such as demonstration projects to build adaptive capacity.

Government policies which lead to new habitat creation, either through expanding existing sites or creating new ones, or increasing the connectivity between habitats (e.g. through Nature Recovery Networks) could help species to colonise new areas. Managing sites better to improve their condition can also help support larger numbers of species and facilitate colonisations. Large-scale habitat creation and improvement usually depends on government action and often is supported by direct government funding, such as agri-environment schemes.

Opportunities to business and trade from adaptation services new products and trade route

There are economic opportunities for adaptation products and services - adaptation finance, increased tourism, agricultural products and trade.

The changing climate could bring opportunities to some sectors and localities leading to new markets for goods and services, better growing conditions or an increased demand for adaptation finance. UK businesses have the potential for market leadership, competitive advantage through early adaptation and being first movers, attracting clients and talent aligned to climate objectives and improved reputation. Specific opportunities discussed in the Technical Report include:

- **New products and services.** There is a growing adaptation sector including environmental monitoring, consultancy and adaptation advice; engineering and manufacturing products to manage climate risks, construction, professional, scientific and technical activities to incorporate climate resilience into new developments and existing infrastructure

- **Finance sector.** New insurance products, investment in various new asset classes such as green bonds, sustainable public or private equity and sustainable infrastructure.

- **Tourism.** Further opportunities might arise from extending the local tourist season due to warmer summers, increasing beach and summer tourism on British Isles from climate change, which in some scenarios is estimated to grow by up to 0.3% of GDP per year.

- **Agriculture.** New business activities in agriculture, horticulture, viticulture and food products, such as wine production, soft fruits or salad crops.

- **New trade routes.** The UK could benefit from increased access to Arctic shipping routes because of climate change (though noting that there are threats to Arctic ecosystems and geopolitical risks that are orders of magnitude larger), as well as increased tourism and the provision of maritime services in addition to trade.

Given the low level of understanding of the opportunities to businesses from climate change, and the likely barriers to small businesses in particular to enter new markets, there is likely to be a role for Government in providing evidence and supporting businesses to transition to new functions as the climate changes.

Opportunities for public health from warmer temperatures

Warmer winters could reduce cold-related mortality, though the effect is likely to be relatively small in the context of an ageing population. As UK summer temperatures are likely to rise with a longer summer season, there are also opportunities for an increase in use of outdoor space for physical activity, leisure activities, cultural activities, and domestic tourism. This could bring physical and mental health benefits of increased physical activity and contact with nature as well as increased Vitamin D exposure which is important for bone health and the immune system.

Increasing temperatures could also potentially lower the risk of mould growth in homes, provided there is sufficient ventilation to remove moisture from the indoor air. However, in some regions, heavier rainfall may offset this benefit. There is scope for policy intervention to capitalise on the opportunities of warmer winters and hotter summers to encourage physical activity.

These could be strategies to increase green infrastructure, opportunities for outdoor recreation and active travel (walking and cycling).

Opportunities for energy supply and demand

Climate change will reduce future household heating demand in winter, which will have benefits in reducing household costs related to space heating. In a medium emissions scenario, the marginal economic benefit could be over £1 billion per year for the UK by the end of the century, assuming that households react to warmer winters by using less energy for heating.

From an energy supply point of view, hydroelectric power could benefit from increased output under moderate increases in river flows but is vulnerable to both low and extremely high river flows.

Impoundment schemes (hydropower facilities that utilise dams to impound water in a reservoir) have the greatest ability to benefit from increased winter river flows and to absorb the impact of decreased summer flow although this depends on reservoir capacity.

For impoundment schemes to take advantage of higher winter rainfall, increases in reservoir sizes and or turbine capacity will be necessary. For new hydroelectric installations, the turbine needs to be designed to maximise output under both current and future flow duration curves and to be resilient to peak flows they may be exposed to - taking into account any flood alleviation schemes in the area.

Opportunities for UK food availability and exports from climate change impacts overseas

Climate change will alter global patterns of food production, creating, at least in theory, potential new opportunities for imports and/or exports for the UK. If longer-term climate change results in a comparative advantage for UK agriculture relative to other food-producing regions, there might be opportunities for increased exports, if production in the UK is maintained.

Actions over the next five years could focus on increasing UK access to a broad range of international markets, via goods, finance & markets transmission pathways, in order to ensure that any opportunities can be capitalised upon.

Opportunities to infrastructure from warmer temperatures

Opportunities may arise from fewer snow and ice days reducing winter maintenance costs, travel time delays and accidents. However, such benefits could be offset by an associated reduction in preparedness or increased complacency in the future to cold weather impacts, which although declining in frequency will still occur from time to time (see Chapter 1).

Opportunities for discovering previously unknown heritage

Climate change could enable new discoveries of UK heritage sites. As an example, The Royal Commission on the Ancient and Historical Monuments of Wales identified approximately 100 new historic assets during the severe summer drought of 2018 due to the different soil moisture patterns exposing previously unknown sites.

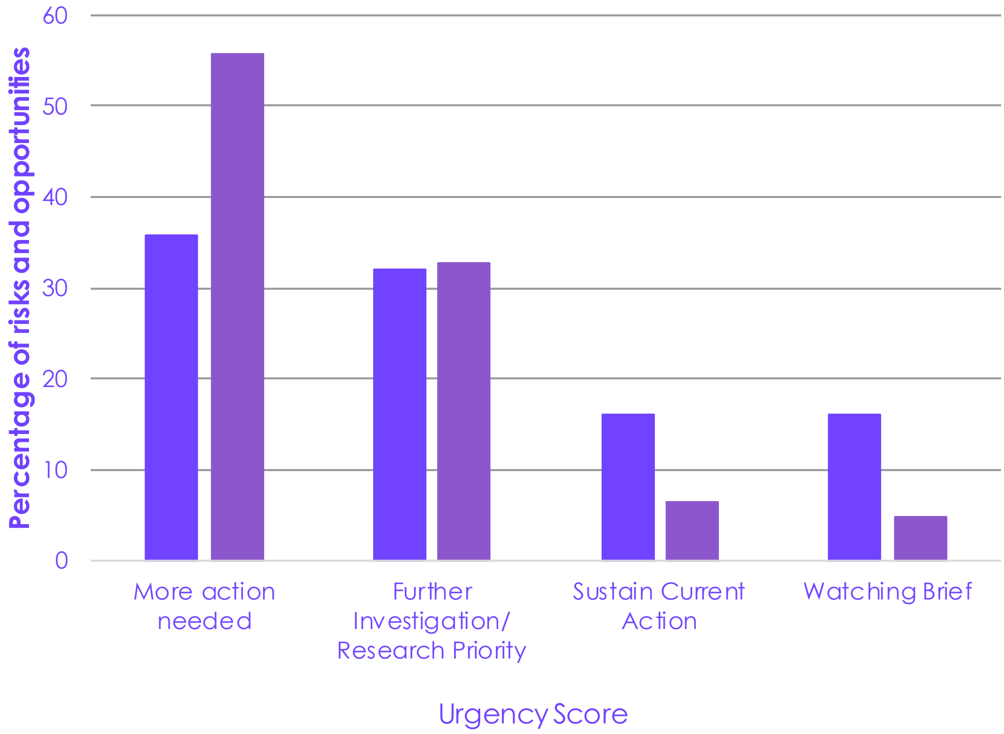
This section briefly summarises some key differences in the CCRA3 assessment of risk and opportunity compared to the two previous CCRAs, CCRA1 (2012) and CCRA2 (2017).

Changes in urgency scores

A larger number of 'More Action Needed' risks and opportunities have been identified in this assessment compared to CCRA2.
The highest urgency category, 'more action needed', has been given to 34 of the 61 (56%) risks and opportunities, compared to 20 out of 56 (36%) for CCRA2 (Figure 2.6).

56% of the risks and opportunities in CCRA3 have been given the highest 'more action needed' urgency score, compared to 36% in CCRA2.

Figure 2.6 Changes in urgency scores between CCRA2 and CCRA3



Source: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London; CCC (2016) UK climate change risk assessment 2017 – Synthesis Report: Priorities for action in the next five years

Box 2.1 describes the main changes in the urgency scores between CCRA2 and CCRA3.

Box 2.1
Description of changes in urgency scores between CCRA2 and CCRA3

A small degree of the increase in the 'more action needed' category is due to splitting of risks from CCRA2 into more groups.

However, much of the change derives from risks that were classified in CCRA2 as further investigation (i.e. needing more research to assess the need for action) moving into 'more action needed', signalling that further evidence has been gathered in the preceding five years that now classes these risks as needing additional adaptation over what is currently planned. At the UK-level, nine risks fall into this category:

- Risks to freshwater habitats from changing climatic conditions
- Risks to marine species, habitats and fisheries
- Risks to cultural heritage
- Risks to transport from changing temperatures, high winds and lightning (from further investigation/ sustain current action)
- Risks to coastal community viability from sea level rise
- Risks to health from vector-borne diseases
- Risks to businesses from coastal change
- Risks to the UK from international violent conflict
- Risks to international law and governance

Another ten risks and opportunities have increased in urgency score due to an assessed need for further action or investigation compared to the CCRA2 assessment:

- Risks to the natural environment from pests, pathogens and invasive species (sustain current action to more action needed)
- Risks to businesses from supply chain disruption (sustain current action to more action needed)
- Risks and opportunities to changes in landscape character (watching brief to further investigation)
- Risks to hydroelectric generation (watching brief to further investigation)
- Risks to infrastructure from subsidence (watching brief to further investigation)
- Risks to food safety and security (watching brief to further investigation)
- Risks to health from poor water quality (sustain current action to further investigation)
- Risks to businesses from water scarcity (sustain current action to further investigation)
- Opportunities for businesses from new services and products (watching brief to further investigation)
- Risks to finance, insurance and investment including access to capital (watching brief to sustain current action)

A smaller number have also dropped in urgency as follows:

- Opportunities to health from warmer temperatures (from more action needed to watching brief)
- Opportunities for new species colonisations (more action needed to further investigation)
- Risks to offshore infrastructure from storms and high waves (further investigation to sustain current action)

In addition, a small number of additional risks that were not covered in CCRA2 are included in this assessment:

- Risks and opportunities from changes to summer and winter household energy demand (more action needed)

- Risks to education and prison services (more action needed)
- Risks to public health from climate change overseas (more action needed)
- Risk multiplication from cascade effects across systems and geographies (more action needed)
- Risks to international trade routes (not just opportunities) (more action needed)
- Risks to the UK finance sector from climate change overseas (sustain current action)
- Opportunities for UK food availability and exports from climate impacts overseas (watching brief).

Source: CCC analysis.

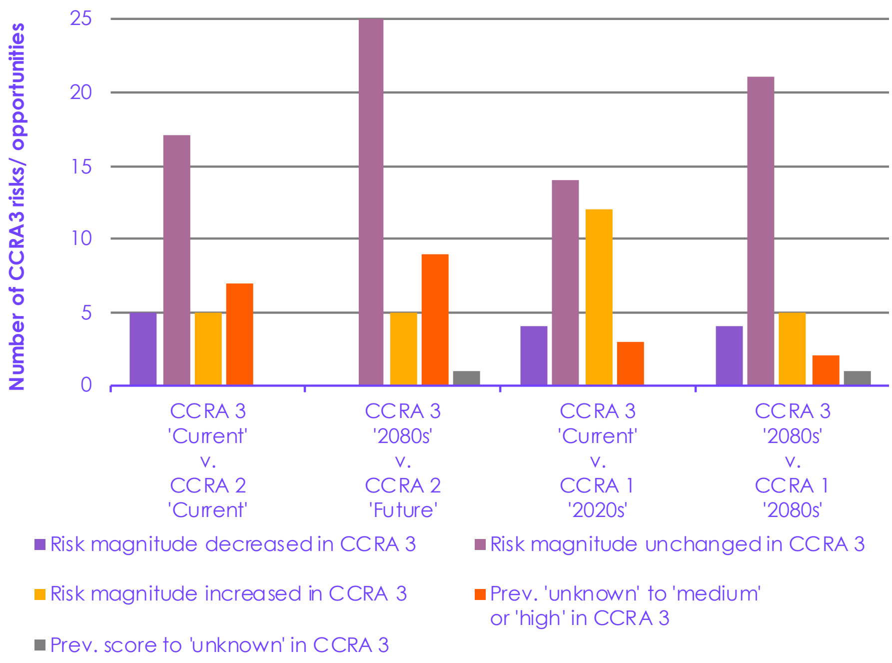
Changes in magnitude scores

There has been an increase in the magnitude of risk between CCRA2 and CCRA3.

The magnitude of the risks and opportunities has also altered compared to previous CCRAs.
Although the list of risks assessed has changed between CCRA1, CCRA2 and CCRA3, some comparisons in the magnitude scores can be made for those risks that are comparable between the three assessments. Fourteen risks have increased in magnitude category compared to the last assessment in 2016 (Figure 2.7), while none have decreased and 25 have remained unchanged. Notably, the present-day magnitude scores for 15 risks in this independent assessment are higher than the magnitude categories predicted for the 2020s in CCRA1.

The valuation assessment for the Technical Report has also demonstrated a much larger number of 'high' and 'very high' categories of damages for individual risks and opportunities, where there is a similar risk assessed in CCRA1 and CCRA3.

Figure 2.7 Changes in risk magnitude in CCRA3 compared to previous assessments



Source: CCC analysis

Endnotes

[1] Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A. (2009), UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

[2] Baglee, A., Haworth, A. and Anastasi, S. (2012) Climate Change Risk Assessment for the Business, Industry and Services Sector.

[3] 'Single Scottish wildfire could have doubled Scotland's climate emissions for the six days it burnt'. Report by WWF.

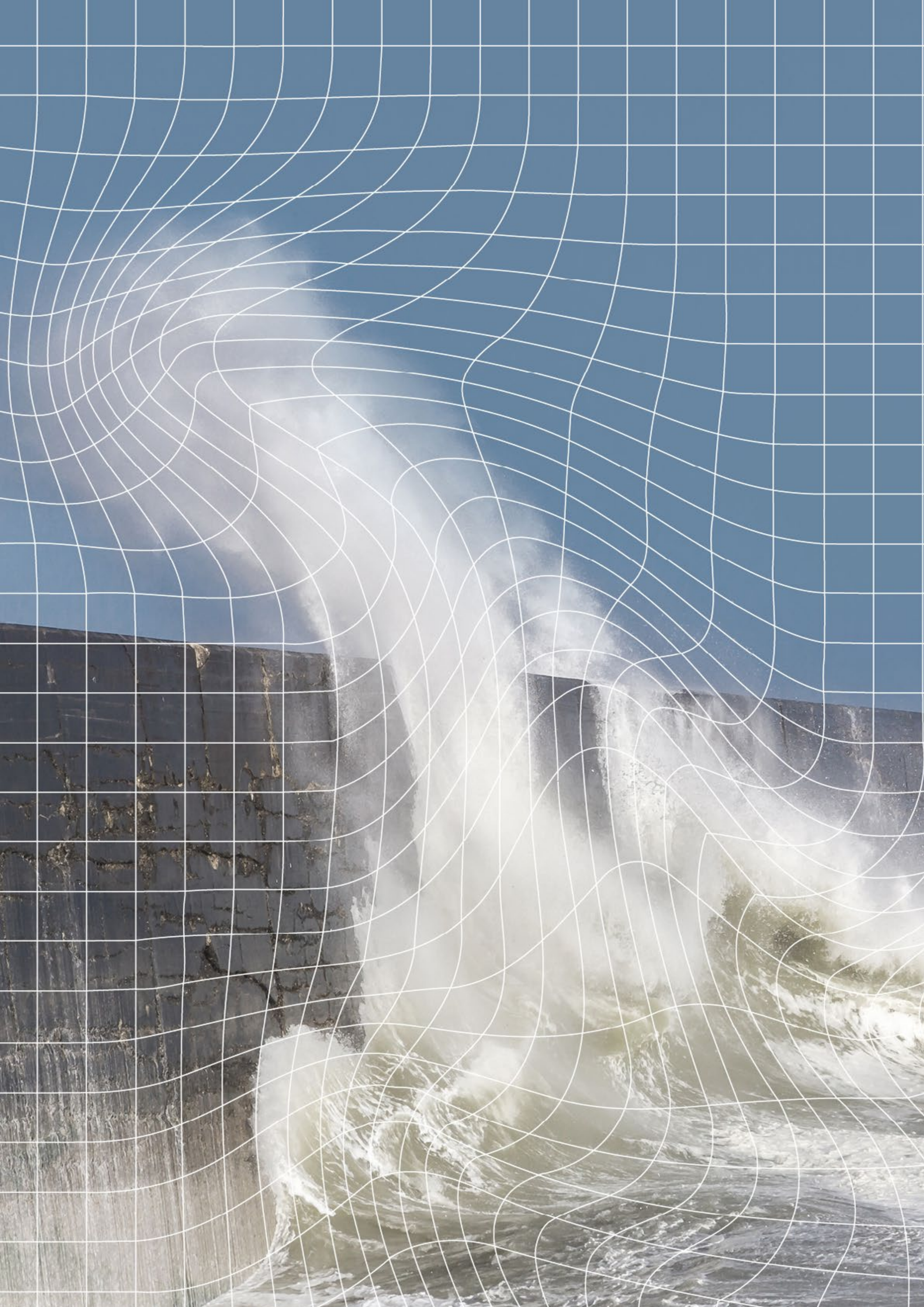
[4] WSP et al. (2020). Interacting risks in infrastructure and the built and natural environments: research in support of the UK's Third Climate Change Risk Assessment Independent Assessment

[5] WSP et al. (2020). Interacting risks in infrastructure and the built and natural environments: research in support of the UK's Third Climate Change Risk Assessment Independent Assessment

[6] See https://www.fsb-tcfd.org/ and https://tnfd.info/ respectively.

Chapter 3

The adaptation return



Introduction and key messages

This chapter synthesises the results of the risk assessment on the benefits that further adaptation can bring in addressing the risks and opportunities from climate change and what cross-cutting issues need to be addressed for effective adaptation planning. The analysis in this chapter informs the Committee's ten principles for effective adaptation.

It summarises the evidence from the CCRA3 Technical Report on actions that can be taken in the next five-year period through the UK's national adaptation programmes. We look at several types of benefit from adaptation:

- Avoided impacts from climate change including both financial and non-financial impacts (e.g. property damage, deaths).
- Benefits from climate change opportunities.
- Other direct benefits, e.g. in terms of improved health and biodiversity.
- Indirect benefits through employment and related induced impacts.

Since CCRA2 was published, more information has become available on the economic benefits of adaptation, both from international work and UK analysis.[1,2] Economic benefits include both those that are within the markets, some of which are direct financial returns or financial cost savings, and those that are non-market such as human wellbeing and improvements in natural environment, only some of which have manifestations in markets.

Our conclusions are:

- **'Good' adaptation should minimise the risks and maximise the opportunities from climate change. It should be conducted in a way that maximises social net benefits, including through maximising positive distributional effects and minimising negative trade-offs.** In addition, the Committee's criteria for good adaptation plan scores from its previous progress reports includes setting clear priorities, with specific, outcome focussed objectives; focussing on the policies and actions that will achieve the highest benefit; reflecting regional differences in climate change impacts; and ensuring effective monitoring and evaluation is in place and allocate sufficient resources to deliver the plan.
- **The case for urgent short-term Government action now (as opposed to waiting to act for another year, or five years) has been made clearer in this assessment.** Urgent action now will reduce irreversible impacts and lower the future costs from climate change that would likely ultimately fall back to the Government. This assessment has demonstrated that the gap between the level of adaptation and the level of risk is increasing. There is also better information available about the probability of previously unprecedented events occurring, that the country needs to prepare for now.
- **Two major cross-cutting issues that should be integrated into all sectoral policies to ensure good adaptation planning are assessed for each risk and opportunity in the CCRA3 Technical Report:**
  - **Avoid lock-in.** Early adaptation action – before impacts actually occur - should reduce vulnerability to current climatic variability and

build in resilience for decisions that have long lifetimes, a long planning process like infrastructure investment or a long lag time such as for restoring damaged habitats. Early action is also needed to prevent as far as possible irreversible changes, such as loss of species or ecosystems. Failing to do this can lead to 'lock-in', where delayed decisions, or decisions that don't consider the long-term risks can lead to irreversible changes, incur high damage costs and higher costs of having to then adapt abruptly and quickly. This assessment has given greater weight than previous CCRAs in assessing the potential for lock-in for different risks and opportunities.

  – **Minimise inequalities.** Climate change itself is likely to widen existing inequalities because socially and economically disadvantaged people are disproportionally affected. Actions to address climate change could also exacerbate existing inequalities if not carefully planned. Inequalities have been identified in the risk assessment in relation to where people live, their income level and assets, and characteristics such as age and ethnic background. These characteristics determine current vulnerabilities and capacity to adapt to climate change. The next set of National Adaptation Plans should map these effects and include actions to deliver positive distributional effects, in line with guidance in the Treasury Green Book.

- **Only a combined approach to tackling climate change through reducing emissions (mitigation) and building resilience (adaptation) will be successful in protecting the UK from the worst effects of climate change.** This combined approach is still largely missing in Government policy and business practice, which increases the potential for unintended consequences, including to the UK's own ability to meet its Net Zero emissions target. It also reduces the likelihood of both sets of policies succeeding in their primary purpose and maximising co-benefits.

- **Taking further adaptation action will generate benefits from avoided damages for almost every risk assessed in the Technical Report.** There is a particularly strong case for early adaptation in the three priority categories of action outlined in the Technical Report*:

  – 'No-regret' or 'low-regret' actions that reduce risks associated with current climate variability, as well as building future climate resilience. Examples include reducing water use, peatland restoration and improving passive cooling in homes, all of which are needed to address risks in the current climate.

  – Early action to ensure that adaptation is considered in near-term decisions that have long lifetimes and therefore reduce the risk of 'lock-in', such as for major infrastructure projects.

  – Fast-tracking flexible adaptive management activities, especially for decisions that have long lead times or involve major future change, e.g. land use change.

* See Watkiss, P and Betts, R (2021) CCRA3 Technical Report Chapter 2 – Method

- **Benefit-cost ratios for adaptation actions are largely positive, and in some cases very large even with partial quantification of benefits.** The net benefits of adaptation action are typically context- and site-specific and are therefore challenging to estimate at a national level. The evidence available, however, shows that many of the adaptation actions highlighted in the Technical Report have net positive benefits, i.e. their benefits outweigh their costs, and some have very high net benefits (benefit-cost ratios of 10:1 or higher). These include for example, early warning systems for extreme heat and flooding events, surveillance for pests and diseases, and water efficiency labelling.

- **There is a lack of available evidence about the size and value of climate change opportunities and the adaptation actions that will deliver them.** It is likely that some of these benefits will not be fully realised without further action. An example is supporting the construction industry to develop the skills base in building climate-resilient homes.

- **Adaptation measures can have important wider benefits, such as improving human health and the natural environment.** Taking these benefits into account increases the net benefits of adaptation and encourages integrated win-win solutions, such as increasing urban greenspace or improving water efficiency. Such solutions can only become apparent if climate change risks are integrated into sectoral plans and investments from the start.

We set out our analysis in the following sections:

1. What is good adaptation?
2. Avoiding lock-in
3. Addressing distributional effects and inequalities of climate change
4. Tackling climate change through mitigation and adaptation
5. Direct economic benefits from adaptation action
6. Other benefits of adaptation action
7. Funding of adaptation

What is good adaptation?

Adaptation is acting to reduce the damages and maximise any positive benefits from climate change impacts.

Adaptation is needed to build resilience to climate change that has already happened or is projected to occur.
Adaptation represents actions to reduce the negative impacts and maximise any positive benefits from climate change that is occurring now or will occur in the future. It is distinct from climate change mitigation which seeks to stop further climate change from occurring. Both approaches are needed to address climate change:

- Mitigation alone cannot prevent all climate change impacts because climate change is already happening due to past emissions of greenhouse gases, and even very ambitious global action to reduce emissions will take time to implement.

- Adaptation alone cannot prevent all climate change impacts because some impacts cannot be adapted to, and adaptation may become ineffective or prohibitively expensive especially at higher levels of warming.

The level of climate change that the UK will have to adapt to is determined by:

- The impacts of past emissions that have already changed the climate

- Global action on mitigation now and into the future and

- Exactly how strongly greenhouse gases (and other atmospheric components like aerosols) affect global and regional temperature and other climate variables, such as rainfall and sea level rise.

The success or otherwise of global efforts to reduce emissions will have a profound impact on the UK's climate in the second half of this century, whereas the level of climate change projected up to 2050 is now largely fixed. Chapter 1 goes into more detail on how we define the boundaries of likely future climate change and the basis of using warming levels of 2°C to 4°C for adaptation planning.

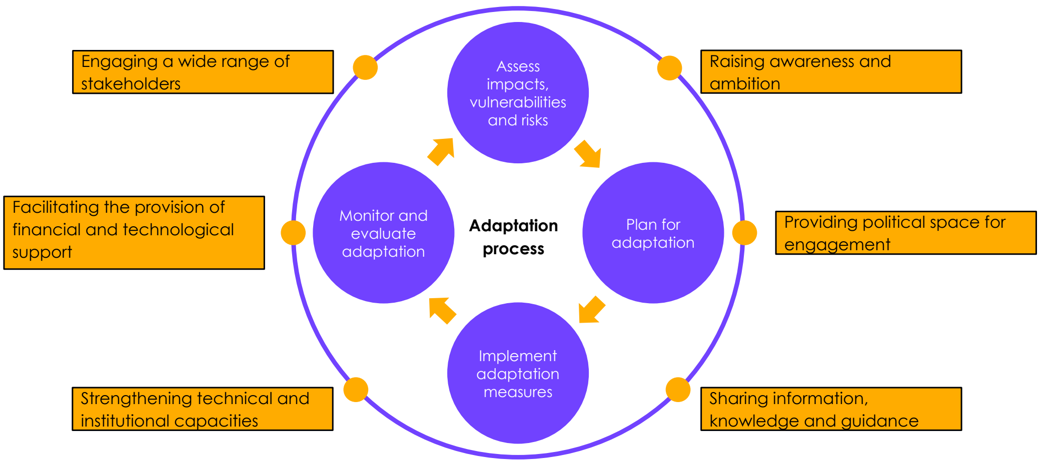
Good adaptation seeks to prepare for the changing climate while maximising social benefits.
'Good' adaptation should act to minimise the risks and maximise the opportunities from climate change, while also adhering to the principles for policy appraisal set out in the UK Government's Green Book. These are:

- Maximise net economic benefits (from a societal perspective)
- Have neutral or positive distributional effects (social equity)
- Minimise negative consequences that result from the action (e.g. increases in greenhouse gas emissions, or negative impacts on biodiversity)

The Government has a role to provide the enabling framework and address market failures to support good adaptation planning in the UK. It can do this through providing information, supporting the coordination of local action, devising a framework of targets, incentives and reporting, and directly funding adaptation action.[3]

The UN sets out how this cycle of understanding and undertaking adaptation should operate at the country level; all of the components shown need to happen to support good adaptation (Figure 3.1).

Figure 3.1 The Adaptation cycle under the UN climate change regime



Source: UNFCCC: What do adaptation to climate change and climate resilience mean? | UNFCCC.

Building on this framework, the Adaptation Committee sets the following criteria for good adaptation to underpin any future national policy, in order to create meaningful interventions and governance processes:[4]

- Clear priorities that ensure the most important issues are addressed.
- Specific, outcome-focused, and measurable objectives that describe outcomes rather than processes and activities.
- A focus on a core set of policies and actions that will achieve the biggest benefit compared to cost.
- Reflection of regional differences in climate change impacts, allowing local organisations to play a role in adaptation action.
- Underpinned by effective evaluation and monitoring of progress.

The UK Government's first National Adaptation Programme in 2013 set out a detailed economic case for adaptation in the UK.

There is a well-established evidence base on the economic benefits of early Government intervention in adaptation.

The economic rationale for government intervention in adaptation in the UK is well-established and was set out in detail in the first UK National Adaptation Programme (Table 3.1)[5], as well as the more recent reports from the Global Commission on Adaptation.[6] There has also been extensive research looking at the long-term costs of inaction for various climate-related risks, including in the CCC's own analysis of adaptation for housing and land use, which shows that the costs of waiting until an impact occurs before acting far outweigh taking adaptive action early.[7,8]

Table 3.1
Economic rationale for Government intervention in adaptation

Barriers to market-led action	Description
Uncertainty	Where action is deferred or avoided due to a lack of certainty about future conditions, leading to confusion about the best course of action.
Information failure	Where organisations and individuals do not have perfect information about their vulnerability or exposure to risks (now or in the future) which can make it hard for them to plan efficiently. An example is a lack of awareness of individual flood risk.
Policy failure	Where the framework of regulation and policy incentives creates barriers to effective adaptation. For example, competing policy objectives can mean that adaptation is 'crowded out' in favour of other policy requirements that have stronger legal or reputational penalties for inaction. Another example is where actions to meet another policy objective are taken that exacerbate climate change risks; for example, making homes more airtight to improve energy efficiency, which can increase overheating risk.
Governance failure	Where institutional decision-making processes lead to barriers to effective adaptation. An example is a lack of coordination in multi-sector responses such as adapting to coastal change.
Behavioural barriers	Where economically rational decisions are not made. For example, there may be low public willingness to accept the degree of risk being faced.

Source: HM Government (2012) National Adaptation Programme - Annex

The case for urgent short-term Government action (as opposed to waiting to act for another year, or five years) is also clear in principle, though efforts to improve quantification of the short-term and long-term impact of delaying action are ongoing.

Urgent adaptation cannot wait for another year, or five years. It is needed now.

There are four reasons why taking action to adapt now (rather than delaying for another year or five years) will reduce irreversible impacts and costs from climate change that will ultimately likely fall back to the Government. These can be illustrated by looking back at the impacts of inaction since our independent report for the second UK Climate Change Risk Assessment was published in 2016:

- **Lock-in has increased.** Since CCRA2 was published, over 570,000 new homes have been built in England alone that are not resilient to future high temperatures, which will mean that costly retrofit will be needed to make those homes safe and habitable. CCC analysis shows that it is around four times more expensive to retrofit shading than including it at new build stage. In the next five years, over 1.5 million homes are due to be built; these will also lock-in increased climate vulnerability unless planning and building policy requires adaptation measures now.

- **Irreversible impacts are occurring that might have been avoided or reduced if greater adaptation measures had been taken.** Since 2018, over 4,000 heat-related deaths have been recorded in England. There is growing evidence that these deaths are associated with high indoor temperatures in homes, care homes and hospitals. While the current Heatwave Plan for England is central to the acute public health response to heatwaves, these findings indicate more strategic prevention action is required from a range of actors.

The number of heat-related deaths in the UK is projected to increase by around 250% by the 2050s in the absence of further adaptation[9], due to climate change and an ageing and growing population. Further adaptation to buildings is required to provide better passive cooling. Looking at damage to the natural environment, the UK has had several major wildfires (Saddleworth Moor, the Flow County, Mourne Mountains) since 2016. These were reported to together severely damage between 70-140km^2 of peatlands, heathland and forest (the area of a medium to large city) and led to increased greenhouse gas emissions, though these estimates vary by source.[10] Damage costs from single events like these will grow in the future and without adaptation in place, the Government is likely to increasingly bear these costs as the insurer of last resort.

- **The future costs from climate change are growing.** This CCRA has highlighted that the risks from climate change have worsened due to increasing magnitude (informed by new evidence) but also a lack of adaptation in the past five years. Fifty-six per cent of the risks studied now have an urgency score of 'more action needed' compared to 35% five years ago. Similarly, the magnitude of future impacts for 14 risks has increased since CCRA2 was published. This means that the resulting costs of climate change over the century are estimated to be higher now than they would have been five years ago, and higher than would be the case had more action been taken following CCRA2.

The UK already faces unprecedented extreme weather events that it may not be prepared for.

There is also a growing probability of unprecedented extreme events occurring. Examples from the Technical Report where quantification has been possible include extreme heat and rainfall:

- **Extreme heat.** The chance of experiencing a prolonged spell of extremely high summer temperatures, like that observed in 2018, is now around 10 - 25% each year compared to less than 10% a few decades ago. There is also a growing chance of experiencing daily maximum temperatures of over 40˚C.

- **Extreme rainfall.** There is currently a 1% chance every year that monthly winter UK rainfall could be 20-30% higher than the maximum observed to date.

Protecting homes from increasing flood risk through investment in flood defences is one of the few examples of where the avoided damages from taking action have been calculated for the present day. The Environment Agency releases statistics of homes protected during major flood events, and since 2015, more than 300,000 homes have been better protected from flooding through the EA's investment programme. Similar analysis needs to take place for other hazards and adaptation actions.

A new Defra-funded study on the economics of adaptation will be completed in 2022, following on from the publication of CCRA3.

Defra is funding a new project on the economics of adaptation, linked to this CCRA assessment, which will be completed in 2022. It will consider the case for further action for a set of priority CCRA3 risks, including the costs of inaction, and then assess the economic benefits and costs of further adaptation.

The CCRA3 approach builds on a well-established literature on identifying short-term beneficial types of adaptation action.
The CCRA focusses on those actions that are needed in the next five years, i.e. short-term responses, even though the benefits of these actions accrue over the long-term. The assessment considers three types of early adaptation priorities for more urgent risks and opportunities within the next five-year cycle.

These include:

- Addressing any current adaptation gap by implementing 'no-regret' or 'low-regret' actions that reduce risks associated with current climate variability, as well as building future climate resilience. Examples include reducing water use, peatland restoration and improving passive cooling in homes, all of which are needed to address risks in the current climate.
- Intervening early to ensure that adaptation is considered in near-term decisions that have long lifetimes and therefore reduce the risk of 'lock-in', such as for major infrastructure projects.
- Fast-tracking early adaptive management activities, especially for decisions that have long lead times or involve major future change, e.g. land use change. These approaches build in flexibility and allow the use of new evidence in forthcoming future decisions.

Avoiding lock-in

Avoiding lock-in is a major reason for taking early adaptation action, well in advance of impacts occurring

Decisions need to incorporate climate change risks and opportunities so that they do not lock-in policies and technology that are not resilient.
Lock-in is defined as 'where actions or decisions are taken that have long-term effects, but where these effects are not included in the decision itself which potentially increases future risk or causes irreversible change'. Some of the actions that can be taken to avoid lock-in include: acting early to avoid irreversible change; building flexibility into policies and systems; planning with long-term climate change in mind; and applying decision making under uncertainty (DMUU) approaches.

An example is integrating climate resilience into the designs for new homes, which is vastly cheaper than forcing retrofit later. The costs of installing a package of passive cooling measures at the new build stage was estimated by CCC analysis to be around £2,300 for a small semi-detached house, compared to £9,200 to retrofit the same measures.[11]

Lock-in will also arise if development in flood risk areas is not resilient to current and future flood risk and where flood risk management measures are currently, or will become, insufficient to manage the risk. Planning policies permit development in areas at risk of flooding, providing mitigations are incorporated, however, evidence suggests this does not occur for all developments. Planning applications for development in areas at risk of flooding need to be supported by independent evidence that flood risk from all sources, including surface water, has been assessed and mitigated and takes account of the implications of climate change.

Understanding the potential for lock-in is an important part of any climate change risk assessment, and the CCRA3 Technical Report method has given greater weight compared to CCRA2 in assessing the potential for lock-in as part of the assessment of future magnitude scores. This is because risks that involve the potential for lock-in are likely to require earlier and more direct intervention.

The CCRA Technical Report's qualitative assessment of potential for lock-in for each of the 61 risks and opportunities identifies three types of lock-in (Table 3.1):

- 'Business as usual' planning. Decisions are taken that plan for the future, but don't adequately take account of changing climate risks. For example, the building of new infrastructure, with a long life-time, which does not consider future climate risks that may be expensive or difficult to retrofit against later.
- Adaptation action is not taken. For example, the degradation of peatlands without restoration, which can lead to irreversible loss.
- Maladaptive decisions. Decisions are taken to address climate risks, but end up exacerbating vulnerability or exposure, or having negative knock-on consequences. For example, the application of neonicotinoids to control rising levels of viruses in sugar beet that are becoming more common with warmer winters, but with a result of killing bees in contact with the treated crops and hence reducing the natural capacity to deal with future risks.

Table 3.2 sets out examples of lock-in risks from across the Technical Report.

Table 3.2
Coverage of lock-in across the CCRA3 Technical Report

	'Business as Usual' planning	Lack of decisions or actions, or maladaptive decisions
Natural environment	Habitat designations are based on historical standards that aren't flexible enough to account for change Managing invasive species on the basis of today's climate only. Pests and pathogens are very difficult to manage once established Planting unsuitable tree species for the future climate increases risk for the plantation and could negatively impact the ecosystem services provided in the surrounding area	Cultural norms can prevent any transformation needed in order to improve resilience (e.g. changing land use type) Hard engineering such as hard flood defences stop the coast from adjusting naturally to sea level rise
Infrastructure	Increased reliance of electrification without boosting resilience and redundancy in the energy system and ICT means that other infrastructure systems like transport will become highly vulnerable to impacts on those sectors, and any impacts that occur will have more knock-on impacts New development in coastal areas that does not take into account long-term sea level rise or coastal erosion risk New Carbon Capture & Storage infrastructure being planned without consideration of future water deficits	Continuing to build new homes and related infrastructure in flood plains – and especially flood plains which are predicted to experience higher risks in the future
Health, Communities and Built Environment	Building new homes and hospitals, care homes etc. without passive cooling for current/future high temperatures, or protection against increasing extreme weather Continued development on the floodplain Late action in planning for increasing numbers of elderly people that will be at risk from extreme heat in future care settings Choice of future production methods that are highly water intensive	Hard engineering such as hard flood defences stop the coast from adjusting naturally to sea level rise
Business	Investing in technologies and selecting sites that could become stranded assets due to climate change Risk insensitive site locations for new assets - not taking into account long-term conditions	Lacking information on the risks down the supply chains or supply chains that are locked to certain suppliers or countries Hard engineering approaches to flood protection and lack of understanding of natural solutions

	Planning on the basis of current flood protection levels for specific sites - these will change	
International Dimensions	Fixed trade agreements could lead to low responsiveness of supply chains to long-term climate change Global finance system is locked to a certain set of pocesses	'Just in time' food supply chains that have little flexibility to change in response to shocks
Source: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.		

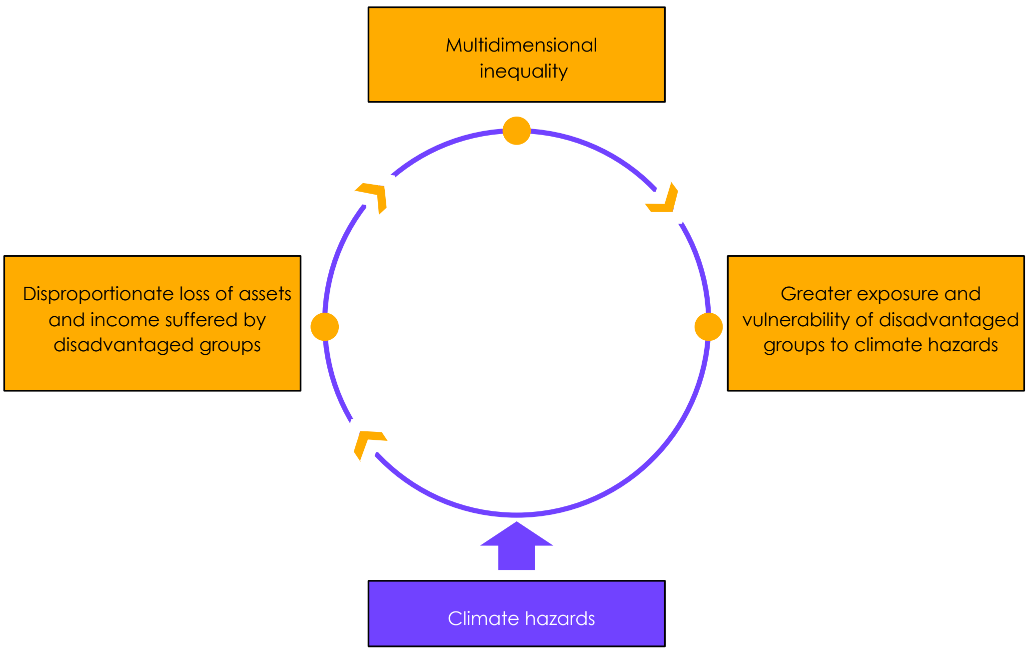
Distributional effects and inequalities of climate change

Adaptation should be an important component of the Government's levelling up agenda.

There is increasing public demand to ensure a just transition as the climate changes, and growing activism and awareness for climate justice.
This demand is highlighted by the adoption of the principle of 'fairness, including for the most vulnerable' by the UK Climate Assembly in their final report*. Strong adaptation planning should go beyond merely avoiding worsening inequality and endeavour to reduce inequality. This requires a particular focus on reducing risk for disadvantaged or exposed communities, and in keeping with the Government's commitment to levelling up across the whole of the UK to ensure that no community is left behind. This links closely to mitigation efforts, which also acknowledge the need for a just transition, as the UK society and economy changes to meet Net Zero targets. Similarly, as the UK transforms to become increasingly adapted to climate change, existing inequalities must be reduced, which will require targeted support to the households and communities most at risk.

While CCRA2 identified distributional effects as a cross-cutting issue, this assessment has gone further to consider inequalities for each risk and opportunity, where possible.
Existing inequalities mean that certain groups are more exposed to climate hazards (for example, coastal communities exposed to sea level rise) and/or more vulnerable to climate hazards (for example, low income households with limited financial savings). Climate change can exacerbate these existing inequalities, leading to a disproportionate impact on some populations over others and resulting in greater subsequent inequality in a negative cycle (Figure 3.2).

Figure 3.2 Cyclical relationship between climate hazards and inequality



Source: Islam, N. and J. Winkel, 2017.
Notes: Illustration of the negative cycle of climate hazards leading to greater inequality.

* https://www.climateassembly.uk/recommendations/index.html

Three main related factors have emerged from the CCRA3 Technical Report of different distributional effects of climate change: location; income and assets; and demographics.
Different risks will have different patterns of spatial inequalities. Specific areas highlighted as having high exposure across a range of risks in the Technical Report include coastal areas, rural, or remote areas. Income and assets are key determinants of adaptive capacity and low income and assets result in households and businesses with insufficient insurance and limited resources for recovery. Finally, demographic factors such as age, gender, and people with underlying poor health could increase vulnerability to individual risks. While not discussed in the CCRA3 Technical Report, there may also be an inter-generational effect, with future generations experiencing greater impacts and suffering compounded inequalities compared to current generations.

"Socially and economically disadvantaged and marginalized people are disproportionally affected by climate change" (IPCC, 2014)

While some risks are skewed towards one factor, in practice these distributional effects can overlap and reinforce each other, with location related to income inequality, in turn related to social and demographic inequalities. Examples of how distributional effects interact with and compound climate risks along lines of inequality are illustrated in Figure 3.3.

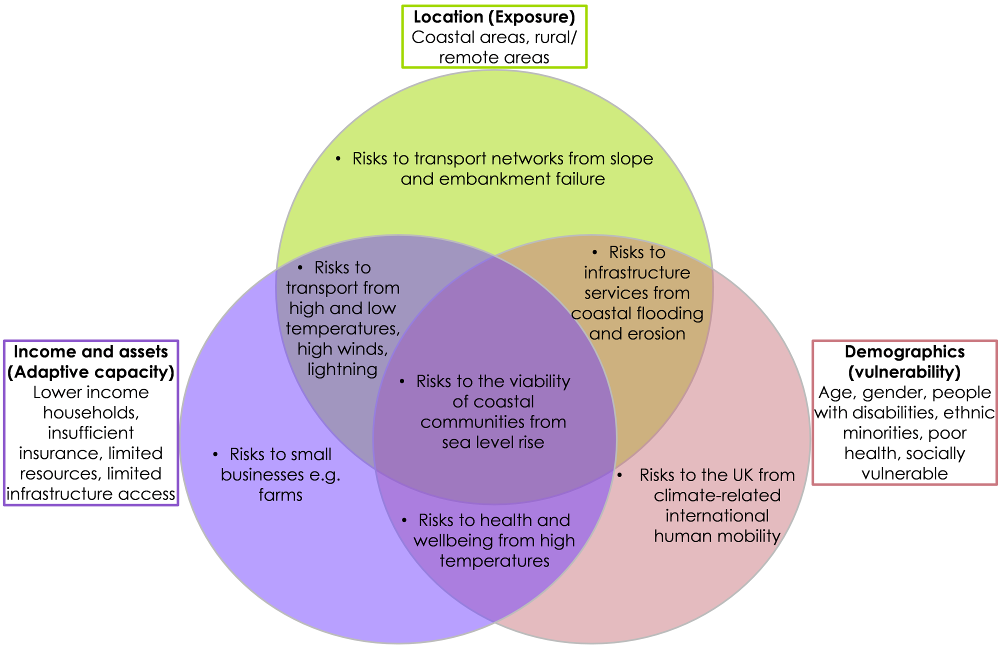
Continuing the example for coastal communities, socially vulnerable communities (a demographic effect) on the coast (a location effect) are disproportionally exposed to coastal flooding and erosion. When further considering income levels and insurance penetration (an income and assets effect), the Relative Economic Pain (ratio between uninsured loss and income) becomes significantly higher in vulnerable communities than elsewhere, increasing their overall vulnerability to the climate risk. This is borne out by past events; after the 2007 floods, those on the lowest incomes were eight times more likely to report severe mental health deterioration than those on the highest incomes, thus leading to poor health and compounding their existing inequalities.

Climate change opportunities are also subject to distributional effects with benefits likely to be captured by some groups more than others.
The CCRA3 Technical Report identifies an opportunity for health and wellbeing from warmer summers and winters, with potential for increased use of outdoor space for physical, leisure and cultural activities. However, access to outdoor space has been shown to be concentrated among wealthier groups and be diminished for lower income and ethnic minority groups, presenting unequal opportunities from a changing climate. The decline of green spaces in urban settings is also a limiting factor on enjoying this benefit. Similarly, other opportunities from climate change may not be realised equitably.

Access to outdoor green spaces is unequally distributed across UK communities.

"Several years after the 2007 floods, those on the lowest incomes were eight times more likely to report severe mental health deterioration than those on the highest incomes" (CCRA3 Technical Report Chapter 5 – Health, Communities and Built Environment).

Figure 3.3 Examples of climate risks with distributional effects



Source: CCC analysis.

Notes: Venn diagram with examples of risks which are increased by one or more distributional effects. Risks within the green circle are higher in specific locations due to higher exposure; risks within the pink circle are higher for certain demographic groups due to higher vulnerability; risks within the purple circle are higher for people or households with lower incomes and/or assets due to reduced adaptive capacity. This diagram is not a comprehensive mapping of risks against distributional effects but illustrates how these three main factors can overlap to compound some risks in particular situations.

Adaptation measures could create further unequal impacts without a better understanding of how climate change affects inequalities.

The current understanding of inequalities that are likely to increase with climate change is limited and incomplete across sectors, highlighting an important area for further research. Without a more robust understanding of existing inequalities in each sector, it is highly likely that some adaptation measures may further increase these distributional effects inadvertently, undermining public trust and support for climate action. The next set of National Adaptation Plans should map out distributional effects, considering future societal trends for example, in employment, transition to Net Zero and demographics, which may alter the baseline. Based on this mapping, actions should be proposed to avoid a deepening cycle of inequality and negative climate impacts from adaptation planning across government, using guidance in the Treasury Green Book.

Government has recently taken welcome steps to improve the consideration of climate change in economic appraisal. New supplementary guidance was published for the Green Book on adaptation in 2020 (Guidance on Accounting for the Effects of Climate Change).

Following internal review, the UK Government is considering the case for extending the lower discount rate of 1.5%, applied to health impacts, to environmental impacts. The discount rate used for climate change risks should be lowered, as higher incomes in the future will not compensate for the welfare loss due to climate impacts, including some irreversible changes.

Climate change cannot be addressed from mitigation or adaptation alone. Both are needed, and they need to be integrated to respond to the threats from climate change.

Both adaptation and mitigation are needed together to address climate change. Climate mitigation is needed to reduce levels of greenhouse gas emissions to ultimately limit the scale of changes in hazards that the world will experience. However, even with very high levels of global greenhouse gas emissions reductions, adaptation will still be required to reduce vulnerability and exposure to inevitable changes in climate hazards, and to plan for uncertain but plausible higher levels of warming (Chapter 1 and 2). Importantly, very high levels of mitigation are not by any means guaranteed globally or in the UK at present. If global emissions do not start to decrease dramatically, and/or if climate sensitivity is high, very high impacts in the UK and worldwide are projected. Chapter 1 explains the range of climate scenarios that need to be planned for in more detail.

Out of 15 relevant major UK Government announcements on addressing climate change made over the past three years, only four have included integrated plans and goals on adapting to climate change alongside mitigation.

Adaptation and mitigation have yet to be successfully integrated across government policy.
Since CCRA2 was published in 2017, adaptation has not been given the level of attention it needs by the UK Government. It is essential that it is properly integrated into decision making alongside reducing emissions. Out of 15 relevant major UK Government announcements linked to addressing climate change made over the past three years, only four have included integrated plans and goals on adapting to climate change alongside goals and plans for reducing emissions (Figure 3.4). In some others, adaptation is mentioned as an additional requirement rather than being part of core of the policy or programme, but in many it is simply absent despite adaptation considerations being critical to delivering effective policy.

Figure 3.4 Integration of adaptation in major announcements since 2017

Relevant announcements without adaptation	Relevant announcements with adaptation mentioned but not integrated	Relevant announcements with adaptation integrated
1. UK's updated Nationally Determined Contribution (2020)	7. 25-Year Environment Plan for England (2018)	12. Flood and Coastal Erosion Risk Management Strategy for England (2020)
2. UK Treasury cost review of transitioning to a green economy (2020)	8. Ten-point plan for a Green Industrial Revolution (2019-20)	13. Taskforce on Climate-related Financial Disclosure Reporting Requirements (2020)
3. Green Homes Grant (2020)	9. Environmental Land Management Scheme for England (2020)	14. Green Book Supplementary Guidance on Climate Change (2020)
4. Future Homes Standard Consultation (2020)	10. Infrastructure Strategy (2020)	15. UKRI Strategic Priorities Fund (2018)
5. UK Climate Assemblies (2019-20)	11. Planning White Paper (2020)	
6. Industrial Strategy (2017)		

Source: CCC.
Notes: 'Relevant announcements without adaptation' include those where adaptation is missing despite the CCC specifically recommending it be included; or where including adaptation considerations would directly address the risks or opportunities set out in this assessment; or where including adaptation would contribute to a strengthened national or government dialogue. 'Relevant announcements with adaptation mentioned but not integrated' represent policies where the word adaptation is mentioned, or cases where there are a narrow set of actions related to adaptation, but where adapting to climate change is not viewed as a core requirement in order to achieve the wider aims of the strategy and where the actions as set out would not enable this. 'Relevant announcements with adaptation included' are those examples where adaptation is part of the core aims and where there are specific actions in the relevant strategy or announcement.

Climate change poses significant risks to the UK's ability to reach Net Zero greenhouse gas emissions by 2050.
The CCRA3 Technical Report has considered climate change risks to meeting the UK's Net Zero target, as well as potential synergies and trade-offs between mitigation and adaptation actions (Table 3.3). Most of the direct climate risks to achieving Net Zero fall in the natural environment and infrastructure sectors. Potential benefits and trade-offs are highlighted in the areas of people and built environment and natural environment, but also for business and international dimensions.

Table 3.3
Net Zero – climate risks, synergies, and trade-offs with adaptation*

Sector	Direct risks from climate change to Net Zero	Actions with benefits for both adaptation and mitigation	Potential trade-offs between adaptation and mitigation
Natural environment	• Risks to soil quality (including peat) and other land cover that leads to reduction in carbon sequestration capacity or even emitting carbon • Increased emissions from wildfire • Reduced plant productivity (crops and trees) from soil moisture deficits • Reduced woodland, crop or livestock productivity from pests and diseases • Risks for marine biodiversity (and natural carbon storage) from warming and acidification • Changing conditions (heat, water scarcity, flood, fire) do not allow for productivity gains from agriculture to be met, so that land cannot be freed up for increased forestry	• mixed species planting • peatland restoration • soil conservation, precision farming • saltmarsh/ wetland creation and restoration • Improved habitat connectivity and condition will assist in species movement to more climatically suitable areas • New crop varieties with higher yields and improved climate resilience through (e.g. reduced soil erosion from planting triticale) • Tree planting for natural flood management • More nitrogen-efficient farming • Marine and coastal habitat protection	• Planting of trees in climatically unsuitable areas, monoculture planting and where trees compete with other land uses (e.g. peat soils) and could negatively affect ecosystem services (e.g. water availability) • Increased connectivity from forest expansion could promote spread of pests and diseases • Over-emphasis on bioenergy crops without corresponding attention on biodiversity and landscape resilience and food supply (e.g. increased soil erosion, water quality reductions) • Increased irrigation demand for agriculture to support high yield cereals • Offshore wind platforms acting as 'stepping stone' habitats for invasive marine species

* More detailed lists of the links between Net Zero and adaptation are given throughout the CCRA3 Technical Report

Infrastructure	• Storms, high or low winds reducing offshore wind production • Greater reliance on electricity networks and ICT increasing impacts of outages • Flood risk to new infrastructure sites (e.g. EV charging stations, coastal CCS sites) • Reduced water availability impacts on hydropower • Insufficient water availability for CCS and hydrogen production • Subsidence risk to buried infrastructure • Performance thresholds of Net Zero infrastructure (e.g. PV, wind turbines) are exceeded more often due to increased extreme events • Increased exposure to extreme weather of people using active travel (walking/cycling), Increased risks to rail from shrink/swell subsidence, flooding	• Use of natural flood management approaches to reduce flood risk to Net Zero infrastructure, and reduce the carbon intensity of flood management	• Increased water demand from biomass, CCS and hydrogen production, putting added strain on the natural environment at times of low flows • Increased carbon intensity if de-salination plants, increased treatment or pumping are needed to address water scarcity • Increased carbon intensity from larger amounts of mechanical cooling of ICT infrastructure
People, communities, and the built environment	• Challenges in designing and implementing the right mix and types of technologies for low carbon heat and energy efficiency in buildings in a warming climate	• Significant reductions in outdoor air pollutants from shift to Net Zero • Tree planting and increased urban greening benefits for carbon storage, flood and heat mitigation • Low-carbon materials in new flood defences • Reduced winter heating demand lowering emissions • Low-carbon energy generation will reduce the negative trade-offs from increased summer cooling demand • Passive cooling would reduce summer energy demand • Lower discolouration of buildings by reduced NOx and CO2 emissions	• Increased overheating and/or poor indoor air quality (damp, mould) risk from more airtight homes without adequate ventilation/ passive cooling • Increased carbon intensity from air conditioning or other summer cooling demand • Greater UK-based tourism driven by reduced flying could place added pressure on heritage assets or vulnerable locations, such as the coastline

Business	• Changes in peak electricity demand from higher cooling demand could pose challenges to balancing energy supply from low carbon sources • Supply chain disruption to key materials needed to support Net Zero e.g. rare earth metals	• Business opportunities from integrated building retrofit for mitigation and adaptation • Reduced water demand by businesses could also reduce energy use	• Emphasis on transition risk in business reporting may reduce attention paid to physical risk • Increased carbon intensity from higher levels of office air conditioning • Reducing the carbon intensity of supply chains by increasing efficiency and reducing stock holdings would lower supply chain resilience
International dimensions	• Need for increased domestic food supply if global food security falls • Changes to supply chains in response to climate shocks could increase (or decrease) carbon emissions • Changing trade relationships or impacts on global governance exacerbated by climate change could affect Net Zero delivery in the UK		• Reduction in land available for agriculture globally in order to meet Net Zero could increase food security pressure • Increase in wetland habitats could become a breeding ground for insect vectors of disease
Source: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.			

An example of where the importance of integrating adaptation with mitigation has been monetised is the case of natural carbon stores and sequestration. The Government's Natural Capital Accounts report that gross CO_2e sequestration (i.e. the total stock, not the annual flow) within UK natural habitats was estimated at 28 billion tonnes in 2017 (Figure 3.5), with an associated asset valuation of £106 billion.[12] In 2017, forest land removed 18 million tonnes of CO_2e. In contrast, cropland emitted 11 million tonnes in 2017 as a result of the loss of carbon stock when converting grassland to cropland. This means UK croplands provide negative net carbon sequestration.

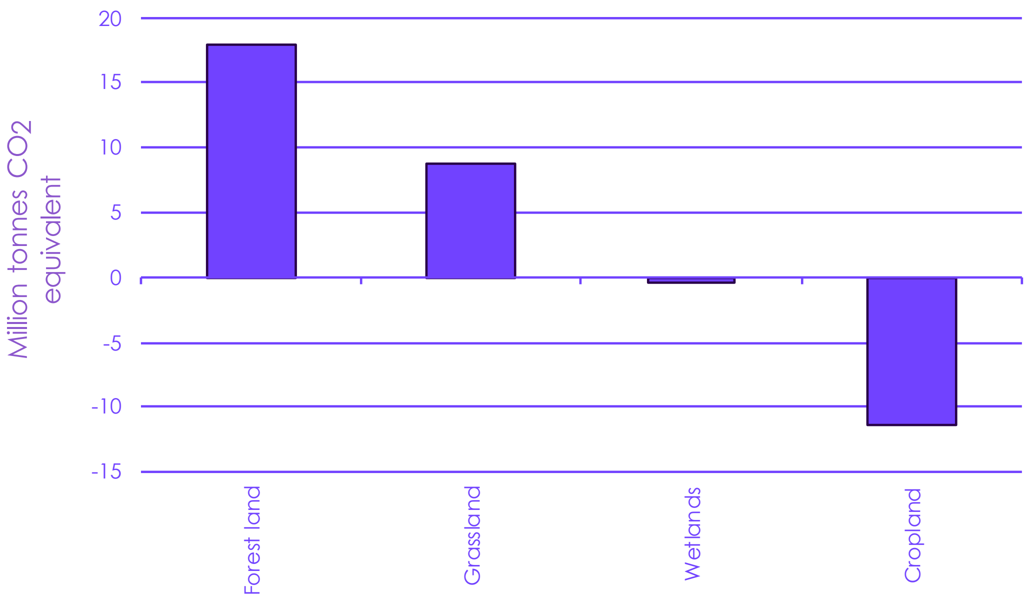
Marine carbon sequestration is significant and requires more research to understand it more fully, but the latest Natural Capital Accounts estimate it at between one-third and more than double the carbon removed by terrestrial habitats.[13]

Climate change will have both positive and negative effects on natural carbon stocks.[*] Present annual values of the change in soil carbon stocks up to 2060 could range from -£1 billion (losses) to +£ 2 billion (gains), depending on climate scenario (low or high emissions) and land use decisions.[14]

[*] See Berry, P. and Brown, I. (2021) CCRA3 Technical Report Chapter 3 – Natural environment and assets

Other estimates focussing on peatlands suggest that increased carbon emissions from peatlands due to hotter, drier conditions could lead to annual average damage costs of £1.1billion (2050s), and up to £1.5 – £2.2 billion (2080s).[15]

Figure 3.5 Net annual natural carbon sequestration by land type, UK, 2017



Source: Natural Capital Accounts, 2019.

Understanding the challenges of achieving Net Zero in the context of a changing climate should be a priority for further analysis.

The CCRA3 Technical Report considers how the transition to Net Zero will affect climate risk, as well as the risks to meeting Net Zero from climate change.

There have been several UK-based studies of the direct costs of achieving the Net Zero target by 2050, both from the CCC's own analysis[16] and an exercise conducted by HM Treasury.[17] The CCC's latest estimates put the net cost of achieving Net Zero at less than 1% of GDP through to 2050 when taking into account the benefits from the falling prices of low-carbon technologies, with scope for the economic effect to be net positive as resources shift from imported fossil fuels to UK investment. The CCC's latest estimates (i.e. the 2020 work on the Sixth Carbon Budget) also began to capture how a changing climate itself would affect the ease and the cost of reaching Net Zero.

The CCRA3 Technical Report considers how the transition to Net Zero will alter the risks from climate change. The transition to Net Zero will change the characteristics of things that are affected by climate change (such as the energy system), altering risks positively and negatively. At the same time, climate change could make the Net Zero target harder in some cases and easier in others (e.g. negatively, by reducing forest productivity from soil moisture deficits, pests or diseases; and positively, by reducing energy demand in winter).

Further work is needed to assess how the Net Zero transition will interact with the effects of increasing climate risk. This is particularly important to encourage synergistic mitigation-adaptation policies.

Direct economic benefits from adaptation action

There are benefits from further adaptation for nearly every risk and opportunity assessed in the CCRA3 Technical Report, either from reducing impacts from climate change (for risks) or enhancing benefits (for opportunities).
The CCRA3 assessment considers the benefits of further adaptation action in the next five years over and above what is already planned, for each risk and opportunity where an adaptation gap was identified and where actions are assessed as being more urgent. The assessment includes the available evidence of these further benefits, including information on co-benefits and trade-offs, and a review of the potential costs and benefits of further actions.*

For nearly every risk and opportunity considered, there are benefits to further action in the next five years. While the Technical Report has not assessed the costs and benefits of specific actions, it identifies a large range of beneficial adaptation actions, shown in Table 3.4. These are not the only adaptation actions that should be considered in policy, but are examples from the literature that occur throughout the Technical Report.

Table 3.4
Beneficial adaptation action in the next five years for the UK

Category	Examples
Engineered solutions	• Building design and retrofit – architecture, shading, ventilation, water efficiency, property-level flood resilience • Road and rail – re-surfacing, change in materials used, earthworks, vegetation management • Drainage • Water supply infrastructure • On-farm water storage • Flood defence investment
Nature-based solutions	• Increasing plant diversity in forestry, hedgerows, arable and horticultural farming • Habitat creation • Peatland restoration • Soil conservation - Buffer strips, mulching, contour ploughing, sediment traps, low-till farming • Water – reducing demand, improving supply • Blue-carbon initiatives e.g. coastal saltmarsh and wetland creation • Managed realignment of coastal areas • Urban greening • Green sustainable drainage systems
New/emerging technologies	• Climate-smart agriculture – precision farming, new crop and livestock varieties, • New modelling and data systems for hazard prediction • Rainwater harvesting systems

* Watkiss, P and Betts, R (2021) CCRA3 Technical Report Chapter 2 – Method, provides a detailed description of the method for assessing the benefits of further action.

	• Remote sensing to detect changes in hazards and asset performance • New designs for shipping and offshore infrastructure • Use of big data e.g. monitoring of indoor environmental quality
Behavioural	• Changing sowing dates of crops • Changing management practices for agriculture and forestry • Building operation choices e.g. use of active and passive cooling • Information sharing • Communication • Training and skills development • Public engagement e.g. through citizen science
Institutional	• Adaptation standards • Organisational and site level risk assessments • Changing trade patterns • Supply chain and product diversification • Business continuity planning • Regulation • Emergency management • Advisory services • Humanitarian aid • Transboundary agreements • Diplomacy
Financial	• Insurance • Disclosure of physical climate risk • Targeted adaptation finance • Green finance
Data, R&D	• Monitoring and surveillance • Inspections • Forecasting and early warning systems • Research on climate impacts, adaptation responses, public attitudes and willingness to pay • Provision of decision support tools and information • Traceability standards for supply chains
Source: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.	

There are strong economic and societal benefits from taking adaptation action.

The CCRA3 Technical Report provides information, where available, on costs and benefits of further action, though it does not provide a full economic assessment of action.

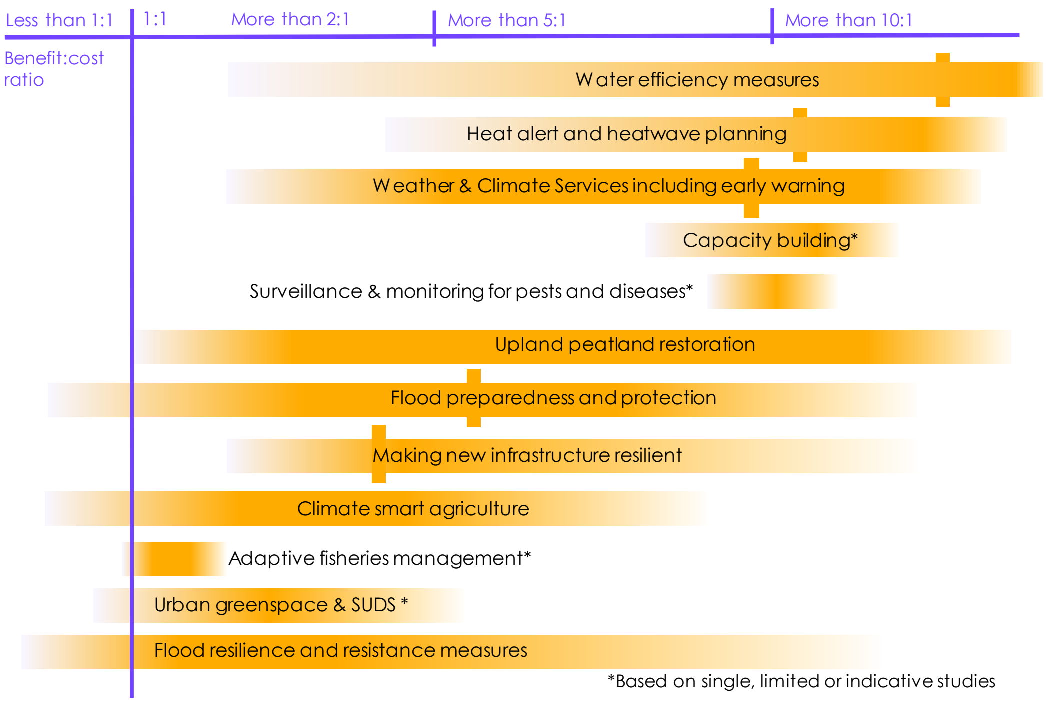
The Technical Report has provided some indicative information on costs and benefits for a number of adaptation measures and highlighted examples of interventions that typically have net benefits. Supporting analysis in the CCRA3 Valuation Report provides an indicative monetary valuation of risks and opportunities in terms of the effects on social value (i.e. aiming to include all costs and benefits that affect welfare and wellbeing, including environmental, cultural, health, social care, etc.) to estimate the costs of climate change before adaptation.

The benefit-to-cost ratios (the ratio of the present value of benefits to the present value of costs) of a selection of measures discussed in the Technical Report are illustrated in Figure 3.6 below.

Some adaptation actions have very high benefit-to-cost ratios in excess of 10:1.

Adaptation actions have high net benefits, and positive benefit to cost ratios, in many cases, even when considering direct benefits alone.
The societal costs and benefits of adaptation measures tend to be very site- and context-specific and can vary significantly depending on the circumstances. An adaptation action that is not cost-beneficial in one context or location can be so in another, and vice versa. The review of adaptation costs and benefits in the Technical Report shows that in many cases, adaptation actions have positive benefit to cost ratios, even when considering the direct reduced impacts from climate change impacts alone (see Figure 3.6). Some adaptation actions such as surveillance and water efficiency labelling have very high benefit-to-cost ratios (10:1 or greater).

Figure 3.6 Benefit-cost ratios of adaptation measures included in CCRA3



Source: Watkiss, P. and Brown, K.A (2021).
Notes: Figure shows the indicative benefit-to-cost ratios and ranges for a number of adaptation measures. It is based on the evidence review undertaken in the CCRA3 Valuation study, which was co-funded by the EU's Horizon 2020 RTD COACCH project (CO-designing the Assessment of Climate CHange costs). Vertical bars show where an average BCR is available, either from multiple studies or reviews. It is stressed that BCRs of adaptation measures are highly site- and context-specific and there is future uncertainty about the scale of climate change: actual BCRs will depend on these factors.

Early action is a key component of effective adaptation. Waiting until a climate impact has occurred before improving resilience often results in higher costs and potentially irreversible losses.

Early action typically has much larger benefits than delaying and taking action after an impact has already occurred.
Delaying action makes it much harder to reduce climate risks and may make large future costs inevitable. There are three types of interventions that are highlighted as priorities for early action.

- **No- and low-regret intervention.** There is a very strong economic case for early action in relation to no- and low-regret interventions, as these have immediate economic benefits from reducing current impacts. Examples include reducing water use or signing up to flood warnings.
- **Climate-resilient design to avoid lock-in.** There is a strong economic justification to intervene early to include adaptation in near-term decisions that have long lifetimes and 'lock-in' risk (see section above on lock-in). In our assessments of adaptation in homes, the economic analysis has found that building homes to be prepared for a future climate with higher temperatures, more flooding and more water stress is far cheaper than retrofitting poorly-adapted homes later. Similarly, previous assessments of adaptation in land use show much larger net benefits when action is anticipatory, i.e. taken in advance of a climate change impact occurring. An example is planting trees that will thrive in the future climate, rather than managing a poorly chosen species mix retrospectively. Analysis of the benefits of these early actions is set out in detail in previous CCC reports on land use[18], and housing,[19] and is also reflected in the Technical Report chapters.
- **Early adaptive management.** For decisions that have long lead times, or where there are large future risks, there is a strong economic case for fast-tracking early adaptive management actions, because of the value of information and opportunity for learning these provide. An example includes flood management planning for London through the Thames Estuary 2100 programme.

At the national level, all three of these types of interventions are likely to be needed.

Relocation or retreat is a fourth type of intervention. However, it may not be a cost-effective option in many cases (unless the impacts are very large).
An example of research into relocation from the Valuation Report relates to protection of electricity substations from flooding. A national-scale analysis looked at direct and indirect economic losses that could occur due to the failure of major electricity assets within England and Wales, as a result of flooding major electricity substations. Of the three potential adaptation options considered: installing flood walls, raising flood walls, and relocation, the installation of a floodwall to protect against failure-related losses results in a positive NPV for all 107 sub-stations; only four substations show a positive NPV for the substation raise option, and no assets showed a positive NPV for the substation relocation option, although investment in the latter options could become more attractive when an asset is approaching the end of its life.

This example also raises the question of what other adaptation measures could be employed in addition to structural flood defences in order to add additional resilience before a relocation option is considered; for example, a wider portfolio of measures shown in Table 3.4. Nature-based solutions such as green sustainable drainage systems could offer an additional benefit for flood protection, particularly against surface water flooding, which is the major cause of current and future flood risk for substations.

There is little available evidence of the benefits of further adaptation to take advantage of the opportunities from climate change.
Chapter 2 sets out the opportunities from climate change that are identified in the Technical Report. Many of these benefits will be realised by non-government action, e.g. by households or the private sector. However, the assessment identifies that in some cases there are likely to be barriers or constraints that prevent or reduce such action, and therefore further government action could help to take advantage of opportunities. This might, for example, create the enabling environment, such as with awareness raising or information provision. An example is government support to improve skills in construction for climate-resilient homes, or providing information about likely future conditions to help farmers to judge when to switch crops to a warmer-climate variety.

The Technical Report found less evidence on opportunities (benefits) in general, e.g. for facilitating new species colonisation, opportunities for wellbeing from warmer temperatures, increased UK food exports and new trade routes, and it found very little information on the potential benefits of further action to support delivery of these direct opportunities. There was also a gap in terms of the costs and benefits of further action. One exception was for the UK wine industry, where some analysis of the economic opportunities, and the possible costs and benefits of further action, was identified.

Adaptation actions can have important wider benefits, such as for health and wellbeing and improved biodiversity. Adaptation can generate wider economic benefits, as well as avoiding climate change damage.
Many adaptation actions generate co-benefits, which are additional to their benefits in reducing the impacts of climate change. Some examples of such actions that are highlighted in the Technical Report include:

- **Peatland restoration.** The benefits of peatland restoration vary by location and the assumptions made about future climate change. According to Watkiss et al. (2019) the range of benefit-to-cost ratios varies from between 1.3:1 to 12:1, depending on how far into the future the analysis goes and which benefits are considered. The net benefits are larger if wider ecosystem services – over and above carbon storage – are included, such as water quality improvements and biodiversity gains from well-functioning upland peat. Climate change also strengthens the case for peatland restoration, as more extreme climate scenarios could lead to irreversible losses for degraded peatland systems, but these potential outcomes can be avoided by early restoration.

- **Improved ventilation in buildings.** As well as aiding the night-time cooling of buildings during hot weather, adequate ventilation is also critical for maintaining good standards of indoor air quality.

- **Green sustainable urban drainage systems.** Blue-green infrastructure in urban areas has a host of known benefits for health and wellbeing, biodiversity, and local environmental quality, as well as for climate change mitigation and adaptation. When considering the benefits from reduced flooding alone, the benefits of green sustainable drainage systems can appear marginal, but when other benefits are included (e.g. amenity value, biodiversity benefits), the benefit-to-cost ratio increases significantly and rise to 2:1 or higher.

Adaptation actions that enhance the resilience of the natural environment have important wider benefits across all of the sectors assessed in the CCRA.
As well as being an important component of interacting risks (see Chapter 2), the natural environment plays an important role across the risks considered in the CCRA of mediating impacts, through its role as an adaptation response. There has been a step change in the understanding of the monetary benefits of biodiversity and the natural environment to people since CCRA2 was published, including through the UK Government's work on natural capital accounting and the publication of the Dasgupta Review of the Economics of Biodiversity.[20] The importance of using a natural capital framework in understanding the benefits of adaptation is summarised in Box 3.1 below. Future iterations of the UK's National Adaptation Plans should consider nature-based solutions in more detail and prioritise those with benefits across protecting biodiversity, reducing emissions and improving climate resilience.

Box 3.1
The role of natural capital in adaptation

The natural environment, in addition to its intrinsic value, provides critical ecosystem services. These include provisioning services (e.g. food and fibre production); regulating services (e.g. water regulation); cultural services (e.g. amenity, recreational and aesthetic benefits) and supporting services (e.g. nutrient recycling). The ecosystems that provide these services (and the flow of benefits provided) can also be thought of as capital assets. The term capital is used to denote a stock that could continue to give, if properly maintained. It also provides a useful analogy to other essential forms of 'capital', although with unique and sometimes less tangible attributes that challenge attempts at generalisation and simplification (see Dasgupta, 2021).

Natural Capital encompasses all components of the natural environment, as well as the processes and functions that link these components and sustain life. Natural capital assets include all biotic (living) and abiotic assets (e.g. species, ecological communities, soils, freshwaters, land, atmosphere, minerals, sub-soil assets and oceans) and include both designated and undesignated habitats and species.

Climate change can have potential impacts on natural capital assets and the benefits they provide. The stability and resilience of ecosystems is maintained by a complex array of natural processes, feedbacks, and functions that are affected in different and profound ways by changes in hazards such as warming temperatures and alterations in seasonal rainfall. While it can be challenging to tease out all of these interacting effects, what becomes clear is that the risks to the natural environment from climate change go way beyond the loss of a single asset or service, and create risks to the stability of biological systems as a whole, including human systems.

However, at the same time, it is possible to use ecosystems to deliver adaptation. Nature-based solutions both aim to recognise and work with (rather than against) the natural resilience and adaptability of the natural environment to preserve natural assets and ecosystem services, and in doing so, maintain the resilience of the core underpinning services they provide.

Source: Adapted from Chapter 3 of the CCRA3 Technical Report (Berry and Brown et al. (2021).

Green finance should help in creating better market conditions for adaptation funding.

An active green finance market is emerging in the UK, which should help to create the right market conditions for adaptation funding if it is integrated as a core aim. Some examples of recent developments in green finance include:

- The use of green 'resilience bonds', for example those now being put in place through water companies. The UK has nearly 80 green bonds already listed on the London Stock Exchange, raising more than US$24bn[55]. Green bonds have focused on mitigation to date and there is no information on the level of resilience bonds. However, the first major resilience bond ($700 million) was recently launched by EBRD.

- The first UK sovereign green bond was announced by the Government in 2020. The stated aims of the Bond were to help finance projects that will tackle climate change, support infrastructure investment and create green jobs across the country. Adaptation should be core to these objectives.

- The Natural Environment Investment Readiness Fund (NEIRF) was launched in 2021 to help make projects more investible in terms of returns and scale and thereby help stimulate private investment.

Funding mechanisms are still not in place for some adaptation measures, and in other cases mechanisms exist but are not incentivising a scale-up in action as adaptation is not considered as a core aim.
A final issue for consideration is the subject of how funds can be made available to support adaptation.

In some cases, funding may be provided privately in response to market signals – for example, households might be expected to pay for property-level flood resilience, if they have good information about their own level of risk and access to finance to make the investment.

However, in many cases missing markets and barriers to action might mean this is unlikely to happen. There may be information failures, the value of the adaptation action may not accrue to where the expense is incurred, there may be a lack of sufficient financial returns, lack of coordinated, large scale, investment opportunities, or a range of other market failures and barriers may prevent effective measures being taken. Examples include flood defences that benefit a wide range of property owners, building-level measures for tenants of private-rented properties, and any measures that protect the natural environment.

Some well-established funding mechanisms for adaptation already exist, such as partnership funding for flood defence schemes, flood insurance and water company financing for water efficiency measures in homes. New environmental land management payments could offer a targeted lever for adaptation in the land use sector, but the details of how these will operate and how far they will achieve this are still not available at the time of writing.

For many of the other beneficial adaptation measures identified above, however, the signals do not exist to encourage effective measures at scale from householders, local authorities or businesses.

This includes building-level measures such as passive cooling, and some nature-based solutions including urban greening and rainwater harvesting.

In other cases there has been an increase in government-funded schemes for the natural environment such as the £640million Nature for Climate Fund, but these lack a specific focus on adaptation and are therefore unlikely to incentivise the best actions in the right places to promote resilience.

The risk assessment has highlighted that resources for local action, such as limited conservation budgets, are also a constraint on implementing adaptation actions which also often have co-benefits for climate change mitigation and biodiversity.

Emerging information from adaptation finance studies in Glasgow[21] highlights that to meet the adaptation finance gap, public funds will need to be scaled up and used in more strategic ways, including to mobilise private investments. Doing this requires the private, public and third sectors to design a process for mobilising public and private resources for innovation, making a broader range of financing instruments and models accessible, as well as developing long-term transformative financing solutions that are aligned to the different interests and requirements of the public and private sectors.

Green finance offers the potential to fund adaptation actions with wide-ranging benefits across climate change mitigation, adaptation and biodiversity protection. The UK Government's Green Finance Strategy identifies climate resilience and an increase in adaptation as strategic objectives to support through green finance. Despite this recognition, the Government does not provide further details on providing funds or financial mechanisms for these goals.

There is an increasing number of options, though not yet at the scale needed to encourage the levels of adaptation required to match the scale of risk.[22] Some suggestions for new financing mechanisms or frameworks mentioned in the CCRA3 Technical Report include:

- Conservation organisations developing finance-ready proposals for investment in biodiversity.
- Lending, advisory services and green 'securitisation', which will help provide finance from institutional investors, and opportunities for banks as underwriters or issuers of green bonds.
- Extending funding mechanisms that currently only focus on low-carbon buildings (e.g. the smart energy programme) to include resilience, which in turn would help to boost profitability and employment in the construction and advisory services.

A key component of the next iteration of national adaptation plans should be a commitment to enable sufficient funding for the necessary scaling up of adaptation action, setting out the mechanisms by which this will be achieved, with a focus on those adaptation actions that have no relevant funding streams at present.

Endnotes

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Chapter 4

Priorities for action

Introduction and key messages

This chapter sets out the Committee's advice – to both the Government and other organisations - on the highest priority risks to address in the next five years.

Of the 61 risks and opportunities set out in the CCRA3 Technical Report, the Committee has highlighted eight priority areas that, in particular, should be taken forward as critical adaptation policies at the highest levels of government in the next two years, in advance of the next round of National Adaptation Plans. These eight priorities are based on the Committee's assessment using the following criteria, which are shown for each risk and opportunity in an accompanying annex to this report:

- the degree of urgency given in the Technical Report
- the gap in adaptation planning
- the growing importance to the UK in the context of the changes taking place, for example the implications of delivering Net Zero
- the opportunity to integrate adaptation into major policies, legislation and strategies over the course of the rest of this Parliament (up to 2024)

Our eight priority areas are*:

1. Risks to the viability and diversity of terrestrial and freshwater habitats and species from multiple hazards
2. Risks to soil health from increased flooding and drought
3. Risks to natural carbon stores and sequestration from multiple hazards leading to increased emissions
4. Risks to crops, livestock and commercial trees from multiple hazards
5. Risks to supply of food, goods and vital services due to climate-related collapse of supply chains and distribution networks
6. Risks to people and the economy from climate-related failure of the power system
7. Risks to human health, well-being and productivity from increased exposure to heat in homes and other buildings
8. Multiple risks to the UK from climate change impacts overseas

We set out our analysis supporting these priorities in three sections:

- The adaptation deficit
- Priority risks for action
- The background assumptions for our risk prioritisation, shown in the accompanying annex for this report

* Note that the priorities are not ranked from one to eight - they are deemed equally urgent

Only four out of 61 risks and opportunities in the risk assessment are deemed to be managed sufficiently on the basis of planned adaptation actions.

Our assessments of progress in adaptation for England and Scotland show a large deficit in the delivery of adaptation.

The Adaptation Committee has a statutory role to assess progress in adapting to climate change for England every two years. We have also produced two reports for Scotland evaluating the first Scottish Climate Change Adaptation Programme. These reports have shown pockets of excellence in each for risk assessment, adaptation plans and delivery, but at the national level the scale of action does not meet the scale of risk. In neither nation are there sufficient plans in place for ensuring adaptation is underway for even a 2°C scenario, let alone a 4°C scenario. In no case have we been able to give a high score for delivery of adaptation to reduce risks. Our next progress report for England will be published shortly.

The CCRA3 Technical Report shows a similar picture in its assessment of adaptation, with sufficient adaptation underway for only four out of 61 risks and opportunities, and no plans in place at all for a further seven (the remainder being given a 'partially managed' score).

The Technical Report includes analysis for each risk and opportunity of the extent to which the level of adaptation underway is sufficient. The method considers whether adaptation will keep the future magnitude of risk at a low level in cases where the risk is currently low in the present day, or if it will avoid an escalation of risks and manage the drivers of vulnerability and exposure where the magnitude is already medium or high (such as for flood risk). For opportunities, the opposite applies, where the assessment judges how far the opportunity is likely to be realised.

The assessment has included consideration of government and non-government action, and the barriers that are preventing further action.

Out of the 61 risks and opportunities, only four have been assessed in the CCRA3 Technical Report as being managed sufficiently on the basis of current and planned government and non-government adaptation for any of the four UK nations (i.e., the adaptation score across the UK is 'yes'). These are:

- risks to aquifers and agricultural land from sea level rise (N10)
- risks to offshore infrastructure from storms and high waves (I11)
- opportunities for UK food availability and exports from climate change impacts overseas (ID2)
- opportunities from climate change on international trade routes (ID6)

A further seven risks and opportunities have been assessed in the CCRA3 Technical Report as having a significant gap in policies and plans in place to adapt in at least one of the four UK nations at the time of writing (i.e., the adaptation score across the UK is 'no'). These are:

- opportunities from new species colonisations in terrestrial habitats (N3)
- risks and opportunities to natural carbon stores and sequestration (N5)
- opportunities for new agricultural and forestry species (N9)

- opportunities to marine species and fisheries from changing climatic conditions (N15)
- risks to digital infrastructure from high and low temperatures, high winds and lightning (I13)
- risks and opportunities from changing summer and winter household energy demand (H6)
- risk multiplication from cascading impacts of climate change overseas (ID10)

All other risks and opportunities at the UK level have been awarded a 'partially managed' score.

The low adaptation scores have contributed to the large increase in the number of risks and opportunities falling into the most urgent 'more action needed' category for government action.

Rationale and criteria for prioritisation

The increase in the number of risks falling into the most urgent category presents challenges for Government in identifying where to focus most attention at the highest levels and through the coordination of adaptation across departments. Chapter 2 shows the large increase in the number of risks falling into the top 'more action needed' urgency category compared to CCRA2. All of the 61 risks and opportunities must be addressed in the forthcoming National Adaptation Plans. However, in addition, the Committee has identified, amongst the 'more action needed' risks, eight top priorities that should be addressed in the next two years at the highest levels of government and jointly across departments and between UK Government and the devolved administrations.

We have identified these priorities using expert judgement around four criteria, detailed for each risk and opportunity in an accompanying annex to this report:

Some risks need urgent attention now, even before the next round of National Adaptation Plans is published from 2023.

- Risks or opportunities with the highest urgency score (more action needed)
- Risks or opportunities where the largest gaps in adaptation policy or action exist; based on both the CCRA Technical Report assessment and the Adaptation Committee's progress reports (covering England and Scotland only)
- Risks which are becoming increasingly urgent because of national and global change, for example the consequences of the transition to Net Zero emissions
- Risks or opportunities where it appears that the largest opportunities for integrating adaptation into key policies are likely to arise over the next 12 months, and where missing the opportunities could lead to lock-in or mal-adaptation

Summary of the priority risks and opportunities for government

The Committee has identified eight sets of risks as needing the most attention at the highest levels of government over the next two years.
The Committee's assessment, using these four criteria across all risks and opportunities for each UK nation is provided in a separate accompanying annex to this report. The results of the prioritisation are shown in Figure 4.1 below, reflecting a UK-wide list of priorities.

Figure 4.1 Highest priorities for adaptation in the next five years

Source: CCC

The sections below provide a brief summary for each of the eight priority risk areas, including the main hazards associated with the risk, the assessment of the adaptation gap, and short-term policy opportunities for further action.

Risks to the viability and diversity of terrestrial and freshwater habitats and species from multiple hazards

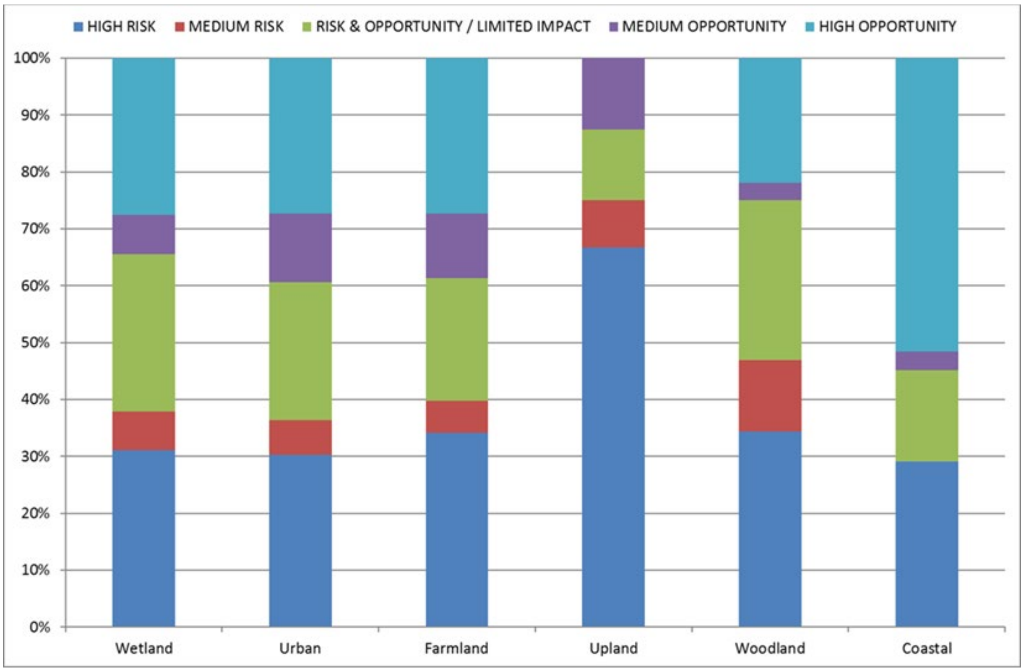
Biodiversity underlies all economic activity and human wellbeing, globally and in the UK. Many of the services that the natural environment provides, such as flood mitigation, water supply and cooling are also key to societal resilience to climate change. However, biodiversity in the UK is degrading, with overall declines in the abundance and distribution of species since 1970.[1] Reversing the decline in UK biodiversity is a major goal for the UK Government and devolved administrations as shown in strategies such as the 25 Year Environment Plan, and Environment (Wales) Act.

Climate change will have complex and mixed effects on UK biodiversity, with some gains and some losses in species and a wide range of effects on different habitats, varying by place and the degree of warming. Terrestrial species and habitats include wildlife that inhabits lowland and upland areas, including farmland, woodland, grassland, heathland, montane habitats, and urban areas.

Freshwater habitats include lakes, ponds, rivers and canals.* While there are projected to be some benefits for terrestrial and freshwater species from warming, there are also significant projected losses that require adaptation action to minimise negative impacts as far as possible, in order to meet the Government's goals to protect and enhance wildlife.

The risk to upland areas is particularly acute with a predicted decline in the suitability of the climate for 75% of present day upland species by 2100 in a medium (SRES A1B) scenario (Figure 4.2). The uplands provide significant ecosystem services for the rest of the country, from carbon sequestration to water regulation. Such drastic declines would have significant economic consequences for the country.

Figure 4.2 Proportion of species estimated to be at risk from climate change, by habitat type (medium emissions scenario, 2070-2099)



Source: Reproduced in Chapter 3 of the Technical Report from Pearce-Higgins et al., 2017.
Notes: Proportion of species categorised as likely to be at risk from climate change, based upon the SRES A1B emissions scenario for 2070–2099 or to have an opportunity, according to the habitat each species is associated with.

The range of risks to terrestrial and freshwater species and habitats considered in the assessment include:

- Higher temperatures (warmer winters and hotter summers) leading to changes in the suitability of different habitats for different groups of species; altering the timing of natural events such as trees coming into leaf in the spring; increasing water temperatures; and increasing the risks of pests, diseases and invasive non-native species.

- More frequent and severe extreme events leading to local extinctions or shifts in habitat type (e.g. from woodland to grassland).

* Marine and coastal habitats and species are covered in other risks in the Technical Report

Wildfire and drought (also leading to low flows) are likely to be the two major hazards that fall into this category, though flooding may also have similar effects.

Beech woodlands are another example of a highly vulnerable habitat type.

The magnitude of current and future risks is assessed in the Technical Report as 'high' (major impacts on or loss of species groups at the UK level) across the UK due to the number of species and habitats adversely affected by climate change, both now and in the future.* While the economic costs associated with these impacts are complex and difficult to estimate in full (see Chapter 3), they are important because of the value of the assets at risk (in terms of the services they provide), as captured using the UK's natural capital accounts. On example is the benefits of UK woodlands, estimated to be £3.3billion in 2017.[2] Beech trees make up 8% of all broadleaved woodland in the UK[3], but are highly sensitive to hotter, drier conditions and their productivity is projected to decline significantly even under moderate levels of warming.

Adaptation for terrestrial and freshwater species and habitats involves reducing other human pressures such as pollution, creating suitable climatic conditions for existing species to persist (e.g. increased shading of rivers using trees), helping species to move (e.g. installing fish passages), active management of habitats to improve their resilience (e.g. mixed planting and removal of fuel loads such as lying dead wood to reduce the risk from wildfire), underpinned by monitoring and surveillance.

The 'Lawton principles' (Lawton Review, 2010) - creating bigger, better, more and more connected areas of semi-natural habitats - are the main set of actions that achieve these aims. Specific actions listed as being beneficial in the next five years in the Technical Report include:

- Increasing efforts to reduce existing human pressures on biodiversity, improving the ecological condition of sites and restoring degraded ecosystems
- Including specific consideration of adaptation in conservation planning, e.g. more planned site alterations to address climate hazards, and spatial planning to allow species to move
- Continued and enhanced monitoring and surveillance of pests, diseases and invasive non-native species
- Ensuring that nature-based solutions are central to the UK's actions to mitigate and adapt to climate change, including using nature to reduce human exposure to flooding and extreme heat.

The Committee has specifically highlighted terrestrial and freshwater habitats and species as a priority due to the more significant gap in adaptation planning highlighted both in the CCRA and in the CCC's progress reports (covering England and Scotland), and the opportunities presented by current policy reforms. The relevant risks are scored as 'more action needed' for all UK nations in the Technical Report. There are ambitious goals for nature recovery in place across the UK, e.g. as set out in the 25-Year Environment Plan for England and the Natural Resources Management Framework for Wales. However, there is a lack of evidence to show that i) the measures included in these plans are being implemented at scale; and ii) they are proving effective at restoring biodiversity.

* See Berry, P. and Brown, I. (2021) CCRA3 Technical Report Chapter 3 – Natural environment and assets

A wholesale review of environmental policy provides a significant – but time-limited – opportunity to improve adaptation for terrestrial and freshwater habitats, soil health, natural carbon stores, agriculture and forestry productivity.

There is a once-in-a-generation opportunity in the next two years to build adaptation fully into policies for protecting terrestrial wildlife, given the national priority being given to restoring nature and because the UK is going through a wholesale review of environmental policy post-EU Exit. Relevant policies that are under development or review across the UK that need to include specific adaptation actions include:

- England – Environment Bill, Nature Recovery Network, Environmental Land Management Scheme, Nature for Climate Fund, National Pollinator Strategy, Nature Strategy, Soil Health Action Plan, Green Finance Strategy, update to River Basin Management Plans (and recently published Tree and Peat Action Plans)

- Northern Ireland – All-Ireland Pollinator Plan, NI Environment Strategy, NI Peatland Strategy, NI Biodiversity Strategy review

- Scotland – Forest Strategy, Environment Strategy outcome pathways and monitoring framework

- Wales – National Peatland Action Programme, Natural Resources Policy

Risks to soil health from increased flooding and drought

Soils* are a key natural asset; well-functioning and fertile soils underpin food and timber supply, carbon sequestration and storage, as well as supporting a diverse range of organisms that form part of the terrestrial food chain for wildlife. UK soils are already under pressure from human actions, leading to erosion, compaction, and pollution. Present day compaction costs are estimated at £470 million per year in England and Wales, while the costs from soil erosion in terms of loss of soil depth and nutrients and offsite impacts to water quality, are estimated to be £150 million per year.

Like biodiversity, there are likely to be a mix of positive and negative effects on soil health as the climate changes, though adaptation is most important for minimising the negative impacts.

The effects of climate change on soil health will be mixed and are difficult to predict precisely, but there is robust evidence that flooding and drought will pose significant risks.

The main climate hazards considered in the CCRA3 Technical Report are heavier rainfall events (erosion and compaction risks), and drier conditions leading to increased soil moisture deficits in summer (loss of biota and organic matter). Wind erosion could also potentially increase in the future, though this is uncertain. The magnitude of risks from climate change to soils are identified as medium (thousands of hectares lost or severely damaged at the UK level per year) for the present day, increasing to high (tens of thousands of hectares or more lost or severely degraded at the UK level per year) in all future climate scenarios by the 2050s and 2080s. For instance, climate projections suggest increasing soil moisture deficits over much of the UK, that are likely to affect soil structure through desiccation effects, modification of soil aggregates, and reductions in organic material that also influence nutrient cycling and water-holding capacity.

In order to meet the UK's Net Zero and other environmental targets, soil health needs not just to remain stable but to improve. For example, the Committee's scenarios for the path to Net Zero involve around a 10% per decade improvement in crop yields.

* Note that peatlands are included in the priority on natural carbon stores rather than in the soils priority.

Productivity improvement is needed alongside diet change to free up land for carbon sequestration through tree planting, which sees forest cover grow from 13% today to around 18% by 2050.

Awareness of the threat from climate change to soils, and the need for ongoing measurement of soil quantity and quality, has improved, but the necessary adaptation responses are not yet commensurate with the level of risk, leading to a 'more action needed' urgency score across the UK.

Although soil health is included in all of the latest UK national adaptation programmes, planning is not yet accompanied by a comprehensive soil monitoring strategy to understand better and monitor progress on climate change adaptation in the context of other drivers, and to assess the effectiveness of different interventions and land management strategies, both locally and at national scale. The Technical Report highlights a large range of beneficial actions for the next five years including:

The UK still lacks a comprehensive soil monitoring strategy.

- More investment in national-scale soil monitoring programmes
- Payments and advice for land managers that incentivise improvements to soil health
- Development and increased uptake of precision farming technology to minimise erosion and pollution
- Improved evidence on the climate-related implications for the multiple benefits delivered by soils; including to maintain water quality, alleviate flooding at catchment-scale, reduce drought risk and support priority habitats and species.

As is the case for the risks to terrestrial habitats and species, forthcoming updated environmental policies across the UK present a unique opportunity to define targets, monitor condition and incentivise widespread soil conservation measures that address the impacts of a changing climate while maintaining and improving productivity. Opportunities to integrate adaptation into major forthcoming policies include:

- England – Environment Bill, Environmental Land Management Scheme, Soil Health Action Plan (and recently published Peat Action Plan)
- Northern Ireland – Sustainable Agricultural Land Management Strategy
- Scotland – Soil and nutrient network and Farm Advisory Strategy
- Wales – Sustainable Farming and Our Land Strategy

Risks to natural carbon stores and sequestration from multiple hazards, leading to increased emissions

UK peatlands are a critically important terrestrial carbon store, but this storage capacity could be greatly reduced due to hotter, drier conditions

This priority considers climate change threats specifically to the carbon storage and sequestration properties of soils, trees, wetlands and the marine environment. The current pressures on natural carbon stores are the same as for habitats and species: pollution, erosion, degradation and removal. UK peatlands are one of the most important terrestrial natural stores for carbon. They are estimated to store the equivalent of around 11,700 (± 1,100) $MtCO_2$ [4], which is an order of magnitude higher than the carbon stored in trees and over 25 times larger than the UK's total annual emissions in 2020.* However, the area of land suitable for peat-forming vegetation in the uplands could decline by between 50% – 65% by 2050.[5] Blue carbon stored in coastal and marine habitats is also thought to be a critical store, though a baseline assessment of the total stock is still needed.

In addition to human pressure, there are both risks and opportunities from the effects of a changing climate on natural carbon stores and resulting greenhouse gas emissions, and therefore on the UK's commitment to achieve Net Zero emissions by 2050 (see Chapter 3). Addressing the risks from climate change will be critical in order for the UK to create the negative emissions needed to meet Net Zero by 2050. This priority focusses on the risks rather than the opportunities to carbon stores, as it is the risks that require the most urgent adaptation responses.

The major threats to carbon stores and sequestration include: hotter and drier conditions reducing the functioning and threatening the existence of peatlands and forests at higher levels of warming; erosion from wind and rain; fire damage; and the potential for increased soil respiration due to higher temperatures. The balance of negative and positive impacts on natural carbon stores remains uncertain though the balance is likely to become increasingly negative with higher rates and levels of warming. The current risk magnitude is assessed as medium across the UK in the CCRA Technical Report, rising to high in the future.

Maintaining the carbon storage capacity of the natural environment through adaptation will be critical for achieving Net Zero by 2050.

Maintaining these carbon stores is critical to delivering the net removal of CO_2 from the atmosphere needed on the path to Net Zero by 2050. The Committee's scenarios involve annual CO_2 removals based on UK nature-based solutions of around 50 $MtCO_2$ per year by 2050. Even a small loss from existing stores could entirely offset this. These stores are already at risk from the human pressures listed above, and climate change adds an additional, significant threat.

The critical role of CO_2 removals from tree planting and growth, peatland restoration, wetlands, bioenergy production and other nature-based solutions on the path to Net Zero make this risk a high priority. There is a high chance of lock-in leading to permanent losses if action is not started now to plant suitable trees for the future climate in suitable locations and restore and recover peatlands and other wetlands.

Actions with benefits in the next five years could include:

- Integrated land use policy with more spatial targeting for land use change initiatives, and integration of the mitigation and adaptation policy agendas.
- More targeted actions to restore degraded carbon stores, particularly peatlands.
- Research to account for climate change risks to carbon stores in UK GHG Inventory projections.
- A better understanding of carbon storage and sequestration potential for blue carbon (aquatic and marine environments) and the risks to these assets from climate change.
- A systematic programme of soil carbon monitoring for diverse land uses, bioclimatic zones, management interventions etc.

* Estimates of carbon storage across UK trees are hard to estimate, but the England Biodiversity Indicators suggest that 460 MtC is stored in trees in England.

Key forthcoming policies that should include measures to protect natural carbon stores include:

- England – Net Zero Strategy, Environmental Land Management Scheme, Soil Health Action Plan, Green Finance Strategy and funding measures (e.g. Sovereign Green Bond), recently published Tree and Peat Action Plans.
- Northern Ireland – Sustainable Agricultural Land Management Strategy
- Scotland – Soil and nutrient network and farm Advisory Strategy
- Wales – Sustainable Farming and Our Land Strategy

Risks to crops, livestock and commercial trees from multiple climate hazards

Productive agriculture and forestry sectors are essential for future domestic food security and for the UK's land to contribute fully on the path to Net Zero emissions by 2050. To maintain and enhance agricultural and forestry productivity, the health and diversity of terrestrial and freshwater ecosystems need to be protected and enhanced.

Climate change poses a direct risk to crops, livestock and commercial trees through increased exposure to heat stress, drought risk, waterlogging, flooding, fire, and pests, diseases and invasive non-native species. Key threats include changing land suitability for both forestry and agriculture; in particular, hotter and drier conditions in the south of the UK, although some northern areas may become more suitable for commercial forestry and arable production. The risks to grassland productivity from increased wetness in the north and west of the UK could limit an otherwise longer growing season. Livestock will be at increased risk directly from heat stress. Wildfire, flooding and erosion also represent a growing risk to commercial agriculture and forestry.

Agriculture and forestry are vulnerable to a wide range of climate hazards. Adaptation is needed to improve land management, change what is planted and grown, and to prepare for increased unpredictability in weather patterns.

The magnitudes of the relevant risks are assessed as medium (impacts on up to 10% of production at the UK level) at present, increasing to high (impacts on 10% or more of production) in future across the UK in all climate scenarios.* This is due to both increased hazard exposure (heat stress, drought risk, wetness-related risks) and inherent socioeconomic factors in the land use sector that increase sensitivity and vulnerability, such as growing pressures on agricultural land for increased food production.

An effective adaptation response will require different or new varieties of crops, livestock and trees that are more climate resilient, changes to land management including better technologies for managing water and nutrient input, and improved soil conservation. The lead times to develop and establish these can be significant. Action now to address future risks is especially important to avoid lock-in. Other actions identified as beneficial in the next five years include better long-term seasonal forecasts for land managers, assessment of land use options given changing water availability, and land use strategies that bring climate change mitigation and adaptation together, particularly when considering any potential future agronomy and bioenergy production in the UK.

There is no clear evidence that climate risks or opportunities for agriculture and forestry are being strategically managed across the UK. There is more strategic

* See Berry, P. and Brown, I. (2021) CCRA3 Technical Report Chapter 3 – Natural environment and assets.

planning in the forestry sector compared to agriculture, but much of the impetus for this is provided by Net Zero, rather than adaptation. There is an opportunity to improve climate resilience in forthcoming national and devolved policies for land management, Net Zero and nature protection, as well as using these new policies to support training and skills. But it is not being taken; the signs so far are that specific actions are not yet being included in these policies. Opportunities to integrate adaptation into major forthcoming policies include:

- England – Net Zero Strategy, Environmental Land Management Scheme, Soil Health Action Plan, recently published Tree and Peat Action Plans

- Northern Ireland – Sustainable Agricultural Land Management Strategy

- Scotland – Future rural support schemes

- Wales - Sustainable Farming and Our Land Strategy, Natural Resources Policy

Risks to supply of food, goods and vital services due to climate-related collapse of supply chains and distribution networks

A single flood in Thailand in 2011 cost over $45 billion in damages including disrupted supply chains.

Most products, including food, finished goods, components and materials, have complex supply chains. Extreme weather is already causing supply chain disruption and exposure to climate hazards is set to increase. For example, severe flooding in Thailand in 2011 disrupted five major manufacturers of hard disk drives. Output declined by up to 30% compared to the previous quarter, and the shortage of hard disk drives increased global prices by 80 - 190%. The World Bank estimated that the total economic cost from this one event was US$45.7 billion, equivalent to around 13% of Thailand's GDP at the time (Box 4.1). These sorts of hazards affect both the supplies themselves and the infrastructure and routes by which they are transported. Businesses are reporting that while heavy rainfall, surface water flooding and high temperatures, including heatwaves, will continue to dominate their supply chain risks, coastal and river flooding and water scarcity will become more significant drivers in the future.

Some supply chains may present a greater risk due to the importance of the goods for people in the UK and/or because of their economic importance. Currently 64% of the total food consumed in the UK is produced domestically – although the figure for food that can be grown most efficiently in Britain's climate, such as meat and cereals, is higher.[6] This can vary among food groups, for example 16.4% of the total UK supply of fruit in 2019 was grown in the UK, a decline on the 2018 figure of 17.3%. Home production of vegetables contributed to around 54% of the total UK supply in 2019, compared to 53% in 2018.[7]

Cars are both the top imported and exported good for the UK in terms of value, with imports and exports each totalling more than £30bn in 2019.[8] The Society of Motor Manufacturers and Traders states that 81% of all vehicles made in Britain are exported. Other high value imports and exports in 2019 included medicinal and pharmaceutical products, refined and crude oil, mechanical power generators (intermediate), clothing and aircraft.[9]

Box 4.1
Impacts from 2011 Thailand Floods

An example of a climate-related supply chain shock is the flooding that affected Thailand extensively in 2011, impacting the supply of components – particularly for the automotive and high-tech sectors – which led to global disruption in these sectors. The flooding was reported to cost the Lloyd's of London insurance market $2.2 billion.

Japanese automakers were particularly hard hit by the inundation of Thai factories and related disruptions to their operations. Toyota and Honda lost operating profit of US$1.25 billion and US$1.4 billion respectively, equivalent to 37% and 55% of their operating profit.

The floods also affected Thailand's role as the world's second largest producer of hard disk drives, accounting for 43% of world production. Many of the factories that make hard disk drives were flooded, leading to worldwide shortages of hard disk drives in the short-term, increasing the price of desktop drives by 80–190% and mobile drives by 80–150%, with losses for re-insurers of around $10 billion.

The World Bank estimated that the total economic cost of flood damage in Thailand was US$45.7 billion, around 13% of Thailand's GDP.

Source: CCRA3 Valuation Report.

Exposure to climate hazards is set to increase, both within the UK and internationally. Businesses are reporting that while heavy rainfall, surface water flooding and high temperatures, including heatwaves, will continue to dominate their supply chain risks, coastal and river flooding and water scarcity will also become more significant drivers in the future.

Both domestic and international supply chains are at risk from climate change.

Imports of goods such as staple crops are also at risk, which are considered in the Technical Report. There is no national estimate for any sector of the total average annual economic damage from supply chains shocks. Expert judgement from the CCRA technical authors has given a medium magnitude current risk rating (£tens of millions in costs per year at the UK level), but an unknown rating in the future.*

Some action has been taken by business and there are opportunities from advances in technologies and from the learning and increased focus on supply chain resilience following the COVID-19 pandemic, and other recent events such as the high profile temporary blockage of the Suez Canal by the Ever Given container ship. However, it is unclear whether this action will keep pace with the increasing risk or how effective it will be specifically in managing climate and weather-related disruption. All of the relevant risks in the Technical Report have been given a 'more action needed' score across all UK nations.

Adaptation actions involve information, awareness raising and capacity building, institutional changes, supply chain management, risk sharing and risk transfer, technology, infrastructure and storage, and trade policy which will take time to develop, test and implement. Enhancing supply chain resilience should be a priority both for post-COVID recovery planning, which has highlighted some vulnerabilities, and in the development of new trade agreements and changing trade patterns following EU-Exit. It will also be important in planning for some of the opportunities for the UK to grow some currently imported fruit and vegetables locally, if soil and water quality and quantity permit.

Opportunities to integrate adaptation into major forthcoming policies include:

* See Surminski, S. (2021) CCRA3 Technical Chapter 6 - Business and industry

- UK - HM Treasury's Plan for Growth; Green Finance Strategy including TCFD and TNFD reporting; the developing global reporting system led by major sustainability reporting organisations (CDP, CDSB, GRI, IIRC and SASB); FCA's Sustainable Finance Strategy and the Climate Financial Risk Forum.

- In addition, increasing awareness of guidance or tools through channels such as the SME Climate Hub; Transforming public procurement programme and public procurement guidance; Department for International Trade's Business of Resilience campaign.

Risks to people and the economy from climate-related failure of the power system

The UK's dependence on electricity will increase significantly because of the transition to Net Zero, leading to much greater impacts from power outages.

The UK will become heavily dependent on electricity as the dominant energy source as the country reduces greenhouse gas emissions to Net Zero. While electricity provides about 15 - 20% of the UK's energy today, by 2050 it could account for 55 - 65%, used for light, heat, communications, transport, industry and delivery of other critical services such as water. People and the economy will be increasingly exposed and vulnerable to electricity system failures.

Different parts of the power sector can be impacted by all of the major climate hazards: flooding, water shortages, increased temperatures and wildfire, sea level rise and potential increases in storms, swells and wave heights. While the power sector generally has good plans today for the risks of 2°C and 4°C warming scenarios, climate-related problems still occur. For example, a lightning strike on an electricity circuit between Cambridgeshire and Hertfordshire in August 2019 (Box 4.2) led to a cascade of impacts on other generators, interrupting supply to over 1 million people and stranding affected trains for hours.

The risk assessment shows these risks will become more common and more damaging as our dependence on electricity grows and the variability of our weather increases. Within a Net Zero power system, weather-dependent renewables like offshore wind are expected to play a dominant role. We strongly recommend that the Government (Cabinet Office and BEIS) works with the regulator (Ofgem) and the industry to review the approach to electricity system design and risk assessment in the context of the central role of electricity in the UK's future energy system and the changing climate.

The CCRA3 Technical Report considers case studies of power outages and other literature in assessing the magnitude of the risk from cascading impacts across infrastructure and the resulting impacts on people and businesses.* The evidence supports an assessment of current high magnitude, with disruption in urban areas potentially impacting hundreds of thousands of people annually. Future magnitude is given as high across the UK in all climate scenarios as the impacts are only projected to grow. All of the major climate hazards considered in the CCRA could trigger a cascade effect from the power sector to other sectors.

Ensuring a power system that is resilient to the future climate impacts is an urgent issue because the next 10 years will see a huge growth in investment in both electricity generation and expansion of the transmission and distribution grids. For example, the Government plans a four-fold increase to 40 GW of offshore wind by 2030, to support decarbonisation of transport, heat and industry and to prepare for a doubling, or even a trebling, of electricity demand by 2050.

* See Jaroszweski, D., Wood, R., and Chapman, L. (2021) CCRA3 Technical Report Chapter 4 – Infrastructure

The implementation of the 2020 Energy White Paper and of the new National Infrastructure Strategy provide opportunities to embed climate resilience in the power system. Climate resilience must also be reflected in the wider energy system governance (e.g. by Ofgem, and in considering the possible role for an independent Energy System Operator). More generally, the Government should implement stronger approaches to systemic risk assessments and resilience for critical infrastructure, especially where the interdependencies are so ubiquitous.

Opportunities to integrate adaptation into major forthcoming policies include:

- UK – the Implementation of the Energy White Paper 2020 and National Infrastructure Strategy 2020, the next National Infrastructure Assessment in 2023, the Offshore Transmission Network Review (and wider network plans), and the upcoming Net Zero Strategy, including any plans to phase out unabated gas power generation by 2035 (as recommended by the Committee).
- England – Review of public procurement rules and guidance, TCFD reporting, implementation of National Flood and Coastal Erosion Risk Management Strategy and Policy Statement
- Northern Ireland – second round of Flood Risk Management Plans for Northern Ireland
- Scotland – implementation of Scottish Government Infrastructure Investment Plan, The final tranche of the Low Carbon Fund investment in Emerging Energy Technology, key energy infrastructure considerations in the fourth National Planning Framework.
- Wales – future Welsh Climate Change Adaptation Plan

Box 4.2
Cascading impacts from 2019 power outages in England and Wales

Power outages in England and Wales on the 9th of August 2019 demonstrate the potential for cascading infrastructure failure (Ofgem, 2020). The event was triggered by a lightning strike on the Eaton Socon-Wymondley circuit between Cambridgeshire and Hertfordshire, causing a routine fault on the national electricity transmission system and the disconnection of a number of small generators connected to the local distribution network. Simultaneously, two larger generators (Hornsea 1 Limited and Little Barford) experienced technical issues and were unable to provide power. The combined power losses exceeded the back-up power generation capacity of the Electricity System Operator (ESO), triggering a power outage.

A total of 892 megawatts (MW) of net demand was disconnected from local distribution networks. The electricity supply of over 1 million consumers was interrupted. The outage had significant knock-on impacts for the rail sector, with the Train Operating Company (TOC) Govia Thameslink Railway experiencing stranded trains, triggered by on-board automatic safety systems. This in turn caused knock-on delays across the rail network (Ofgem, 2020). Hornsea 1 Limited and RWE Generation UK plc (operators of Little Barford) each agreed to make voluntary payments of £4.5m to the Energy Industry Voluntary Redress Scheme.

Source: Jaroszweski, D., Wood, R., and Chapman, L. (2021) CCRA3 Technical Report Chapter 4 – Infrastructure.

Risks to human health, wellbeing and productivity from increased exposure to heat in homes and other buildings

People in the UK are at risk of illness and death from high temperatures. For those with existing health conditions (mainly heart and respiratory conditions), death rates start to increase even at moderate temperatures over 17 - 20°C, depending on location. High temperatures contribute to significant excess mortality in England, with more than 2,500 heat-related deaths during three 2020 heatwaves, higher than at any time recorded since statistics began to be collected in 2003.[*] While there is a lack of evidence of present-day impact on mortality in the devolved administrations, the risk from heatwaves and higher temperatures will increase across the UK in the future. The Met Office's UK Climate Projections (UKCP18) show a hot summer like 2018 will likely occur on average every other year by 2050. There is also a small chance of exceeding 40°C before 2040; by 2080 the frequency of exceeding 40°C could be similar to the frequency of exceeding 32°C today in a high emissions scenario.[†] Night-time urban heat island effects are expected to be more intense, leading to more 'tropical nights' in major cities.

As well as a risk to life, high temperatures will lead to productivity losses for UK workers. Analysis across 11 UK city regions estimated that the benefits of urban greening in avoided productivity losses and reduced cooling costs was nearly £300 million in a single year.[10] Before the pandemic, around 5% of people in employment worked mainly from home. [11] As a result of the COVID-19 pandemic, levels of homeworking have risen substantially, with an average of around 30% of the workforce working exclusively from home each week during 2020.[12]

Exposure to heat in homes could increase if some businesses and workers choose to adopt this style of working on a permanent basis. This also has implications for the future delivery of health and social care as trends indicate a move to more home-based care rather than in hospitals.

There is more evidence since CCRA2 about the risks of overheating in buildings and the effectiveness and limitations of strategies for space cooling. Building designs and technology exist that, if implemented at scale, could deliver buildings which have high levels of thermal efficiency (staying warm in winter while cool in summer), while being moisture-safe and with excellent indoor air quality. Key actions that have been identified as beneficial in the next five years include:

- The updating of building regulations or other policy measures to address overheating in new and refurbished homes through passive cooling measures.
- Increased guidance and incentives to address overheating in existing homes to reduce exposure to excessive heat indoors.
- Regional or local level climate risk assessments by NHS Trusts, Health Boards and local government social services (where these are not already happening) to help them plan with climate risks in mind.
- Ensuring that designs for new and refurbished care homes, hospitals and other health and social care assets consider future temperatures.
- Undertaking an economic analysis of adaptation options for care homes alongside the use of adaptive measures such as improved glazing, draught

* See Kovats, S. and Brisley, R. (2021) CCRA3 Technical Report Chapter 5 – Health, communities and the built environment

† See Slingo, J. (2021) CCRA3 Technical Report Chapter 1 - Latest Scientific Evidence for Observed and Projected Climate Change

proofing, shutters, reflective surfaces, green cover and green space and ceiling fans, where appropriate.

- Increasing green infrastructure, setting greenspace targets and monitoring uptake of green infrastructure, which has the potential to reduce urban temperatures along with delivering other benefits around air pollution, flood alleviation and increased biodiversity.
- Better coordination between decarbonisation and adaptation policies and strategies for homes to manage potential trade-offs between increasing air tightness for energy efficiency gains, and overheating risk.
- Including long term risks and action planning within current emergency preparedness planning.
- Monitoring of indoor temperatures and other indicators across homes, care homes and health care buildings.

Policies still remain largely absent to address the risks to health from heat, even though it has been highlighted as one of the largest risks in all three UK climate change risk assessments.

Out of the Committee's list of priorities, this risk is notable for being the one where policies still remain largely absent. There is still little preventative action being taken to address health risks from overheating in buildings, and in homes in particular. In England, where a quarter of homes are at risk from overheating, the Ministry of Housing, Communities and Local Government (MHCLG) published a consultation in early 2021 proposing to introduce an overheating standard in new residential buildings (including houses, flats, care homes, and residential educational settings). If brought into policy this would help tackle the risk of overheating in new buildings. The Welsh Government ran a similar consultation in 2020 proposing a new part of Building Regulations focussing on overheating risk in new build homes.

For existing dwellings, there remains little incentive for retrofitting across the UK. Given that at least 300,000 homes are due to be built each year, along with a focus on enhanced energy efficiency and low-carbon heating in new and existing homes, there is a major risk of lock-in if urgent action is not taken now. As well as escalating costs, inaction could make many existing and new homes largely uninhabitable as temperatures rise.

Opportunities to integrate adaptation into major forthcoming policies include:

- England – Building Regulations review; review of the National Planning Policy Framework; revision of the Heat and Cold weather plans; NHS Green Plans; Heat and Buildings Strategy, any replacement for the Green Homes Grants or similar schemes, Homes England requirements, new Building Safety Regulator.
- Northern Ireland – New Housing Strategy; review of Building Regulations; expand Northern Ireland Climate Change Adaptation Programme to include actions to address heat hazards in health and social care settings.
- Scotland – Review of energy standards and supporting guidance; use of Green Infrastructure Fund and Green Infrastructure Community Engagement Fund to support urban greening; creation of NHS Boards adaptation plans; NHS Scotland Sustainability Strategy.
- Wales – Introduce overheating standards into Building Regulations; PHW extreme weather strategy review; PHW climate change Health Impact Assessment; commitment to address climate risks to health and social care delivery and update of contingency plans.

Multiple risks to the UK from climate change impacts overseas

Many of the risks to the UK from climate change overseas have increased in urgency since CCRA2 was published, as more evidence has become available.

There is growing potential for hazards in the UK and globally to create cascading risks that spread across sectors and countries, creating impacts an order of magnitude higher than impacts that occur within a single sector. These systemic risks act in a non-linear way, may not be attributed to any one driver, and have tipping-points that are highly unpredictable.

The COVID-19 pandemic has been a recent example, albeit not a climate-driven event, with government spending costs in the UK projected at over £300bn.*

The climate hazards that can trigger similar cascading impacts globally are becoming more frequent and more severe. The Technical Report highlights that all elements of climate risk; hazard, exposure and vulnerability, are increasing globally, with a high present day and future magnitude in all climate scenarios and all UK nations.

There is growing potential for weather-related hazards – such as floods, hurricanes, or drought - to spark these cascading impacts globally. Due to the potential for hidden tipping points and the unpredictability of systemic risks, the current model of conventional risk governance in the UK that focusses on single events, single sectors and characterisation of reasonable worst-case scenarios should be reviewed. There is a need to plan better for classes of risk (such as interruptions to food supply chains) rather than predicting specific risks and their transmission pathways.

There is an immediate opportunity to learn from the experience of the COVID-19 pandemic to embed resilience building across government functions. There is also a longer-term opportunity following the UK's exit from the EU to incorporate considerations of systemic risk into future trade agreements and foreign policy aims.

Opportunities to integrate adaptation include:

- Increased capacity building by FCDO programmes overseas to improve global capacity for climate resilience, including supply chains, health systems and early warning systems for climate hazards. Overseas programmes should work to reduce underlying vulnerabilities and not just respond to disasters. This ties in with the Government's 'levelling up' agenda and aims for global leadership, including through presidencies of the G7 and upcoming UN climate talks (COP26).

- Increased research and capacity building by BEIS via its International Climate Finance work overseas, to ensure low-carbon development and delivery of Net Zero include co-benefits of adaptation and are not undermined by climate risks.

- Increased research through the UKRI global challenge fund to improve understanding of interacting risks, which regions and sectors are most fragile and how to improve resilience.

- Development of a UK Resilience Strategy by the Cabinet Office.

* See Challinor, A. and Benton, T. (2021) CCRA3 Technical Chapter 7 - International Dimensions

- Clear commitments at COP26 to leverage increased adaptation financing and support developing countries with capacity building for implementing national adaptation actions.

Endnotes

[1] Hayhow DB, Eaton MA, Stanbury AJ, Burns F, Kirby WB, Bailey N, Beckmann B, Bedford J, Boersch-Supan PH, Coomber F, Dennis EB, Dolman SJ, Dunn E, Hall J, Harrower C, Hatfield JH, Hawley J, Haysom K, Hughes J, Johns DG, Mathews F, McQuatters-Gollop A, Noble DG, Outhwaite CL, Pearce-Higgins JW, Pescott OL, Powney GD and Symes N (2019) The State of Nature 2019. The State of Nature partnership.

[2] Woodland natural capital accounts, UK - Office for National Statistics (ons.gov.uk)

[3] https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/woodland-areas-and-planting/national-forest-inventory/woodland-area-by-species-broadleaves/

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[5] CCC (2013) Managing the land in a changing climate

[6] Dimbleby, H. et al. (2020) *The National Food Strategy: Part One.*

[7] Defra horticultural statistics 2019.

[8] ONS (2020) UK trade: April 2020.

[9] https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/bulletins/uktrade/april2020, https://www.smmt.co.uk/industry-topics/europe-and-international-trade/key-exports-data/

[10] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalaccounts/2019#regulating-services

[11] Office for National Statistics (2020), *Coronavirus and homeworking in the UK labour market: 2019.*

[12] Office for National Statistics (2021), *Social behaviours during the different lockdown periods of the coronavirus (COVID-19) pandemic dataset*.

Magnitude categories

Chapter 2 of the CCRA3 Technical Report explains the rationale for the magnitude categories. Criteria for each category at the UK and devolved level are shown below.

Annex 1
UK-level magnitude categories

	High Magnitude	Medium Magnitude	Low Magnitude
Quantitative evidence	Major annual damage and disruption or foregone opportunities:[1]	Moderate annual damage and disruption or foregone opportunities:	Minor annual damage and disruption or foregone opportunities:
	• £hundreds of millions damage (economic) or foregone opportunities, and/or	• £tens of millions damage (economic) or foregone opportunities, and/or	• Less than £10 million damage (economic) or foregone opportunities, and/or
	• Hundreds of deaths2, thousands of major health impacts, hundreds of thousands of people affected / minor health impacts, and/or	• Tens of deaths, hundreds of major health impacts, tens of thousands of people affected / minor health impacts and/or	• A few deaths, tens of major health impacts, thousands of people affected / minor health impacts, and/or
	• Tens of thousands of hectares land lost or severely damaged3, and/or thousands of km of river water/km2 of water bodies affected, and/or	• Thousands of hectares of land lost or severely damaged, and/or hundreds of km of river water/km2 of water bodies affected, and/or	• Hundreds of hectares of land lost or severely damaged, and/or tens of km of river water/km2 of water bodies affected, and/or
	• Major impact (~10% or more at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	• Intermediate impact (~5% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	• Minor impact (~1% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or
	• Major impacts on or loss of species groups, and/or	• Intermediate impacts on or loss of species groups, and/or	• Minor impacts on or loss of species groups, and/or
	• Major impact (10% or more at national level) to an individual natural capital asset and associated goods and services[4], and/or	• Intermediate impact (1 to 10% at national level) to an individual natural capital asset and associated goods and services, and/or	• Minor impact (~1% or less at national level) to an individual natural capital asset and associated goods and services, and/or
	• Major loss or irreversible damage to single nationally iconic heritage asset (e.g.	• Medium loss or irreversible damage of nationally iconic heritage asset (e.g.	• Low loss or irreversible damage to nationally iconic heritage asset (e.g. Stonehenge, Giants' Causeway)

	Stonehenge, Giants' Causeway)	Stonehenge, Giant's Causeway)	
Qualitative evidence	Expert judgement of chapter authors, confirmed with agreement across authors, CCC and peer reviewers suggest there is a possibility of impacts of the magnitude suggested above		
Confidence	Quality of evidence and level of agreement – confidence ranking (see Tables 4 and 5)		

Annex 2

Adjustment factors for scoring magnitude for devolved administrations

<table>
<tr><th></th><th>UK / England</th><th>Wales</th><th>Scotland</th><th>Northern Ireland</th></tr>
<tr><td>Economics</td><td>As table above</td><td colspan="3">Metrics in table above adjusted for gross value added[1], thus to give relative importance, values in table are reduced by 1 order of magnitude, and applied equally to Scotland/Wales/NI
• £tens of millions damage or foregone opportunities,
• £ millions damage or foregone opportunities
• Less than £1 million damage or foregone opportunities</td></tr>
<tr><td>Health</td><td>As table above</td><td colspan="3">Metrics in table above adjusted for population2, factoring down levels in table by 1 order of magnitude, and applied equally to Scotland/Wales/NI
• Tens of deaths, hundreds of major health impacts, tens of thousands of people affected / minor health impacts, and/or
• A few deaths, tens of major health impacts, thousands of people affected / minor health impacts, and/or
• No deaths, a few major health impacts, hundreds of people affected / minor health impacts, and/or</td></tr>
<tr><td>Land</td><td>As table above</td><td>Metrics in table above adjusted for land3, factoring down levels in table by 1 order of magnitude
• Thousands of hectares land lost or severely damaged
• Hundreds of hectares of land lost or severely damaged
• Tens of hectares of land lost or severely damaged</td><td>Given high land area of Scotland (approx. one third of UK) values in table above are used</td><td>Metrics in table above adjusted for land3, factoring down levels in table by 1 order of magnitude
• Thousands of hectares land lost or severely damaged
• Hundreds of hectares of land lost or severely damaged
• Tens of hectares of land lost or severely damaged</td></tr>
<tr><td>Valued habitat / Natural capital</td><td>As table above</td><td colspan="3">As table above</td></tr>
</table>

Independent Assessment of UK Climate Risk

Advice to Government
For the UK's third Climate Change Risk Assessment (CCRA3)

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