HM Government

Climate Adaptation Research and Innovation Framework

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Ministerial foreword

We are all experiencing the impacts of climate change today, whether it be through storms, flooding or heatwaves. Globally, 2024 was the hottest year on record with average temperatures 1.5°C higher than the pre-industrial period for the first time. Continued climate change will bring more regular drought, rising sea levels and changes in rainfall patterns.

To tackle this, we need to redouble our efforts globally to curb greenhouse gas emissions. Every increment of warming that is avoided makes a substantive difference to the severity of climate impacts and reduces the risk of drastic, abrupt and irreversible changes to our planet. That's why the UK government's target to reach Net Zero by 2050 is so vital.

At the same time, we must accelerate our efforts to adapt to climate change to reduce the impact on people, livelihoods and the natural environment. We must not only adapt to the impacts of a climate that has already changed, but also prepare for projected climate impacts that are still to come.

The Climate Adaptation Research and Innovation Framework marks a new approach to addressing the UK priorities for research and innovation in this important area. Climate adaptation is critical to ensuring the ongoing resilience of the UK and the success of the government's five missions to kickstart economic growth, make Britain a clean energy superpower, make Britain's streets safe, break down barriers to opportunity and build an NHS fit for the future.

This framework supports government's work to ensure the resilience of the UK to the effects of climate change, our role as a global leader in climate action and our commitment to world-class science.

Emma Hardy MP,
Minister for Water and Flooding

Foreword

Climate change already challenges us, with storm, flood, fire and heatwave events regularly in the news. These challenges are increasing, even as we seek to limit climate change, and will threaten coastlines, infrastructure, human health, and natural and food systems. Our ability to adapt to the changing climate will be critical for safeguarding our economy, society and natural environment.

Achieving climate resilience requires widespread action across governments, business, academia and civil society. It is not a singular issue but an interconnected systems challenge involving infrastructure, ecosystems, health, finance, data and governance. In many situations, the action we need to take is clear, including organisational planning for change and investment in resilient systems to avoid damage and greater costs in the future. Elsewhere, we need new research to inform our adaptation response, and innovation to improve how effectively and affordably we ready systems for change.

The UK has world-leading science capabilities which we can harness to ensure we are ready for future climate impacts. We have spoken with academia, industry, UK government and the financial sector to produce this first Climate Adaptation Research and Innovation Framework. It aims to drive use of our science capabilities to address the climate adaptation challenge.

As the Government Chief Scientific Adviser and the Chief Scientific Adviser for the Department for Environment, Food and Rural Affairs, we are committed to ensuring that adaptation research and innovation are embedded into policy and practice. This will require investment in both mature adaptation technologies and solutions, as well as cutting-edge research to drive new discoveries and approaches.

This Climate Adaptation Research and Innovation Framework sets out the UK's research and innovation priorities for adaptation by sector. Multiple actors will be needed to realise this research and innovation, and multiple actors will use the results. Some of the research will be UK government-funded and sit alongside policy and regulatory activity, but private sector investment and academic contributions will also play a key role in addressing and using these research and innovation needs. By fostering collaboration across the public and private sectors, we can accelerate the development and deployment of adaptation measures, leaving us better prepared for climate risks while unlocking economic and social opportunities. By clearly signalling these UK's priorities, we aim to provide a foundation for collaborative action, ensuring that our research and innovation ecosystem is mobilised to make all aspects of the UK more resilient to climate.

Dame Angela McLean, Government Chief Scientific Adviser

Gideon Henderson, Chief Scientific Adviser for the Department of Environment, Food and Rural Affairs

Research and innovation for a well-adapted UK

Under the UK Climate Change Act 2008, the UK government is required to prepare a UK Climate Change Risk Assessment every five years, followed by a National Adaptation Programme, setting out actions by relevant UK government departments to address the risks and opportunities identified in the latest risk assessment. The third UK Climate Change Risk Assessment (CCRA3) was published in January 2022, with the third National Adaptation Programme published in July 2023.

This Climate Adaptation Research and Innovation Framework outlines the research and innovation (R&I) needed to address the risks and opportunities identified in CCRA3 and support adaptation plans across UK governments and sectors. The Framework sets out R&I challenges across 11 sectors, based on the CCRA3 monitoring framework:[1]

- nature
- working land and seas
- food security
- water supply
- energy
- telecommunications and ICT
- transport
- towns and cities and community preparedness/response
- buildings
- health
- business and finance

The Framework also identifies cross-cutting and systems-wide issues and linkages between sectors. Ultimately, investments to develop both adaptation solutions and policy mechanisms are required to ensure that the UK adapts to a changing climate effectively and equitably.

Adapting to a changing climate

Our climate is changing. Human activity – primarily burning fossil fuels for energy – has increased the concentration of greenhouse gases in the Earth's atmosphere and caused global temperatures to rise (see Figure 1). Globally, 2024 was the warmest year on record, with average temperatures surpassing 1.5°C above the pre-industrial average for the first time.[2]

1 CCC Adaptation Monitoring Framework – Climate Change Committee

2 Grahame Madge (2025), 2024: record-breaking watershed year for global climate – Met Office

We are already seeing severe climate impacts across the globe as a consequence of this warming, with observed increases in the frequency and intensity of heatwaves, drought, wildfires and heavy rain events leading to floods.[3] In addition, the oceans are warming and glaciers and ice sheets are melting, causing sea levels to rise at an accelerating rate.[4] The scientific evidence is increasingly clear that human-induced climate change has increased the likelihood of many extreme weather events across the globe.

The impact of global rises in temperature is also being experienced directly in the UK. In July 2022, temperature records were set across the UK, with a record high of 40.3°C in Coningsby, Lincolnshire. In a climate unaffected by human influence, it is virtually impossible that temperatures in the UK could reach levels of 40°C and higher.[5] In response to the extreme heat, the UK government issued national emergency heat health warnings. Over 3,000 excess deaths were recorded in the UK across the hot summer of 2022, with over 1,000 of these coinciding with the 40°C heatwave period.[6]

The UK Climate Projections, produced by the Met Office on behalf of the Department for Environment, Food and Rural Affairs, tell us that the UK will continue to warm in the future, with an increase in the frequency and intensity of hot spells. The likelihood of exceeding 40°C somewhere in the UK in a given year is increasing, and such extreme events, similar to those experienced in 2022, could occur every few years in the climate of 2100 under a high emissions scenario.[7] UK winters are also expected to become warmer and wetter. An increase in the intensity of heavy rainfall events across all seasons is expected.

3 Working Group II (2022), Sixth Assessment Report of the Intergovernmental Panel on Climate Change: Impacts, Adaptation and Vulnerability – Intergovernmental Panel on Climate Change.

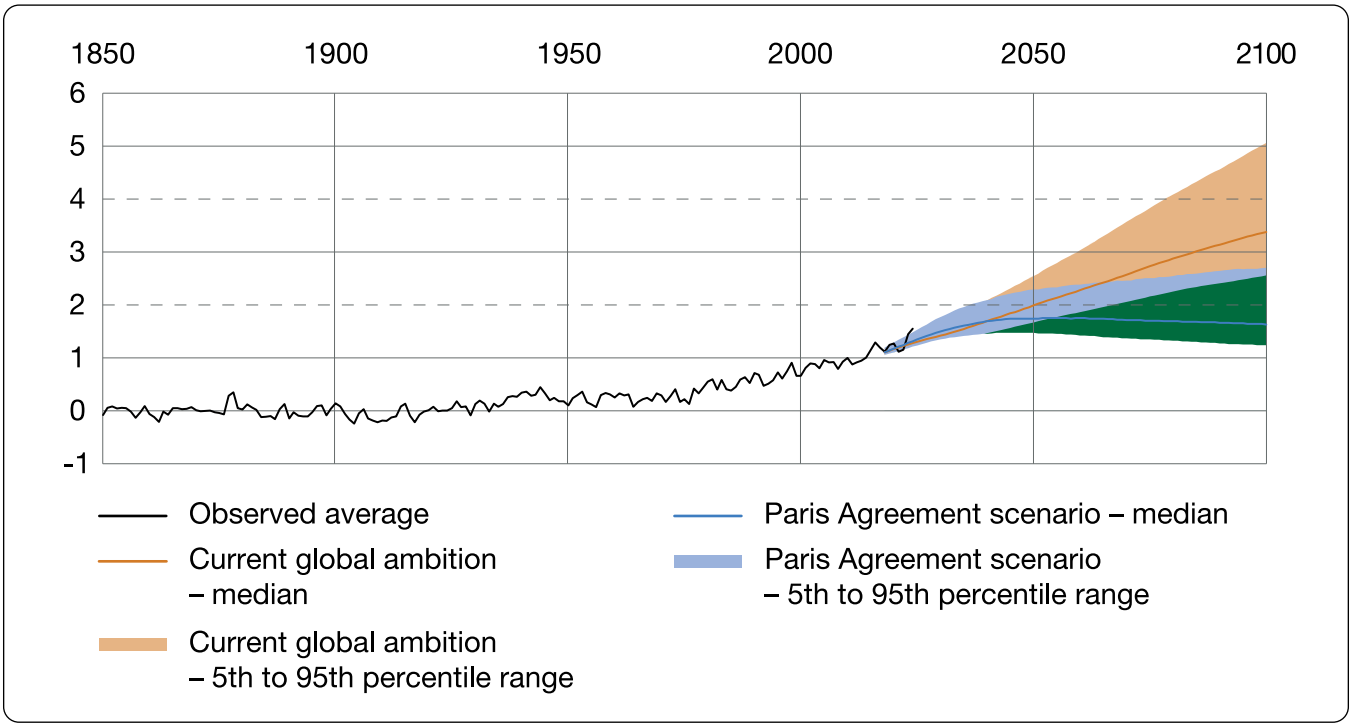
4 Mike Kendon and others (2022), State of the UK Climate 2021 – International Journal of Climatology (Wiley Online Library)

5 A milestone in UK climate history – Met Office

6 Candice Howarth and others (2023), The 2022 heatwaves: England's response and future preparedness for heat risk – Grantham Research Institute on Climate Change and the Environment

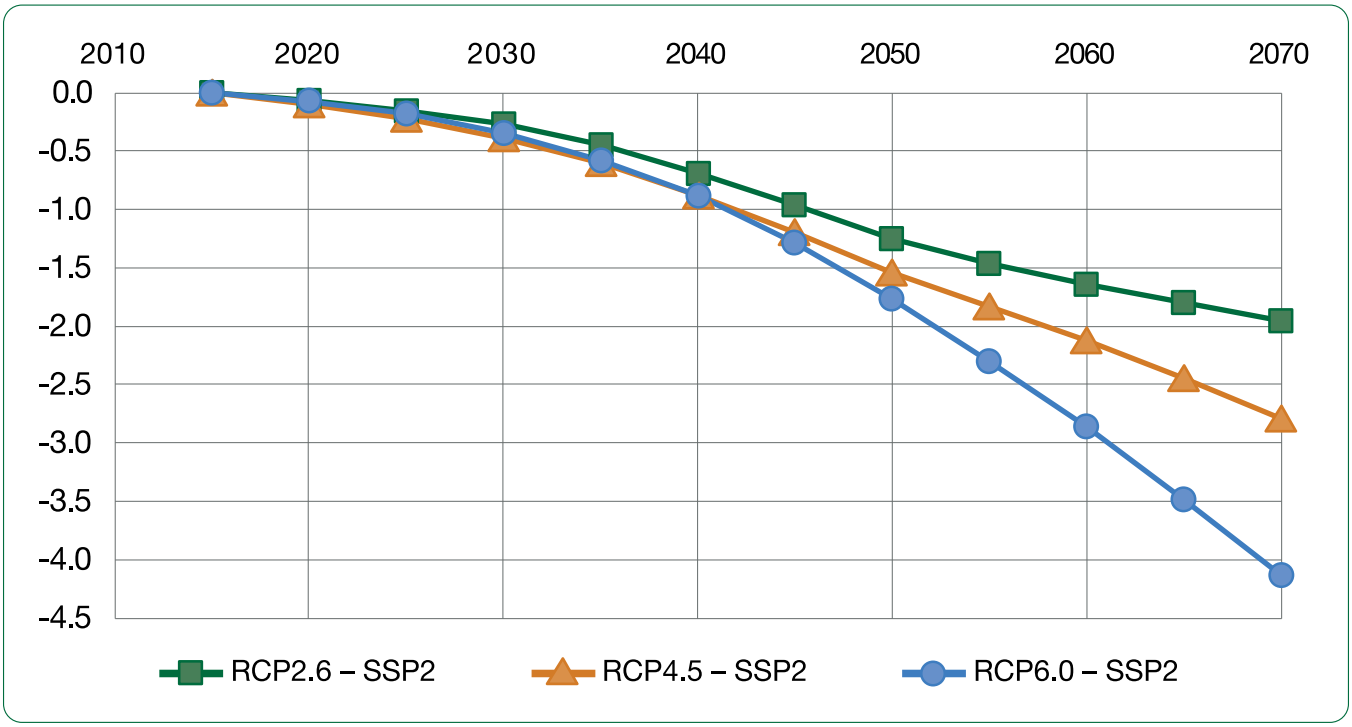
7 Nikolaos Christidis and others (2020), The increasing likelihood of temperatures above 30 to 40 °C in the United Kingdom – Nature Communications

Figure 1. Observed and projected global average temperature rise



Source: Data available at Met Office (2025) and CCC (2021)

Figure 2. % GDP impact of climate change in England



Data from Paul Watkiss (2022) The Costs of Adaptation, and the Economic Costs and Benefits of Adaptation in the UK

The scale of impact of this changing climate on the UK economy is substantial (Figure 2), making it imperative that we adapt and build resilience to climate impacts. Climate adaptation is the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.[8] Climate resilience is the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure.

As shown in Figure 3, the risk of harm associated with climate change is determined by a range of interacting factors, including the likelihood of a climate 'hazard' event occurring, and the level of exposure and vulnerability should it occur. Even with our ambitious targets to reduce greenhouse gas emissions, some climate impacts are 'locked in' on the timescales of decades, making adaptation essential to minimise exposure and vulnerability.[9] With uncertainty in future climate, we need to plan adaptation and build resilience to different possible levels of temperature rise and associated climate change impacts.

Individuals, communities and countries will need to make a range of adjustments.[10] Changing the way we do things, where we do things and when we do things can all help to reduce society's vulnerability and exposure to the impacts of climate change. However, the effects of climate change will not be felt evenly across society. Those who are economically vulnerable and socially marginalised are likely to be most affected. Climate adaptation R&I needs to consider these socio-economic vulnerabilities so that adaption does not introduce or reinforce social inequalities.

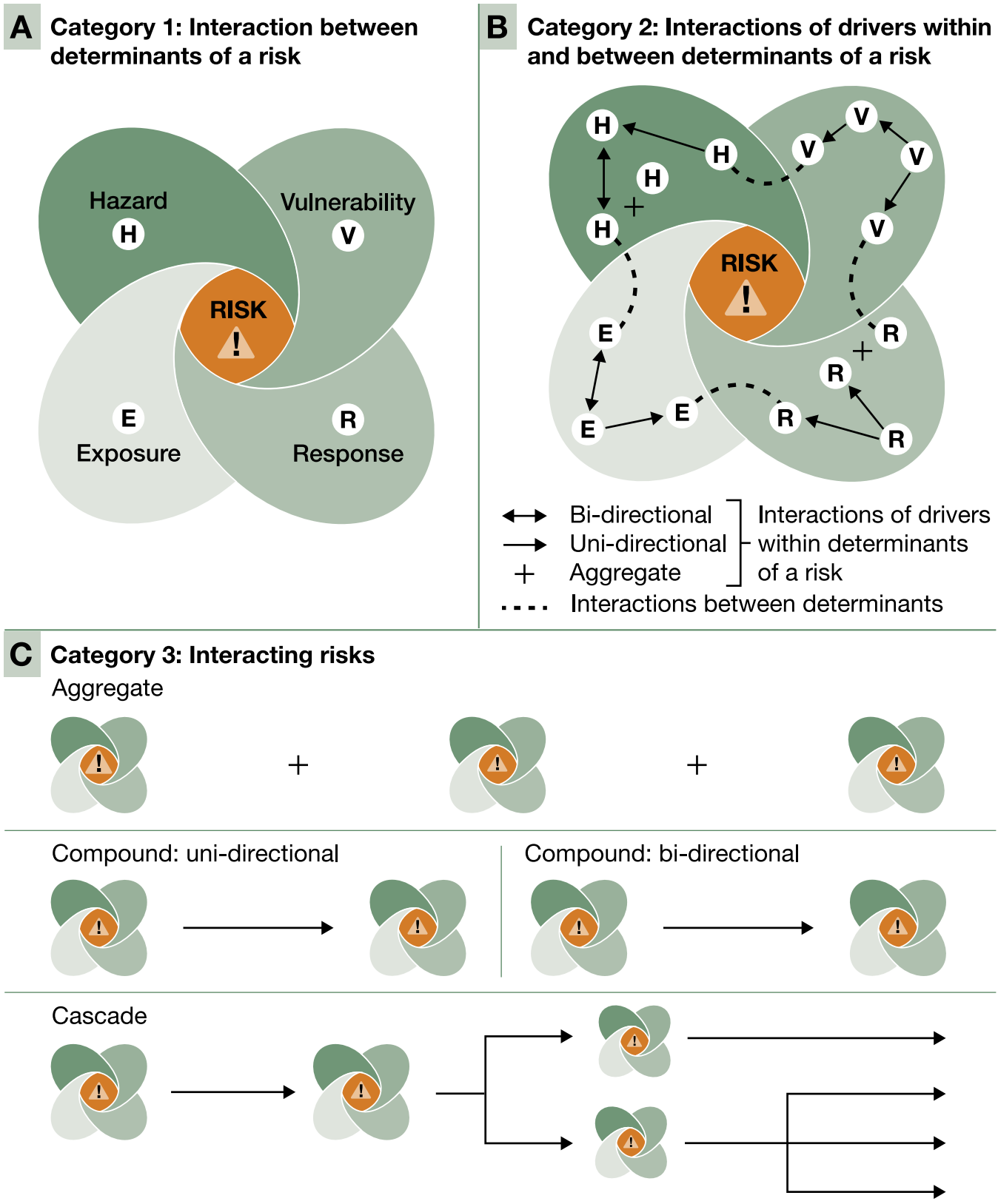
Adapting effectively also means exploiting opportunities presented by climate change where they arise, such as the possibility of growing and exporting different crops. R&I are required to enable this.

8 Pam Berry and Iain Brown (2021), Natural environment and assets, in the Third UK Climate Change Risk Assessment Technical Report – UK Climate Risk

9 COACCH (2020), Macro-economic costs of climate change – CO-designing the Assessment of Climate Change costs. COACCH is a Euro 5 million research project which brings together Europe's leading climate adaptation economists and models. This analysis is based on assessment of RCP2.6, RCP4.5 and RCP8.5 pathways, with impact information fed into a general equilibrium model.

10 Climate change adaptation – Met Office

Figure 3. Three categories of increasingly complex climate change risk



Source: Nicholas P. Simpson and others (2021), A framework for complex climate change risk assessment – One Earth

Research and innovation needs

While there has been significant work to better understand the climate risks we face and the potential solutions to manage them, continued efforts are needed to fill gaps in knowledge, support adaptation decisions and evaluate the effectiveness of innovative solutions.

For example, although advances in climate modelling have improved our understanding of future risks and vulnerabilities, these models can be limited in capturing extreme events and impacts. There are significant gaps in translating this understanding of risks into the adoption of practical, scalable solutions. Similarly, while current science provides valuable insights into nature-based solutions, such as wetlands for flood management and urban green spaces for cooling, more research is needed to assess their long-term effectiveness under evolving climate conditions. Additionally, technological innovations, like advanced building materials and climate-resilient infrastructure, lack sufficient long-term testing across diverse settings and climates.[11]

Research should consider that adaptation decision-making takes place in this uncertain environment, and that there is a need for innovative decision-making and policy in this area as a result, including adaptive management thinking.

Addressing these R&I challenges requires interdisciplinary and transdisciplinary approaches to integrate social, environmental and technological dimensions of adaptation, ensuring solutions are equitable, efficient and ready for deployment.

It is also important to make sure that information on climate risks and responses, the products of R&I, is made widely available in an accessible format. This can enable local decision-makers and members of the public to take evidence-based adaptation actions.

11 AR6 Synthesis Report: Headline Statements – Intergovernmental Panel on Climate Change

Adaptation to support mission-driven government

By investing in R&I, as well as its scale up and deployment, the UK can develop adaptive measures that not only address climate challenges but also advance the UK government's five national missions, fostering a resilient and prosperous society.[12]

Mission 1: Kickstart economic growth

- Successful and cost-effective adaptation will avoid future costs to individuals, businesses and UK government that will otherwise be a drag on growth.[13] For example, extreme heat in the UK in 2022 led to an estimated 11 million lost labour hours.[14] Investing in building adaptations to mitigate extreme temperatures can reduce hours lost and improve productivity.
- Providing adaptation goods and services (construction, engineering, software and advice) presents a business opportunity, especially to first-movers, both domestically and internationally.

Mission 2: Make Britain a clean energy superpower

- Adaptation of energy infrastructure – for example electricity generation, transmission and distribution networks – is essential for achieving the clean power mission and for maintaining security of supply. Equally, innovations such as passive cooling designs for buildings can significantly reduce future clean energy demand and costs.
- It is also critical that wider actions to reduce greenhouse gas emissions and reach net zero in all sectors are themselves resilient to climate change.

Mission 3: Make Britain's streets safe

- There is strong evidence that warmer temperatures are associated with increased levels of crime and violence, putting pressure on the criminal justice system.[15]
- Adaptation of the prison estate to reduce risk of overheating and flooding will be important to allow the criminal justice system to properly function.

12 Adapting to a changing climate: Action to support national renewal – Green Alliance

13 10 Year Infrastructure Strategy Working Paper – GOV.UK

14 Candice Howarth and others (2024), Turning up the heat: learning from the summer 2022 heatwaves in England to inform UK policy on extreme heat – Grantham Research Institute on Climate Change and the Environment

15 Jonathan Corcoran and Renee Zahnow (2022), Weather and crime: A systematic review of the empirical literature – Crime Science; Hayon Michelle Choi and others (2024), Temperature, crime, and violence: A systematic review and meta-analysis – Environmental Health Perspectives; Kim Robin van Daalen and others (2022), Extreme events and gender-based violence: a mixed-methods systematic review – The Lancet Planetary Health

Mission 4: Break down barriers to opportunity

- There are significant risks to education from overheating and flooding, which are expected to increase with climate change and are likely to disproportionately impact vulnerable populations. Adaptation of the school and wider education estate, as well as transport and housing, is critical to minimise the risks of lost learning and lower attainment (student performance decreases during heatwaves) and the consequent impact on children and young people's opportunity.

Mission 5: Build an NHS fit for the future

- Heat-related deaths are increasing to around 2,000 annually and disproportionately impact the very young, the elderly and those with existing long-term health needs. Addressing climate threats can reduce mortality and alleviate pressures on the NHS and social care system. This will involve adapting NHS and social care infrastructure and informing the public about appropriate precautions to take in extreme weather to protect their health.

A framework for prioritising research and innovation

This Framework aims to identify the main challenges requiring focused R&I to enhance the UK's ability to adapt to climate change, as well as cross-cutting and systems-wide research issues and linkages between sectors. This includes improving our assessment of climate risk, supporting policy and implementation decisions, and driving innovative solutions to adaptation needs. It considers scientific and technological innovation, as well as research into how people might respond to new ways of doing things, along with long-term evaluation trials of any new practices and measures. The objective is to help set the direction for publicly and privately funded R&I on adaptation.

Adapting to climate change in the UK will require R&I investment across the public sector, businesses and research communities. It can be challenging to invest in adaptation, as monetising adaptation measures can be difficult. Government collaboration with partners in industry and academia will be essential to address the R&I needs set out in this document. Government-led funding can catalyse R&I in areas which the private sector is less likely to fund by de-risking investment in these areas. Public sector investment is also essential to ensure public sector assets are well-adapted to a changing climate. At the same time, UK businesses have a critical role to play in adaptation R&I, either on their own, or via joint public-private programmes. For example, at later stages in the innovation cycle, private investment sources enable incubation support or to reach to wider markets.

The following factors may help researchers in all sectors when considering options for R&I activities to pursue.

- **Critical action:** Urgency scoring in CCRA3 and forthcoming insights from CCRA4 (to be published in January 2027) indicates priority areas from the perspective of urgency of climate risk and importance of the sector to the economy. For example, existing and new critical national infrastructure (water, power and transport), or the efficiency of urban and community services in a changing climate.
- **Impact at scale:** Identifying adaptation solutions that can deployed at scale, especially to help increase efficiency and drive down costs of action. Some of these solutions may be modular, such as modular building designs, which are easier to scale up.
- **Confidence in delivery and cost-effectiveness:** Cost-effectiveness includes identifying where adaptation measures can increase value for money – for example, decreasing cost of maintenance and renewal for infrastructure projects. This should include consideration of economic, cultural, social and environmental co-benefits and trade-offs of adaptation solutions.

A systems approach

The impacts of climate change are complex, uncertain and dynamic. Effective climate adaptation will involve action throughout our society – within and across communities, sectors, geographies and scales.

A systems approach considers relationships and interdependencies among various components within a system, identifying factors of influence and the dynamic interactions that can combine to affect an outcome. Despite the additional complexity it brings, a systems approach can help to identify where there might be opportunities to maximise the co-benefits of adaptation across sectors and minimise any unintended consequences of adaptation action in one sector on others. It is also critical to avoid maladaptation (when adaptation actions result in increased vulnerability to climate change).[16]

Each sub-section in Chapter 3 therefore draws out linkages between adaptation R&I challenges in other sectors of the economy. To give two straightforward examples, the operability of the water sector is directly linked to the resilience of electricity sub-stations, and food security of a city relies on the functioning of the transport network. Ways of measuring progress across the whole system, not just within the risk area in question, are required to better understand how adaptation interconnects across systems. For example, benchmarks for resilience or 'good adaptation' processes in different sectors will need to be compatible across sectors.

The Framework also considers the fact that the UK economy is globally connected via multiple networks, such as a shared environment, infrastructure, supply chains and financial systems. For example, the extreme weather episodes in 2010 in Western Russia destroyed a substantial portion of the wheat harvest, leading to export ban and hence sharp price increases in several countries, including the UK.[17] Multidisciplinary and transdisciplinary R&I can help to understand and manage risks to the UK from climate impacts that cascade across borders.

We have identified the following cross-cutting systems challenges, which are themselves interlinked.

16 E. Lisa F. Schipper (2020), Maladaptation: When adaptation to climate change goes very wrong – One Earth

17 The Parliamentary Office of Science and Technology (2022), Climate change and security – UK Parliament POST and Timothy R. Carter and others (2021), A conceptual framework for cross-border impacts of climate change – Global Environmental Change

Systems challenge	Key R&I needs
Setting coherent adaptation goals and resilience standards, and monitoring progress	A clear societal goal and system-level objectives for adaptation are necessary to define adaptation success measures. R&I are required to do the following: • define adaptation and resilience standards and benchmarks, combining scientific research with societal values, risk appetite and cost to identify thresholds for success or failure of sectors and the wider system under future climate • map out the interactions and trade-offs between different sectors to ensure a holistic development of adaptation goals and resilience standards • quantify limitations of adaptation by region and sector to support decision-making in adaptation planning • create long-term monitoring data which can be used to appraise the effectiveness of different adaptation interventions (both physical and societal) in terms of outcomes, across different sectors • ensure more systematic evaluation and learning from adaptation interventions – and communicating it to decision-makers in an effective way to support more targeted and effective interventions at scale
Harnessing data for well designed and implemented adaptation strategies	Data needs to be more accessible and interoperable to enhance monitoring and learning of adaptation activities by government agencies, industries and researchers.[18] In terms of R&I, the requirements are as follows: • create interoperable data by developing standards for data quality (including data format and integrating different systems and models working across differing timescales) to enable evidence-based decision-making[19] • ensure data accessibility to end users across different sectors to improve their ability to monitor adaptation progress again benchmarks • understand the potential and limitations of artificial intelligence, digital twins and augmented reality in informing projections and adaptation

18 Second National Infrastructure Assessment – National Infrastructure Commission

19 FAIR Principles – GO FAIR and Open Research Data Task Force: final report – GOV.UK and Ensuring open research – UK Research and Innovation

Systems challenge	Key R&I needs
Making the business case	Research is required to support economic assessment and to identify new business models that better weigh the expected costs and risks of proposed actions (including inaction or maladaptation) against expected returns and benefits. In terms of R&I this includes: • study risks beyond physical climate risks, such as those arising from changes in commodity prices, regulation, liabilities and social expectations linked to climate change – this can include studying approaches to other chronic risks • research, innovation and long-term trials to identify modular and scalable solutions that drive down costs for effective adaptation • identify economic opportunities in adaptation with potential for exporting adaptation-related solutions, such as climate-resilient engineering services and climate insurance • identify new business/finance models to enable an enhanced level of adaptation uptake • provide useable and salient information to businesses and local decision-makers about the cost-benefit of climate adaptation in the short- to long-term • enhance data on climate impacts (including interactions with other environmental impacts and cascading impacts) and clean-up costs to make the case for future interventions and investment in adaptation

Systems challenge	Key R&I needs
Spatial analysis and a place-based approach	Improved spatial mapping of climate risk is important to understand how climate change might exacerbate existing economic, health and social inequalities, and a place-based approach can ensure actions are better tailored to the local context. R&I priorities therefore include: • develop ways to ensure meaningful and inclusive stakeholder engagement – including co-creation where appropriate – to properly tailor effective and equitable adaptation actions • identify ways in which a place-based approach can be used to help maximise the co-benefits of adaptation, for instance in biodiversity, natural capital, and health and wellbeing • develop living labs and local testbeds to test multisectoral adaptation strategies • develop urban adaptation measures that address resilience of all infrastructure, buildings and other urban systems concurrently for uninterrupted urban services • identify place-based behaviour changes to enable place-based action

Systems challenge	Key R&I needs
Understanding social, behavioural and governance barriers to adaptation and impacts of adaptation solutions	Understanding the social and behavioural barriers to adaptation action or inaction, and the economic, cultural, social and environmental impacts of adaptation solutions are crucial to ensuring sustained change. R&I priorities include the following: • develop a better understanding of attitudes towards adaptation and adaptation interventions, and their likely trajectory under different scenarios • develop a better understanding of social and behavioural drivers – including the role of information provision to the public – to inform design of effective, equitable and scalable adaptation solutions • develop evidence on the impacts of repeated exposure to extreme weather events on people and how this changes behaviours • understand impact of potential unintended consequences of adaptation measures on people, including on their social vulnerability • better understand the willingness to change among individuals, for example accepting the need to ‘pay more for resilience’ • develop a pathway for the institutional and regulatory changes required to enable adaptation • better understand actors and power dynamics (including mandates, responsibilities and spheres of influence) to identify effective governance approaches for interconnected, multisectoral risks and corresponding stakeholders

Systems challenge	Key R&I needs
Early warning systems and tailored climate services	Design and delivery of comprehensive operational early warning systems and tailored climate services – where climate science is translated for a specific application or purpose – are crucial to support public resilience to climate impacts and to ensure that emergency responders, infrastructure providers, food producers and supply chains can plan for and maintain operations during extreme events. R&I requirements for this include: • identify best ways – including using the media – to deliver impact-based early warning systems that lead to sustained behaviour changes • develop ways to tailor climate predictions and projections for use in particular climate services, and to exploit increasingly sophisticated forecasting capability across timescales to improve the timeliness and accuracy of early warnings • better understand the need for sector-specific and cross-cutting climate services to support development of a National Framework for Climate Services[20] • further climate projection information, tailored to requirements of users, to continue to inform on changing climate hazard • research on emergency services and how adaptation can shape the need for them – for example, we will see more concurrent crises, requiring an evolved emergency service response

20 Louise Wilson and others (2022), Recommendations for the UK National Framework for Climate Services – UK Climate Resilience Programme

Case study

Scaling climate services with the Met Office Local Authority Climate Service

The Met Office Local Authority Climate Service (LACS) provides local authorities with climate information tailored to their local area in way that is easy to use for developing risk assessment and adaptation plans. Climate reports provide all UK local authorities with robust climate projection data for their local area, whilst Esri's geospatial platform allows users to explore Met Office climate data geospatially. The LACS also includes a community site, providing further information and guidance for using climate information and planning adaptation action.

The LACS is the result of successful upscaling from a pilot climate service, 'City Pack', which was first co-developed with Bristol City Council in 2019 as part of the UK Climate Resilience Programme. Following the pilot, the service was scaled to an additional 20 local authorities who helped to develop the service, providing feedback and examples of practical application. The LACS platform launched in autumn 2024, making climate reports available to all UK local authorities, funded by the Department for Environment, Food and Rural Affairs.

Key outcomes

In the first few months following launch, the LACS service received over 7,600 local authority climate report views. Climate reports are used in the following ways:

- to provide data for decision-making – for example, City Pack informed the Bristol City Council Climate Change Risk Assessment
- as a communication and training tool within city councils and other organisations such as emergency responders and orientation material for new staff within the council
- as a public engagement and communication tool to raise public awareness and understanding of the key issues associated with climate change locally within the city
- to inform the development of other climate services and resources within the city council

References

UK Climate Resilience Programme outputs – Met Office

Prototype development: meeting urban user needs – UK Climate Resilience Programme

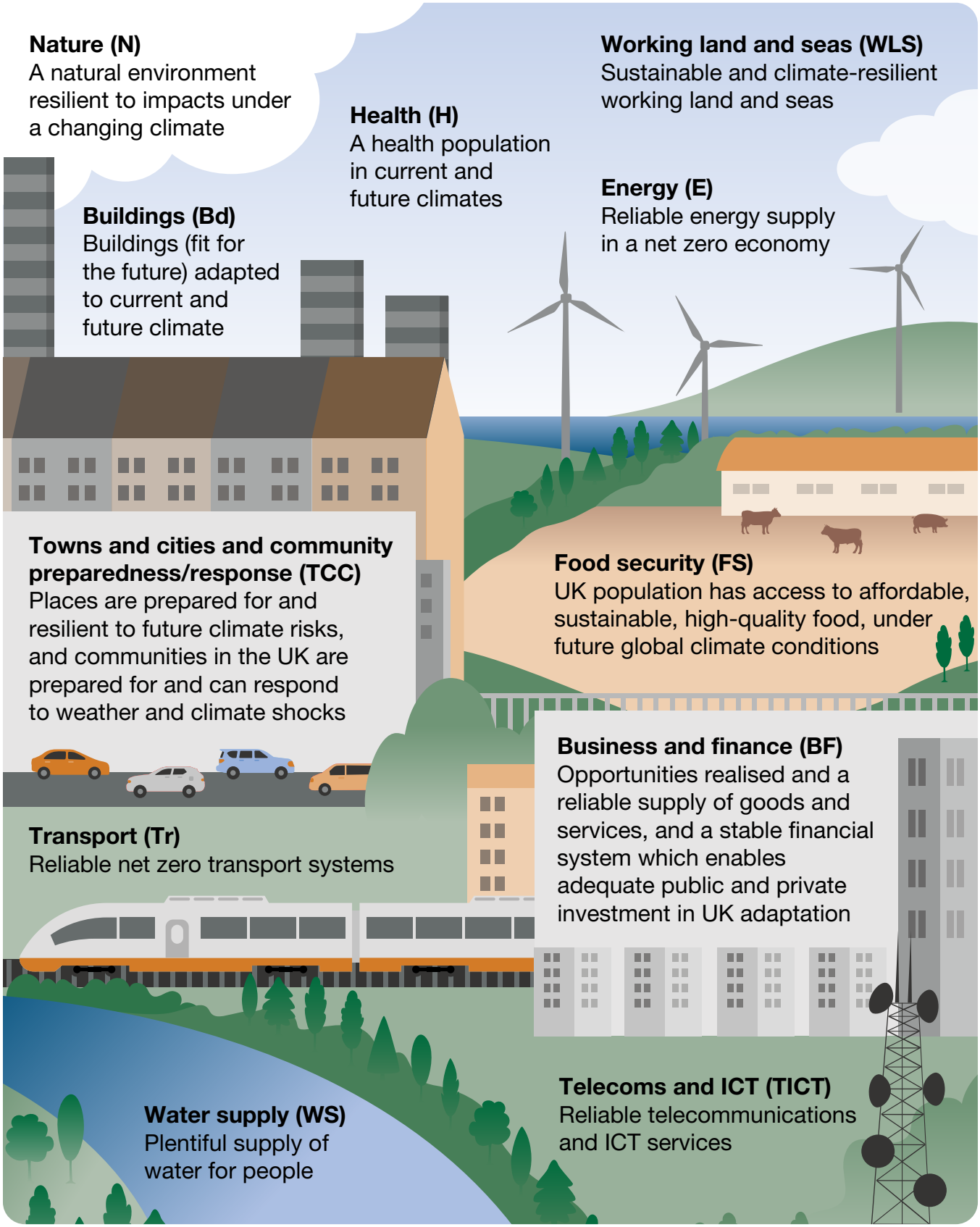
Sectoral research and innovation challenges

This chapter sets out R&I challenges and needs across 11 sectors. The sectors are based upon those in the CCRA3 assessment framework that was developed by the Climate Change Committee and set out in its 2023 report to Parliament on progress in adapting to climate change (CCC, 2023).

The overall adaptation goal and main adaptation outcomes for each sector are taken from the Climate Change Committee's adaptation monitoring maps.[21]

21 Chapter 3 of the Adaptation Monitoring Framework – Climate Change Committee

Figure 4. Adaptation outcomes for 11 sectors of the economy



Source: Authors' own

The lists of R&I needs for each sector were compiled by synthesising input from external stakeholders, UK government departments, the CCRA3 technical report (Betts, Brown and others, 2021), the Intergovernmental Panel on Climate Change Sixth Assessment Report Working Group 2's Europe chapter (Bednar-Friedl and others, 2022) and other literature. The lists are not exhaustive and there may be gaps where R&I needs are not yet realised or well-defined.

The R&I needs identified for each sector are categorised into three challenge areas.

- **Risk assessment:** This relates to the evidence and methods needed to give a good understanding of the changing hazard, including the likelihood, magnitude and extent of extreme weather events, alongside changing exposure and vulnerability. Risk assessment also includes requirement for scenarios for stress-testing existing thresholds and potential adaptation options, alongside considering broader uncertainty for design purposes.
- **Decision support and solutions:** This relates to the evidence required by decision-makers, whether in governments or business, as well as the innovation, design, testing, cost-benefit analysis and evaluation of adaptation interventions. It includes rationales for adaptation, response options, metrics of success, pathways for financing adaptation, scaling considerations, effectiveness of and limits to adaptation, cost-benefit analysis, innovative solutions, learning and evaluation, the prioritisation of interventions, and articulation of co-benefits or trade-offs where interdependencies are identified.
- **Data needs:** This includes availability and access to evidence that underpins assessment and management of climate risks.

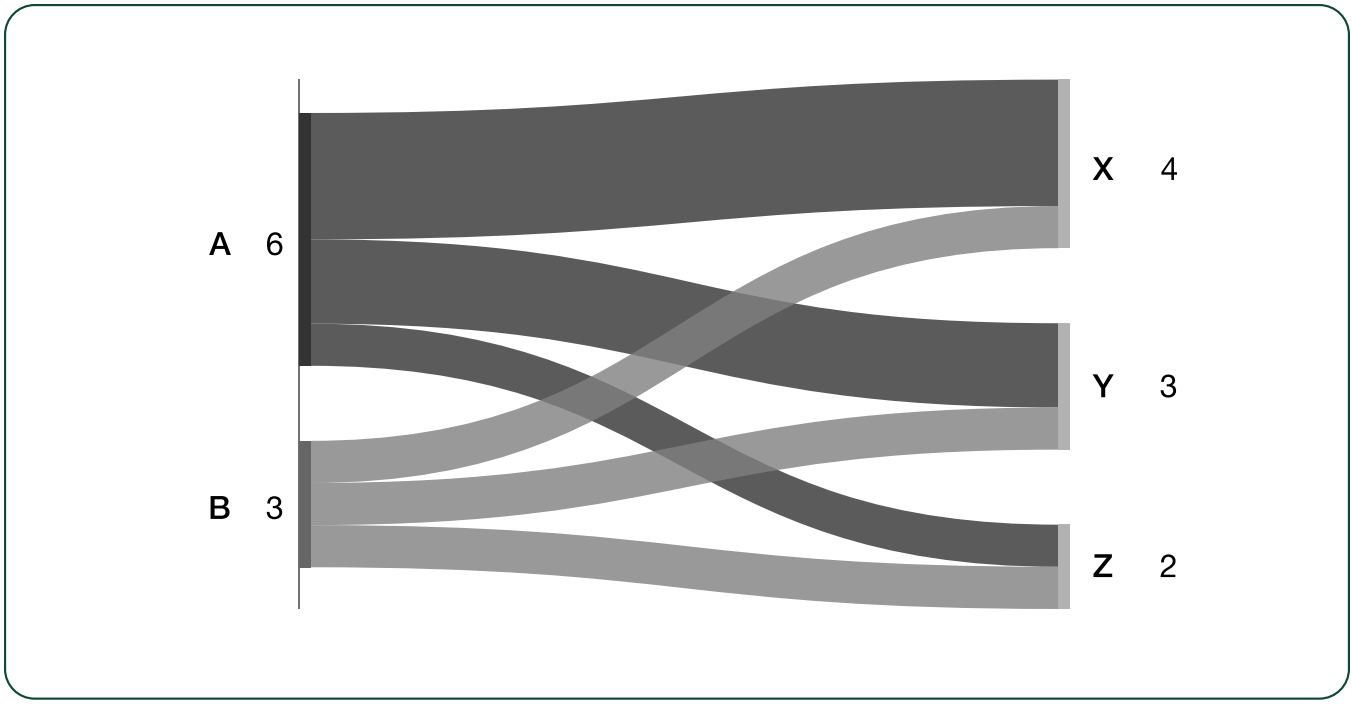
Each sector can be read in isolation for the benefit of those with a specific sectoral interest. As a result of this sectoral split, R&I needs that are common to multiple sectors are duplicated within each.

To illustrate how sectors are interrelated, each sector sub-section below contains a Sankey diagram showing connections between that sector's R&I needs and challenges, and those of other sectors. The coloured rectangles are nodes representing R&I needs (grouped into R&I challenge categories) and sectors. Connections between nodes show where efforts to address R&I needs in a particular sector may have a beneficial impact on other sectors. The width of lines represents the number of connections between two nodes, and the numbers next to each node represent total connections.

For example, in Figure 5, node A has six connections in total: three with node X, two with node Y and one with node Y) and node B has three connections in total (one each with nodes X, Y and Z).

Data for the Sankey diagrams was gathered from expert input and can be found next to the R&I challenges and needs for each sector under the heading 'With direct implications on'. The data is not exhaustive, and some connections may be missing.

Figure 5: Example Sankey diagram



Nature (N)

Healthy natural ecosystems that can thrive despite climate change are essential not only for their intrinsic value, but also for the numerous benefits they provide to people and the UK economy, such as crop pollination and enhanced flood mitigation. If natural ecosystems are damaged, other societal goals (including climate adaptation, nature recovery and net zero) will increasingly be jeopardised (CCC, 2023).

Overall goal

A natural environment resilient to impacts under a changing climate.

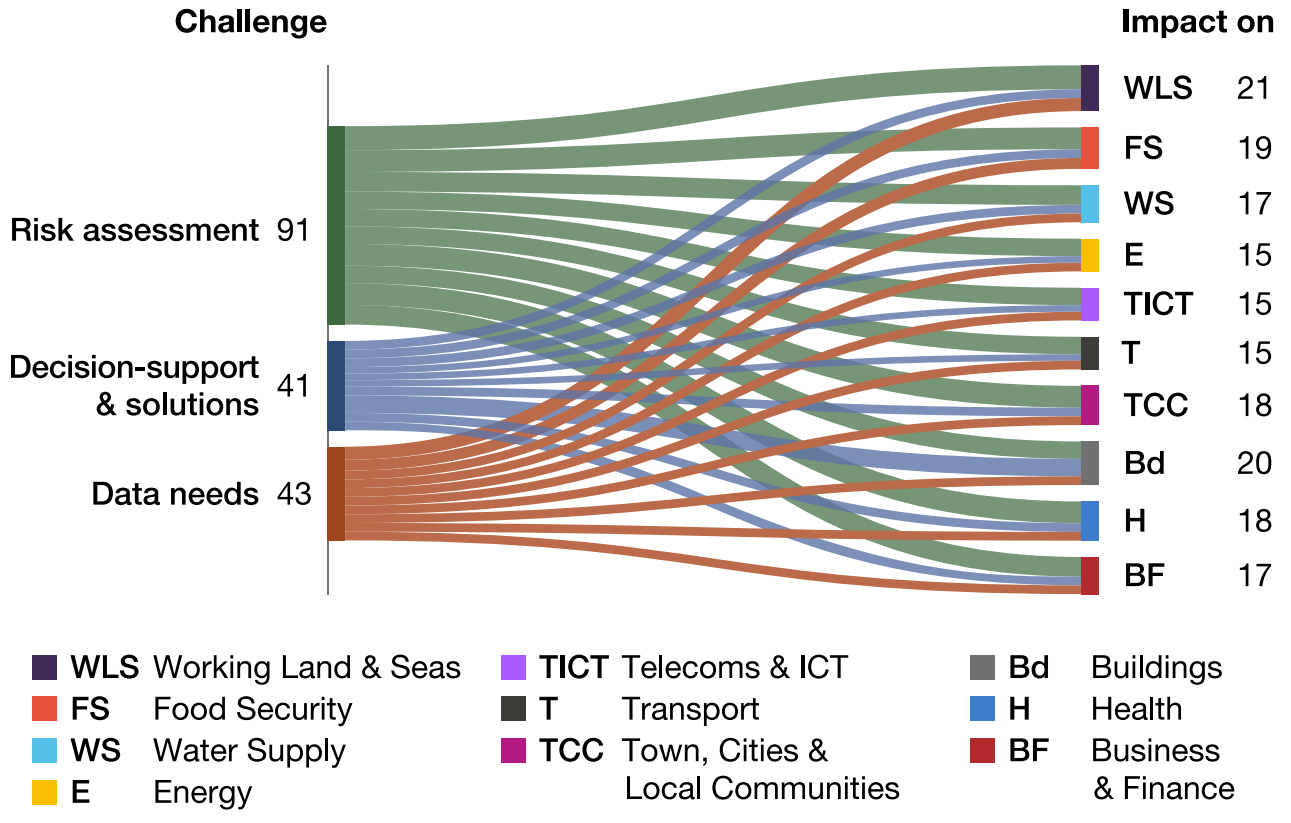
Main outcomes

- Terrestrial, freshwater, marine and coastal habitats are in good ecological health
- Habitats are larger, more connected, more diverse, more protected and more resilient
- Species are more abundant and diverse
- Pressure on ecosystems is reduced
- Nature-based solutions are maximised

Key UK government department

Department for Environment, Food and Rural Affairs.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Near-term risks:** Near-term risks of climate change on natural systems to complement current research focusing more on medium- and long-term impacts.	All
	Interactions between risks: Interaction between different climate and non-climate risks and the response of complex natural systems.	All
	Interaction between nature and climate: Understanding the drivers of nature loss and how they will impact climate and adaptive capacity.	All
	Wildfire risks: A spatiotemporal understanding of future UK wildfire risks, including near term, and their impacts on ecosystems, accounting for the interaction between climate drivers and non-climatic factors.	All
	Flooding, water resources and drought risks: A spatiotemporal understanding of future UK flood, water resources and drought risks, and their impacts on ecosystems, accounting for the interaction between climate drivers and non-climatic factors.	All
	Coastal erosion risks: A spatiotemporal understanding of future UK coastal erosion risks, including near term, and their impacts on ecosystems, accounting for the interaction between climate drivers and non-climatic factors.	All
	Pests, pathogens and invasive species: The climate change-driven spread patterns of pests, pathogens and invasive species.	WLS, FS, T, TCC, Bd, H, CPR, BF
	Soil health and function: Understanding of the impact of climate change on soil biodiversity and function.	WLS, FS, WS, TCC, H
	Natural carbon stores and sequestration: Improved quantitative evidence on the effect of climate change on land and marine carbon loss from carbon stores (e.g. peatland and saltmarsh).	WLS

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Impact on habitats and species:** Species movement projections (including through connective landscapes); Identification of climate-resilient native species; Impacts of changing ocean temperature and chemistry; Climate change impacts on freshwater habitats; Impacts of air quality and other pollution impacts on species and habitats; Understanding climate thresholds at which certain species will be lost; Assessment of state of the art adaptation concepts (including assisted colonisation and novel ecosystems).	All
	Nature-commercial sectors interactions: Understanding of the ways that natural risks under climate change impact on commercial sectors.	All
	Groundwater and aquifer system risks: Climate change induced risks to groundwater and aquifer systems (including water quality and surface water biodiversity) and how these can be addressed with the water management strategies; Changes in water quality under climate change; Interactions of ground water and aquifer systems with surface water biodiversity; Understanding compound impacts of climate change together with changes in land use and management practices on groundwater and aquifers.	WLS, FS, WS, TCC, Bd, H, CPR, BF
	Temporary resilience: Response to potential tipping points; Temporary resilience of (parts of) natural systems in a potential overshoot scenario.	All
	High resolution precipitation, temperature, wind, soil moisture and streamflow data: High temporal resolution and spatially dense monitoring of precipitation, temperature, wind, soil moisture and streamflow data, and improved cataloguing of and access to historical data from a range of sources, with estimated uncertainties, for better understanding and characterising changes and their potential causes.	All

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Measuring adaptation success:** Definition of and success criteria and metrics for adaption success for nature; Develop novel ways of observing success (e.g. use of drones, satellites and automated monitoring).	All
	Enabling resilient ecosystems: Effectiveness, trade-offs and co-benefits of different interventions and the compound effect of a suite of interventions at scale for enabling ecosystem health and improving climate resilience across different climate scenarios.	All
	Landscape-scale adaptation: Landscape-scale adaptation with broad ecological benefits, including cost-benefit analyses of buffer zones or migration corridors.	WLS
	Early warning systems: Early warning systems design to support public resilience to climate impacts and ensure that emergency responders and other stakeholders can maintain operations (e.g. in a wildfire context); Provision of near real-time data to enable advanced integrated modelling.	All
	Soil management practices: Assessment of the effectiveness of soil management practices on climate adaptation.	WLS, FS
	Nature-based solutions: Value and efficacy of nature-based programme of works (e.g. rainwater separation, urban drainage solutions and rewilding); Compound effect of suite of nature-based solution interventions at the landscape/catchment scales for different eco-geo-climate contexts and change scenarios.	All

R&I challenge	R&I needs	With direct implications on
Data needs	**Biodiversity and ecosystems monitoring:** Data to quantify how systems are changing (including in the face of overexploitation, habitat change, pests and diseases) as well as to measure progress in reducing climate change risk and the effectiveness of interventions.	All
	Soil health and water quality: Monitoring of soil health and water quality to understand the impacts of climate change on these systems.	All
	Protected and local wildlife site conditions: Data on the condition of these sites; Data on the effectiveness of natural flood or other risk management within these sites.	WLS
	Citizen science data: Citizen science data collection to enhance and complement other data for the planning and delivery of adaptation.	All
	Marine species and habitats: Data on individual and combined impacts of acidification, temperature and salinity on marine species, and changes in pressures on the seabed from human activities.	All
	Society-nature interactions: Place-based understanding of how society values nature and ecosystems and how they can support adaptation.	All
	Terrestrial water cycle monitoring: Data to demonstrate changes in the sources, stores and pathways of water and to quantify all aspects of the terrestrial water cycle at larger scales.	All

Case study

Promoting Adaptation to Changing Coasts (PACCo) project

Coastal communities are especially vulnerable to the increasing risks caused by rising sea levels and extreme weather events associated with climate change. The PACCo project aims to demonstrate large-scale estuarine adaptation by restoring 100 hectares of coastal wetland in developed areas at two pilot sites: the Otter Estuary in Devon (UK) and Saâne Valley in Normandy (France). This restoration will enable better management of flooding, absorb carbon, and provide benefits for people and wildlife.

The PACCo project aims to show how collaboration with stakeholders in estuarine regions to pre-emptively adapt to climate change can deliver a range of benefits for people and the environment. The model can be used to ascertain whether adaptation is right for a coastal area and provide guidance on how to proceed. It is designed to be a transferable tool to empower, assist and encourage community leaders, policymakers, contractors and stakeholders to improve resilience to rising coastal challenges through nature-based solutions.

Key outcomes

- Communicating about climate change and raising awareness
- Protecting and restoring lost intertidal habitats
  - 5km of river and 5km of tributary reconnected to their floodplain
  - 105 hectares of intertidal habitat created
- Relocating businesses and amenities to areas at lower risk of flooding
  - 3.7km public footpath raised and enhanced
  - Municipal camp site and cricket club relocated
- Developing resilient design for new infrastructure
  - A wastewater treatment plant created, and an old tip protected from erosion
  - Two bridges built and a road raised from flooding
  - 30km of sewerage networks created and nearly 1,500 homes connected

References

The PACCo project's guide to successful climate adaptation – GOV.UK
PACCo guide summary – PACCo

Working land and seas (WLS)

This sector includes agriculture, commercial forestry, and fisheries and aquaculture. These activities provide jobs, vital products and inputs to other sectors, while also contributing to food and resource (such as fibre, timber and biomass) security. Weather and climate-related disruptions in these sectors can have significant cascading economic, environmental and social impacts (CCC, 2023).

Overall goal

Sustainable and climate-resilient working land and seas.

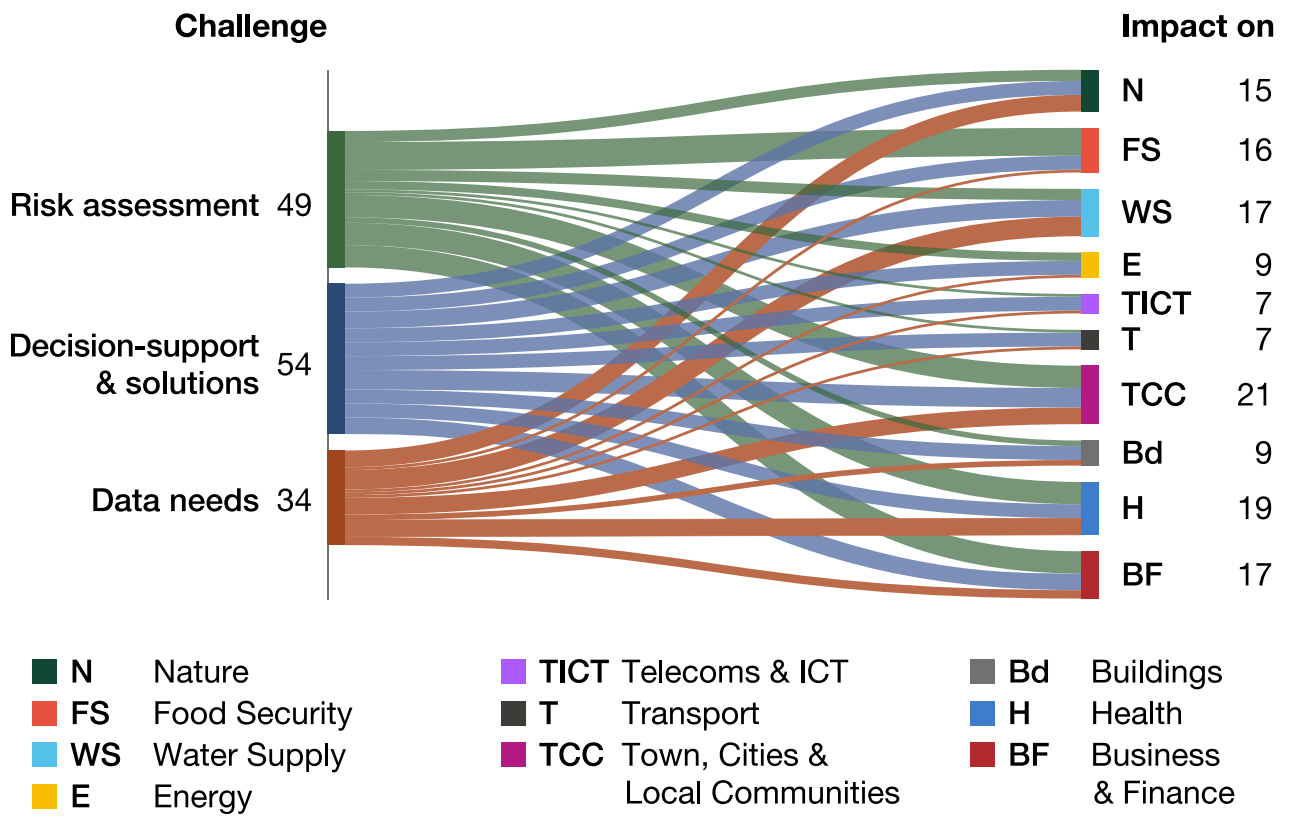
Main outcomes

- Climate-resilient agricultural production
- Climate-resilient commercial forestry sector
- Climate-resilient commercial fisheries and aquaculture sector
- Take-up of sustainable farming measures
- Healthy soils
- Effective wildfire planning
- Responsible practices
- Climate-resilient operations
- Impacts from pests, diseases and invasive non-native species managed and reduced

Key UK government department

Department for Environment, Food and Rural Affairs.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Productivity across land and seas:** Assessment of how hazards cascade across land and sea-based habitats under climate change; Climate change impacts on productivity across land and seas (e.g. trees, biomass crop and fish productivity); Opportunities for new crops, fruits and vegetables in the UK's future climate.	FS, WS, E, H, BF
	Spatial assessment: Spatial assessment of climate hazards and impacts on WLS at regional and local scales.	FS, WS, E, TCC, Bd, H, BF
	Climate-appropriate species research: Climate-appropriate species or genotypes for different locations.	All
	Agriculture: Impact of potential climate change-induced changes in planting schedules and agriculture shortfalls on domestic supply and economy, including a more complete assessment of the risk from pests, pathogens and invasive species, and how this interacts with international climate shocks and other risks (see 'Food security'); Risks from flooding or extreme temperatures to crops and livestock.	FS, WS, TCC, H, BF
	Forestry: Impact of extreme and anomalous weather events as well as longer-term changes in climate on forestry, including from pests, pathogens and invasive species.	N
	Fish stocks: Impacts of changing ocean and freshwater temperature and chemistry on fish stocks.	FS, TCC, H, BF
	Marine and land-based ecosystems: Combined, cascading and interacting impacts of climatic and non-climatic pressures on land-based, marine and coastal socio-ecological systems.	FS, TCC, H, BF

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Irrigation water needs:** A spatial assessment of changes in our needs for irrigation water under climate change and ways to minimise shortfalls.	FS, TCC, BF
	Leaching risks: Near-term risks associated with point and diffuse pollution due to flooding and coastal erosion; Potential hazards of material leaching into the marine environment along with implications on fish stocks and water quality.	FS, H, TCC, BF
	Soils under climatic stresses: Interaction between soil types (e.g. compressible and clay shrink-swell) and climate-induced stresses; Understanding compound impacts of climate change together with changes in land use and management practices, as well as impacts on hydrological extremes and transitions.	N, FS, BI
	New species: Potential trade-offs or unintended consequences of introduction of new species.	N, FS, TCC, H
	Impact of wildfires on net zero: Future risk projections for impact assessment of wildfires on net zero.	All
Decision support and solutions	**Exposure and vulnerability:** Ways to reduce exposure and vulnerability for primary producers (e.g. local protection of soil resources); Ways to improve climate services for the producers to minimise vulnerability.	All
	Costs: Costs of adaptation across the supply chain and across landscapes (e.g. costs of natural flood management measures upstream provide benefits to communities downstream), including the costing of inaction with respect to adaptation.	All
	Communication: Evidence and communication needed by producers, retailers, the wider supply chain, and their customers to recognise and support adaptation.	FS, TCC

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Measuring adaptation success:** Definition of success criteria and metrics for adaption for working land and seas.	All
	Balancing multiple goals: Ways to balance multiple goals such as food security, climate mitigation, adaptation and nature recovery, including assessment of trade-offs and co-benefits.	All
	Financing: Ways to channel finance from the supply chain into farming to empower farmers in the face of a changing climate.	TCC, BF
	Water shortage management for agricultural purposes: Environmental impacts of greater adoption of desalination and wastewater reuse; Impacts of greater adoption of surface water storage and nature-based solutions for groundwater recharge.	FS, WS
Data needs	**Indicators:** Data on impacts to agriculture from unpredictable and unseasonal weather, such as yield and profit changes, crop or livestock losses due to flooding or heatwaves, and fish losses due to sea temperature rises or changes to ocean chemistry; Applicability of other international contexts with similar changing climates.	All
	Resilience of commercial species: Data on the resilience of commercial species to climate change, such as genetic diversity of crops, livestock, trees and fish.	N, FS, TCC, H, BF
	Agri-environment scheme uptake and outcomes: Data on the actions taken by agricultural land managers to reduce vulnerability of production to changing climate conditions (e.g. on-farm water storage, tree shading, wildfire management activities and natural flood management) and data on their effectiveness.	N, FS, TCC, H, BF

R&I challenge	R&I needs	With direct implications on
Data needs	**Soil health:** Monitoring soil from a range of types and uses for a better understanding of its health and erosion under compound impacts of climatic pressures and changes in land use and management practices.	N, FS, T, TCC, Bd, H
	Wildfire: Prevalence of local wildfire plans in place and capacity of local firefighters to address wildfires in agriculture and forestry; Management of fuel load to mitigate wildfires.	N, FS, TCC, H
	Marine and coastal environments: Localised, fine-scale marine and coastal water temperatures and acidification; Long-term data on pathogen-host interactions, nutrients and pollutants, and effect of climate and extreme events on disease.	N, FS, TCC, H
	Pests: Enhanced surveillance and horizon scanning; Change in occurrence and abundance of pests, pathogens and invasive non-native species.	N, FS, TCC, H

Food security (FS)

Food security will be affected by climate impacts on food production, both domestically and in regions overseas from which the UK imports food and feed, as well as climate hazards affecting the supply chains for food and feed.

Overall goal

The UK population has access to affordable, sustainable, high-quality food under future global climate conditions.

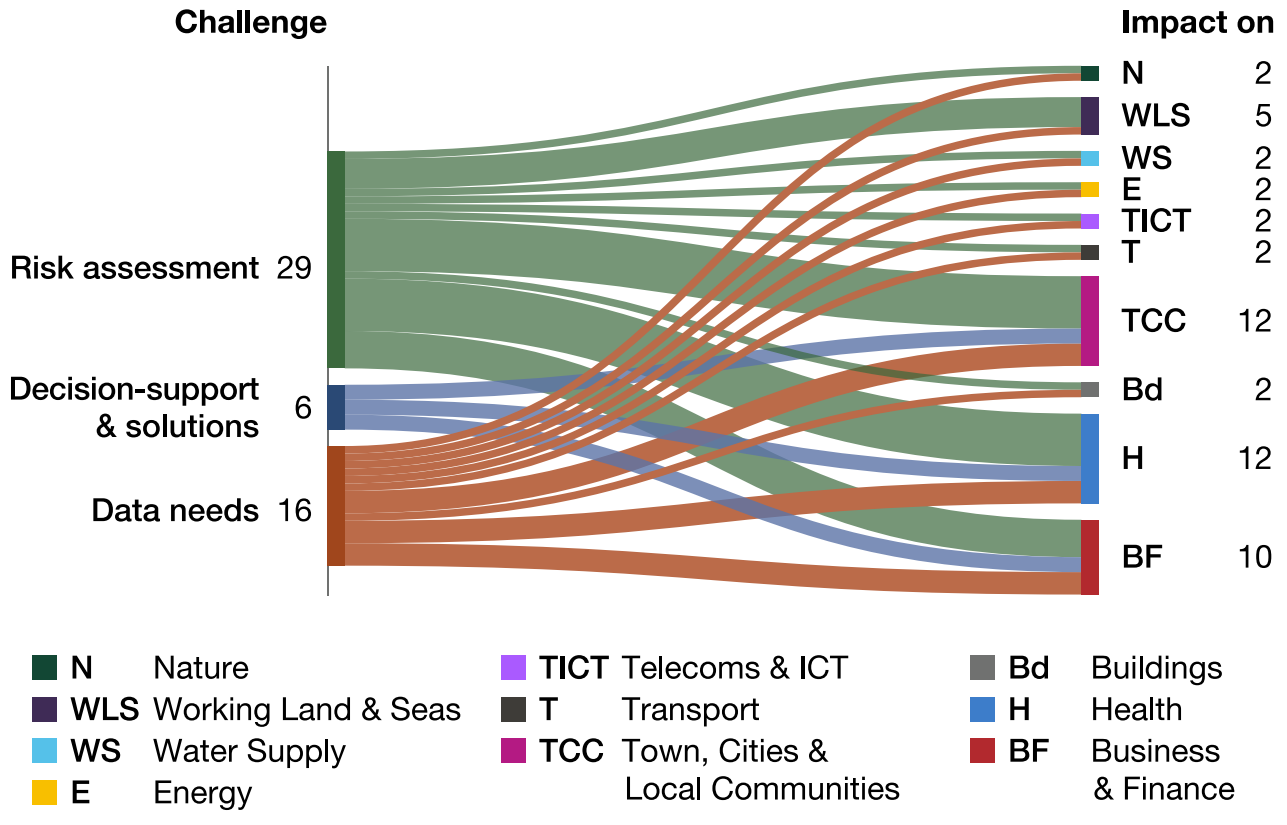
Main outcomes

- Disruption to food and feed import supply chains due to climate change is minimised
- Vulnerability to food price shocks is reduced
- Domestic food production is resilient to climate shocks

Key UK government department

Department for Environment, Food and Rural Affairs.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Species-specific responses:** Species-specific responses to direct and indirect climate change impacts and how this affects food security.	H, TCC, BF, N, WLS
	Food supply chains: Vulnerabilities and strengths in food supply chains in the face of a changing climate.	H, TCC, BF
	Vulnerability to price shocks: Vulnerability of different households to price shocks from climate and other environmental impacts across the full extent of food supply chains.	H, TCC
	Exposure of UK food security: Exposure of the food system and food products to climate and other environmental shocks and stresses within and outside the UK.	H, TCC, BF
	Chemical contamination: The potential for climate change to increase risk of chemical contamination of food.	H, TCC, WLS
	Opportunities for new food production and supplies: Increased evidence to assess opportunities for new food production and supply means in a warmer UK.	H, TCC, BF, WLS

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Early warning system:** Development of early detection and warning systems targeted at hazards that can impact on food supply (e.g. flooding and droughts, and compounds or cascades) to mitigate the effects of climate change induced food insecurities.	H, TCC, BF
	Climate stress testing: Climate stress testing by large food and feed companies in order to provide information on the resilience of the system to climate hazards.	TC, H, TCC, BF
	Trade-related responses: Responses of food trade to food security risks, and how these can be managed.	BF
	Costs: Costs of adaptation, including the costing of inaction with respect to food security.	All
Data needs	**Horizon scanning:** Horizon scanning for potential risks to food security as global temperature increases and in the face of droughts, floods, changed precipitation, nutrient shortages and air pollutants.	H, TCC, BF
	Food quality monitoring: Food quality monitoring to provide information on any changes in nutrition or prevalence of food-borne pathogens.	H, TCC
	Efficiency and food waste: Reporting on food waste reduction initiatives to understand the efficiency and resilience of the system.	E, H, TCC, BF
	Land use change: Land use change data to underpin projections to complement models on food security.	WLS, T, H, TCC BF

Water supply (WS)

The uninterrupted provision of clean water to households and businesses is necessary for comfortable homes, functioning business premises and public health. This needs to be maintained despite the range of current and future weather hazards that could be experienced (CCC 2023).

Overall goal

A plentiful supply of water for people.

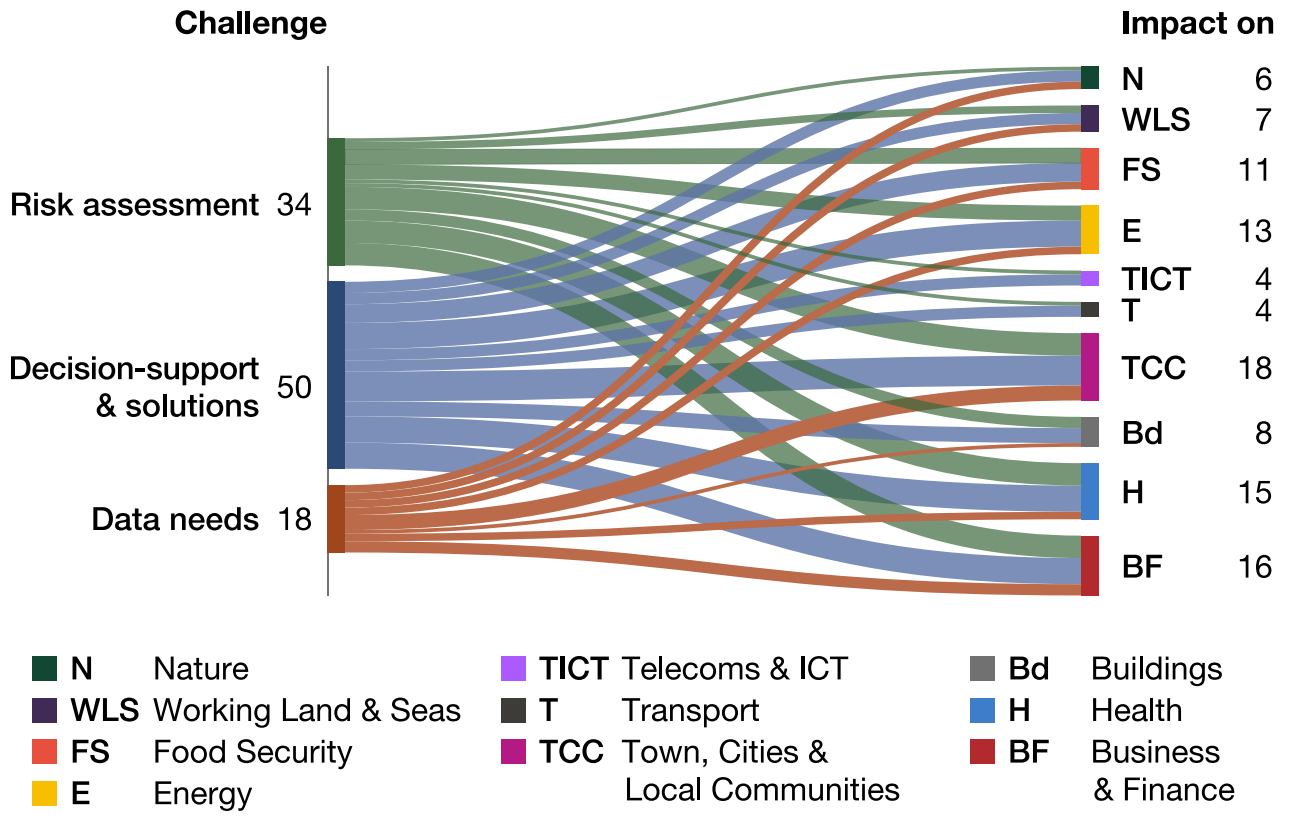
Main outcomes

- Reduced demand
- Improved system performance
- Increased supply
- Interdependencies identified and managed

Key UK government department

Department for Environment, Food and Rural Affairs.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Water supply and quality risks:** Risks associated with adequacy of public water supply in the future under climate change and how this impacts different vulnerable populations; Water quality risks from reduced household water supplies; Seasonality of rainfall in future climates.	WLS, FS, TCC, H, BF, E
	Water use: Methods to sustainably reduce water use and leakage in the face of potential depletion of water supplies under climate change; Changing water use trends including industrial water use, e.g. driven by the shift to net zero energy, and trends due to changing weather.	E, Bd, H, TCC, BF, FS
	Connectivity: Connectivity within the water supply system and how regions can be better connected to increase resilience against climatic pressures.	FS, T, TCC, H, BF
	Wastewater: Climate impacts on wastewater drainage and potential adaptations (e.g. sewer spills in wet weather or reduced dilution in dry weather).	E, TCC, Bd, H, BF
	Grey water management: Resilience of grey water infrastructure (rainwater collection and sewage effluents treatment) to climate change.	TCC, H, BF

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Nature-based programmes:** Value and efficacy of nature-based interventions (e.g. rainwater separation, urban drainage solutions and rewilding).	All
	Costs: Costs of adaptation, and the cost of inaction, in the water sector.	All
	Early warning systems: Early warning systems for identification of water quality infringements and planning for scarcity; The use of ecosystem monitoring data to develop metrics tailored to discerning and quantifying the impacts of climate trends and extreme events, providing early warnings and opportunities to track the efficiency of adaptation measures.	All
	Customers attitudes: Understanding and managing social attitudes to long term decision-making and risk perception regarding water supply.	E, TCC, H
	Science of incident responses: Best ways to respond to local supply failures under a range of weather and other conditions (e.g. heat, drought and summer floods).	TCC, H, BF
	Circular water systems and water shortage management: Technologies for a circular water system to manage water shortages (e.g. microbial and micropollutant cleaning); Impact of greater adoption of desalination and wastewater reuse.	E, TCC, H, BF
	Water use priorities: Support decisions on priorities for water uses in the context of limited availability.	FS, E, TCC, T, H, BF
	Community-based water management practices: Community measures around flooding and drought/ water storage and demand and leakage reduction; How community measures can be incentivised and more evidence on their effectiveness.	All

R&I challenge	R&I needs	With direct implications on
Data needs	**Monitoring and visibility of network:** Effective monitoring and visibility of the network for better identification of water movement and of users, allowing interventions on demand and leakage.	FS, E, TCC, Bd, BF
	Monitoring and planning for transfers: Monitoring and planning for transfers to minimise restrictions in water use in areas affected by water scarcity during dry periods; Data to enable understanding of the catchment water balance and the implications of interventions; Monitoring would provide reduced uncertainty in quantifying components of catchment water balances.	FS, E, TCC, Bd, H, BF
	Water use: More detailed region-specific water use data to underpin trends and predictions.	E, TCC, BI
	Spill monitoring: Enhanced sewage spill monitoring systems which will also enable an understanding of longer-term impacts of spills on habitats and biodiversity (including the capacity of the drainage system).	WLS, N, TCC, BF
	Water quality monitoring: River, lake and pond water quality data for better planning and assessment of harm from spills and other contaminants, preferably coupled with habitat and biodiversity monitoring.	WLS, N, FS, H, TCC, BF

Energy (E)

The energy system encompasses the generation of electricity and the extraction and imports of fossil fuels (such as North Sea oil and gas), along with the transmission and distribution of electricity and fuels to consumers and industry. Secure and affordable energy supplies are essential for UK society and its economy to function, including critical sectors and services such as health, banking and telecoms (CCC 2023).

Overall goal

Reliable energy supply in a net zero economy.

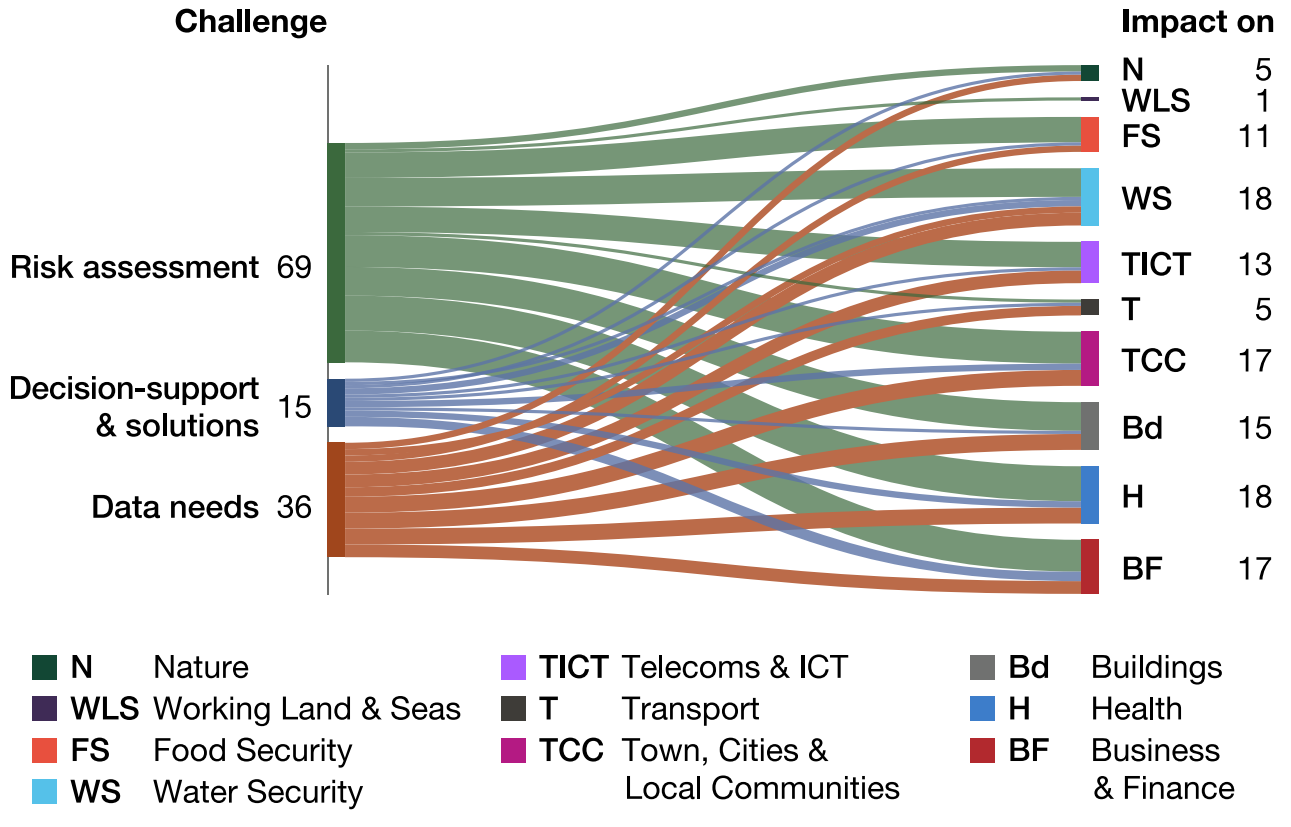
Main outcomes

- Reduced vulnerability of energy assets to extreme weather
- System-level security of supply
- Interdependencies with other systems are known and managed

Key UK government department

Department for Energy Security and Net Zero.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Infrastructure resilience:** Projections of exposure of energy assets to climate-related hazard, considering future infrastructure expansion; Changes in future flood events on a local level considering multiple sources of flooding; Economic and business effects of systemic failures from energy infrastructure due to climatic pressures; Ways in which high temperatures, wind conditions, wildfires and convective (and other types of) storms challenge energy infrastructure; Validation techniques to assess the modelled risk and associated impacts; Potential for infrastructure damage from future high-flow events and floods, particularly for hydroelectric facilities; Sensitivity of electricity networks to windthrown trees during storms, considering contributing atmospheric variables; Restoration challenges for energy supply following extreme temperature events and storms; Impact of an increase in summer storms over clays susceptible to shrink-swell, particularly the impact of increased lightning on energy infrastructure (pylons).	FS, WS, TICT, T, TCC, Bd, H, BF
	Infrastructure interdependencies and risks: For and impact of cascading infrastructure failures; Mapping of sectoral interrelations under energy infrastructure failures; National assessment of interdependency risks and how to improve resilience of infrastructure; Power system risks from the combined impacts on generation, network and consumer from a weather event, especially for implications on ICT, water and transport.	All
	Ecosystem capacity: Assessment of the ability of natural and managed ecosystems to adapt to the impacts of climate change and how this might affect the resilience of energy infrastructure.	FS, WS, TICT, T, TCC, Bd, H, BF

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Heating and cooling demand:** Attribution of historic reductions in heating degree days on observed heating demand trends; Socioeconomic drivers associated with cooling technology uptake; Identification and definition of summer fuel poverty; Risk of overheating in highly insulated dwellings; Contribution and interaction of non-climatic factors (e.g. net zero policies) on cooling and heating demand; Implications for food security, including impacts on the cold supply chain.	TCC, Bd, H, BF
	Water resources for energy production: Assessment of future water resources for water-intensive energy infrastructure; Scenario analysis for water resources for hydrogen production under different climate futures; Spatial mapping of water resources for climate futures; Impact of water temperature on energy generation efficiency; Effects of water extraction for hydrogen production on flow rates, ecosystems and upstream/downstream users; Lifecycle analysis of hydrogen production, focusing on the impacts on water resources throughout the entire process; Impacts of reduced water availability on water source heat pumps.	WS, TCC, Bd, H, BF
	Compounding hazard assessment: Coastal flood and erosion; Storm dynamics (extreme wind, waves, storm swell and heavy precipitation); Impact of compound hazards on energy infrastructure; Impacts of heat, drought, and shrink/swell.	FS, WS, TICT, T, TCC, Bd, H, BF

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Wind and solar energy, and bioenergy:** Future changes in wind and solar potential, and their implications on resilience of green energy pathways and of the dependent sectors; Soil desiccation and erosion from solar and wind farms, including potential adaptation measures (e.g. geotextiles to mitigate evapotranspiration from the soil); Climate risks and impacts to bioenergy feedstocks; Prolonged periods of limited sunlight and little wind, and how the frequency and duration of these periods might change with a changing climate.	FS, WS, TICT, T, TCC, Bd, H, BF
	Coastal risks: Improved modelling of current and future coastal risks (including erosion, sediment transport and inundation) to support identification of effective adaptation responses across the coastal energy infrastructure system.	FS, WS, TICT, T, TCC, Bd, H, BF
	Offshore energy assets: Offshore energy asset systems risk, including their locations, connectivity, and redundancy; Number, location, design practices and structural reliability of current and planned offshore/tidal infrastructure under climate change impacts.	FS, WS, TICT, T, TCC, Bd, H, BF
	Hydropower generation: Quantification of changes in river flows, influenced by climate variables like temperature and precipitation; River flow regimes' impact on sediment load, turbine efficiency and maintenance needs, plus potential for landslides and increased competition for water resources; Regional variability of climate change impacts on hydroelectric generation in UK.	WS. TCC, H, BF
	Risk on energy storage technologies: Vulnerability of energy storage technologies and replacements for diesel backup generators to climatic hazards; How demand response services are affected by climate hazards and how this changes availability.	All

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Investment:** Approaches to help energy infrastructure operators to build the case for investment in long-term climate resilience; Scale and nature of investment needed for energy network resilience.	BF
	Customers' energy use: Citizen science to identify and manage patterns of energy use; Understanding behaviour change and how to drive uptake of adaption measures.	TCC, BF
	Asset management systems for adaptation: Best adaptation measures based on the specific characteristics and contexts of energy assets' locations, considering also interdependencies; Optimal incorporation of adaptation in the asset lifecycle; Climate-related design specifications for energy infrastructure and equipment, and when these are expected to be breached.	WS, TICT, Tr, TCC, Bd, H

R&I challenge	R&I needs	With direct implications on
Data needs	**Tracking:** Development of indicators to track progress in increasing the resilience of the energy system.	All
	Cooling: Data on residential air conditioning uptake and cooling demand; Data on non-residential cooling and refrigeration demand (e.g. data centres, cold chains and for the health and social care sector); Household perceptions regarding cooling need and resilience.	Bd, BF, H
	Centralised data on weather-related outages: National data on weather and climate-related impacts on the energy system and the extent of adaptation actions being delivered to enable a better understanding of the level of resilience of the energy system.	All
	Major infrastructure projects: Data on consideration of climate risk adaptation in major infrastructure project approvals.	WS, TICT, T, TCC, Bd, H
	Local resilience groups: Data provision to local resilience groups on interdependencies for better planning.	TCC, WS, TICT, Tr, Bl
	Energy assets: A comprehensive inventory of bridges and pipelines in the energy sector; Data on individual energy assets' exposure to climate-related hazards (e.g. flooding and erosion).	WA, TICT, T, TCC, Bd, H

Telecommunications and ICT (TICT)

Telecommunications (telecoms) and information communications technology (ICT) network infrastructure includes telephone, mobile communications and internet services, including around 500 data centres across the UK and extensive networks of optical fibres, cables and masts. This infrastructure is at the core of the UK's economy and needs to be protected from disruption associated with extreme weather now and in the future.

Overall goal

Reliable telecommunications and ICT services.

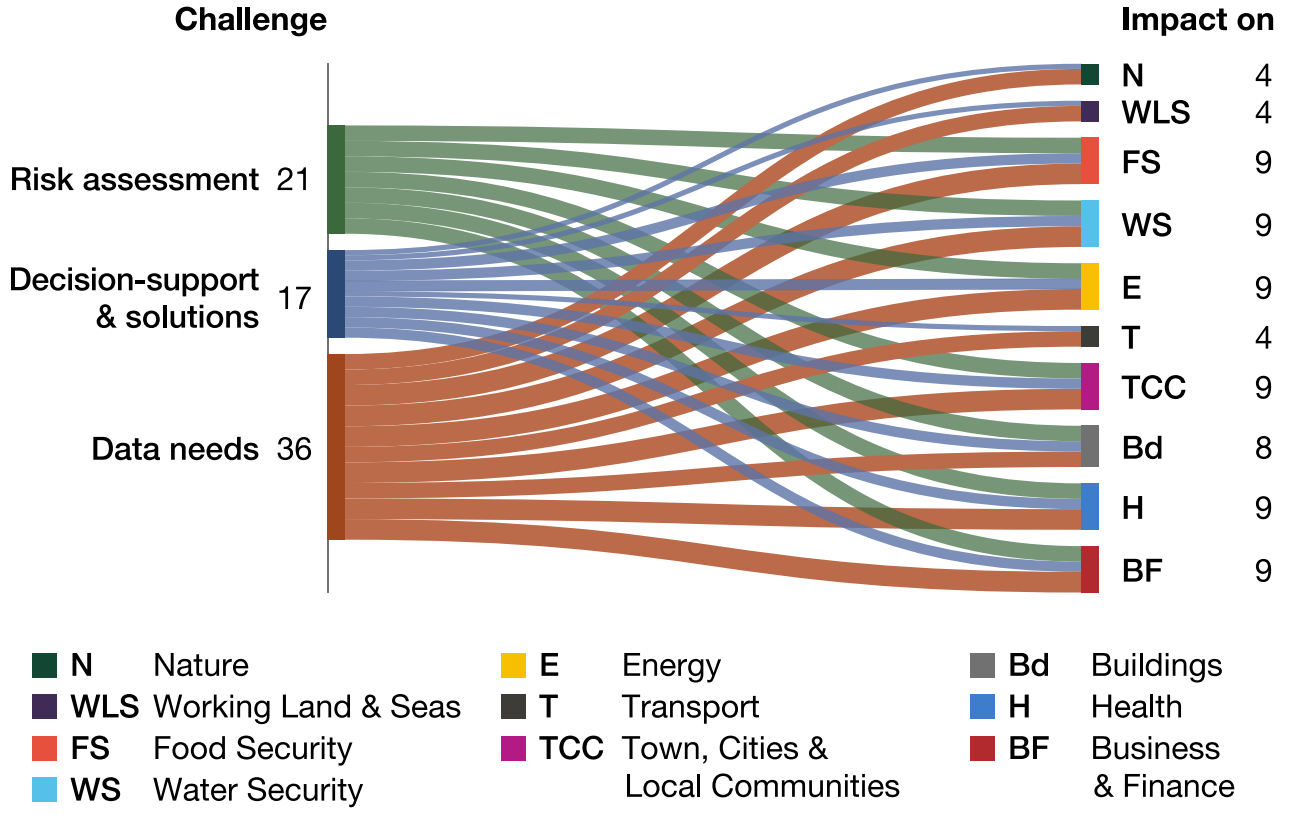
Main outcomes

- Reduced vulnerability of assets to extreme weather
- System-level resilience
- Interdependencies with other systems are known and managed

Key UK government department

Department for Science, Innovation and Technology.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Infrastructure resilience:** A spatiotemporal impact assessment of climate change on current and future digital infrastructure and its resilience; Establishment of resilience standards.	FS, WS, E, T, TCC, Bd, H, BF
	Interruptions: Quantitative projections for climate change-induced interruptions; Assessment of how technology trends are influencing the vulnerability of homes and organisations to ICT disruptions including disruption to offshore cabling.	FS, WS, E, T, TCC, Bd, H, BF
	Cascading failures and interdependent risks: Potential impact of climate change in causing cascading infrastructure failures; National assessment of interdependency risks; Interrelations between risks to telecommunications and ICT and other sectors.	FS, WS, E, T, TCC, Bd, H, BF
Decision support and solutions	**Costs:** Costs of adaptation, and the costs of inaction, for the TICT sector.	All
	Coastal flood risk management: Guidance on managing coastal flood risks to telecoms, digital and ICT infrastructure.	FS, WS, E, TICT, T, TCC, Bd, H, BF

R&I challenge	R&I needs	With direct implications on
Data needs	**Weather-related outages:** Data on weather and climate-related impacts on telecoms and ICT networks, and on the extent of adaptation actions being delivered.	All
	Vulnerability of assets: Assets at risk of flooding and other climatic risks; Conditions of cables and other network infrastructure; Maximum temperature operating thresholds of system components; Other indicators and metrics able to define the vulnerability of relevant assets.	All
	System-level resilience indicators: Level of redundancy in system design and operation for power supply, emergency generation, communications and cooling; Extent of contingency plans for weather-related outages.	All
	Major infrastructure projects: Extent to which climate resilience is considered in major infrastructure project approvals.	FS, WS, E, T, TCC, H, BF

Transport (Tr)

Transport infrastructure networks include strategic and local roads, railways, ports and airports. Functioning transport networks are necessary for personal mobility and public services, as well as corporate supply chains. Weather-related disruption to transport systems can cause significant cascading impacts across society with substantial financial impacts. Weather conditions can also lead to the safety of transport system users being compromised (CCC, 2023).

Overall goal

Reliable net zero transport systems.

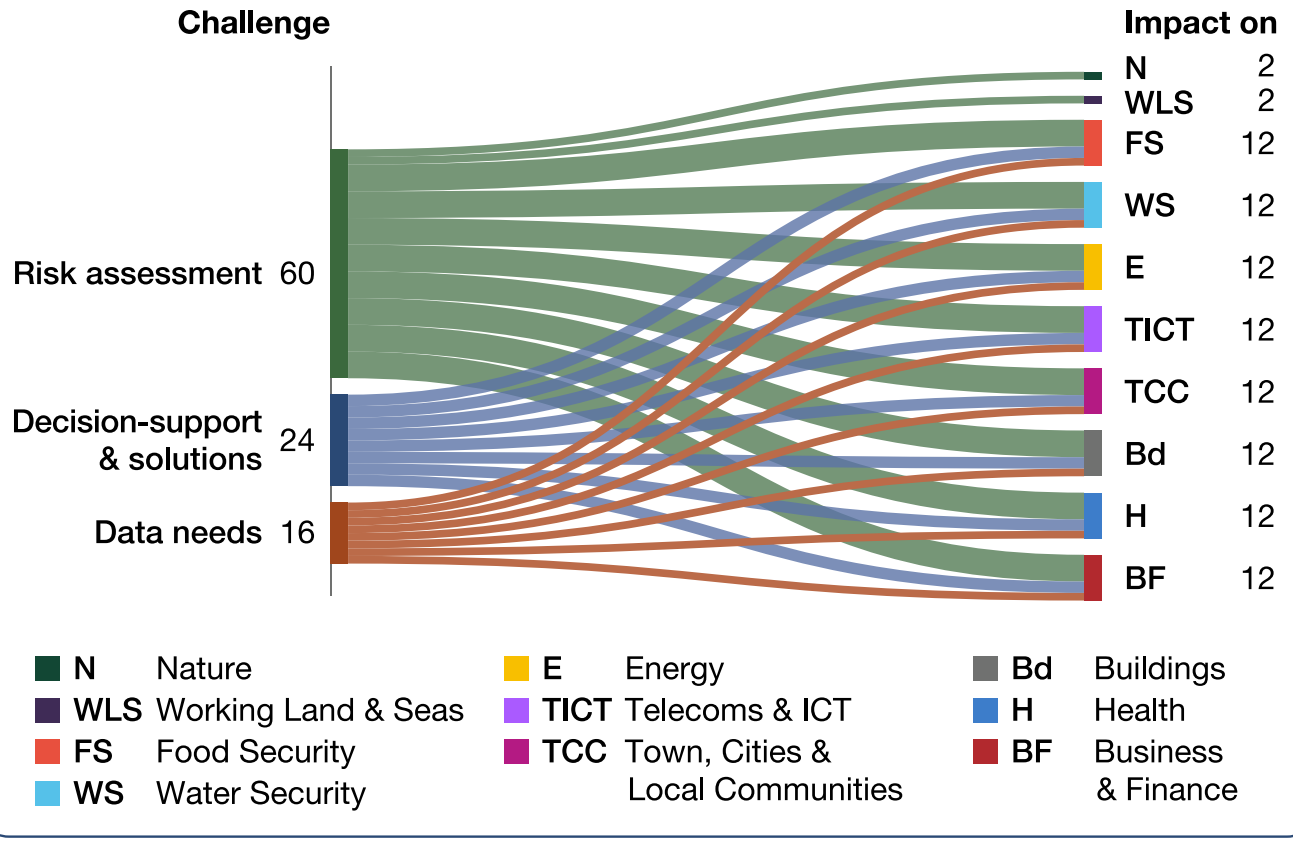
Main outcomes

- Asset and system-level reliability of rail network
- Asset and system-level reliability of strategic road network
- Asset and system-level reliability of local roads
- Asset and system-level reliability of airport operations
- Asset and system-level reliability of port operations
- Interdependencies identified and managed

Key UK government department

Department for Transport.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Whole-system assessment:** Whole-system assessment of transport system resilience under climate change.	All
	Railway failure trajectories: Failure trajectories of individual railway components and network under climate risks.	All
	Slope and embankment failure: Asset, slope and embankment condition and exposure; Deterioration mechanisms under climate change.	FS, WS, E, TICT, TCC, Bd, H, BF
	Coastal risks: Improved accuracy in predicting risks associated with sea level rise and extreme coastal event likelihood, and their consequences.	FS, WS, E, TICT, TCC, Bd, H, BF
	Bridges, pipelines, culverts and drains: Climate-induced risks to bridges, pipelines, culverts and drains; Improved understanding and analysis of ground movement and subsequent effects.	FS, WS, E, TICT, TCC, Bd, H, BF
	Wind, flooding and heat: Improved understanding of the impact of increased wind speeds, frequency of high wind speed events, flooding, extreme heat and other climate impacts on transport infrastructure; Understanding of the impact of changing climate on emergency planning and response.	FS, WS, E, TICT, TCC, Bd, H, BF
	Cascading failures and interdependent risks: Potential impact of climate change on causing cascading infrastructure failures; National assessment of interdependency risks; Interrelations between risks to transport and other sectors.	FS, WS, E, TICT, TCC, Bd, H, BF
	Electric vehicle and charging infrastructure vulnerability: How electric vehicles and charging infrastructure will be impacted from exposure to climate risks.	FS, WS, E, TICT, TCC, Bd, H, BF

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Climate impacts on operators, passengers and goods:** How the transport system operators, passengers and goods are likely to be affected by climate change; How the climatic impacts likely to change accessibility requirements.	FS, WS, E, TICT, TCC, Bd, H, BF
	Risks to roads: Risks to roads from sink holes appearing triggered by heavy rain.	FS, WS, E, TICT, TCC, Bd, H, BF
	Risks to ports and ships: Climate-induced risks to ports and ships; Impact on ferry services and operating thresholds.	FS, WS, E, TICT, TCC, Bd, H, BF
	Waste transport: Ability under climate change to safely move waste to the site of disposal.	FS, WS, E, TICT, TCC, Bd, H, BF
Decision support and solutions	**Decision support tool:** Tools to provide additional climate information for the transport sector under severe weather events of different frequencies to inform climate adaptation investments, risk assessments and asset designs; Cost-efficient remediation methods.	All
	Costs: Costs of climate risks to transport systems and assets, including the costing of inaction with respect to adaptation; Costs of adaptation for the transport network; A critical appraisal of different approaches to valuing; Storyline approaches to help transport infrastructure operators invest in and build the case for long-term climate resilience.	All
	Enablers of adaptation action: Funding for research and development, trials, and measures to remove barriers to adaptation action taking an evidence-based approach, working in partnership with all parts of the transport sector.	All

R&I challenge	R&I needs	With direct implications on
Data needs	**Weather-related disruptions and costs:** Data that transport stakeholders capture on weather and climate-related disruption and costs.	All
	System-level resilience indicators: Development of indicators able to describe climate resilience of the transport system as a whole, and to measure adaptation outcomes and impacts with the view to having more effective metrics for local roads, airports and ports to inform NAP4.	All
	Asset monitoring: Asset condition monitoring, such as for earthworks, bridges, drainage.	All

Towns and cities and community preparedness/response (TCC)

Most of the UK population live in urban areas. Towns and cities represent areas that are exposed to a high level of risk from climate change due to higher densities of people, buildings, infrastructure and businesses (CCC, 2023). Community preparedness and response covers local-level awareness, planning and response to weather and climate impacts, ensuring the protection of cultural heritage from the effects of climate change.

Overall goal

Places are prepared for and resilient to future climate risks.

Communities in the UK are prepared for and can respond to weather and climate shocks.

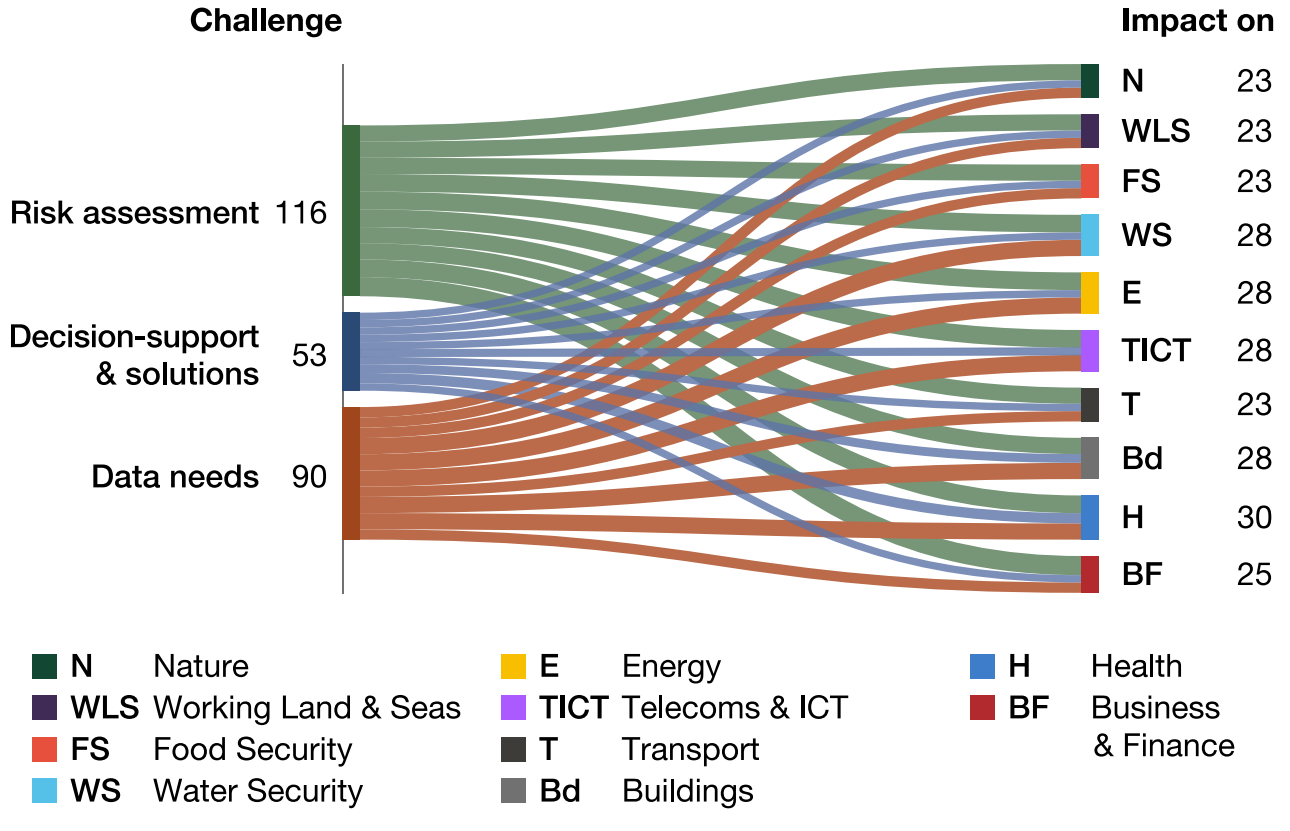
Main outcomes

- Places are prepared for and resilient to river, coastal, surface water and groundwater flooding
- Sustainable and long-term coastal erosion plans
- Urban heat risks are mitigated
- Communities are prepared for and can respond to climate shocks
- Local cultural heritage is conserved

Key UK government department

Ministry for Housing, Communities and Local Government.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Whole-system assessment:** Whole-system assessment of towns and cities' resilience under climate change; High resolution spatial risk assessment of towns and cities under climatic hazards, including the less studied hailstorms, urban wildfires and lighting; Role of complex of social vulnerabilities and market characteristics (e.g. competitors) in shaping risk; How location- and sector-specific knowledge on climate risks for firm assets, operations, business, industry, finance and insurance inform areas of attention and future adaptation actions.	All
	Risks on coastal cities and settlements: Coastal risks especially in relation to sea level rise and coastal erosion, for better shoreline management and to prepare for potential displacement; Uncertainty associated with cliff collapses and the societal implications of permanent inundation and coastal change.	All
	New technologies for assessment: Deployment of remote data acquisition systems (e.g. satellites, drones, and sensors) and artificial intelligence or machine learning for better monitoring, modelling and forecasting; Demonstration of the potential of new technologies for data acquisition and providing the digital systems to support the collection, integration and analysis of the data collected.	All
	Improved flood modelling: Improved flood modelling in urban areas to outline areas requiring attention; Improved evidence base on future groundwater and flood risk.	WS, E, TICT, T, BI. H, BF

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Cascading failures and interdependent risks:** Potential impact of climate change in causing cascading failures and disruptions in towns and cities; National assessment of interdependency risks; Interrelations between risks to major urban infrastructures, such as transport, telecommunications, and food and water supplies; Connectivity analyses to delineate sectoral interactions and potential escalations and cascades under different scenarios.	All
	Effective urban services under climate change: Compound risks on transport, school and health infrastructure, and how to address these for effective and uninterrupted urban services; Indirect impacts (e.g. delays and economic losses).	All
	Climate induced risks on tourism: Future projections of climate change impacts on tourism (e.g. historic city centres, other historic and natural heritage sites, and snowmaking capacity for ski centres) and their impact on communities and businesses.	BF
	Costs and benefits: Improved understanding of costs and benefits to building resilience and adaptation actions (including retrofit of existing infrastructure), including costing of inaction.	All
	Climate risks to communities: Potential impacts of changing normal and extreme events on communities, their health and wellbeing, and their assets at local level and the associated socioeconomic vulnerabilities for an enhanced assessment of risks; How different social groups are affected by and respond to key risks; Climate resilience indicators and a spatial study of these to identify communities and community assets that require attention.	All

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Impact of climate change on tangible and intangible heritage:** Climatic risks on heritage and adaptation measures to be put in place to improve resilience; Social implications of climate risks on cultural heritage.	All
	Sectoral interrelations for community resilience: How failures and disruptions in major infrastructure or assets and services are managed by other sectors, and their impact on community resilience.	All
	Infrastructure: Infrastructure interdependencies for functional urban and community services; Effects of seasonal changes, dewatering, an end to dewatering, and sea level rise on infrastructure (including potentially deeper water cycles because of climate change); Effects of drought on infrastructure, particularly the potential for trees and vegetation to damage infrastructure via swelling pressures as they seek water.	All
Decision support and solutions	**Nature-based solutions:** Specific returns on investment for and the resilience of nature-based solutions in different circumstances; Different adaptation action pathways for nature-based and urban planning solutions.	All
	Resilience standards: How to benchmark resilience in towns and cities; How chosen resilience standards applied to infrastructure impact the exposure of different socio-economic groups to infrastructure failures.	Bd, H
	Public communication: Ways to communicate climate risks to the public (e.g. on groundwater flood risk, sea level rise and coastal erosion) for enhanced preparation.	H

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Land use planning:** Land use planning strategies will be implemented to target urban specific climate pressures, such as heat islands, collective risks to health and wellbeing, and flood risk; Land use planning tools will allow the effects of different spatial land use scenarios on multiple urban specific climate pressures to be investigated jointly.	All
	Standardised risk mapping: Development of standardised approaches to risk mapping across scales (local to national).	All
	Public awareness for more efficient management of climatic risks: Citizen science approaches to benchmark and enhance communities' awareness of climate risks, and to empower them to adapt and build resilience by way of finance, advice, prioritisation and tools for action.	All
	Community-led adaptation programmes: Community-led adaptation programmes, including those targeted at community heritage; Traditional or indigenous knowledge use for co-designing adaptation at community level.	All
	Green and blue infrastructure uptake: Key barriers (practical, cultural, financial and governance) inhibiting the large-scale establishment of green and blue infrastructure in UK urban areas.	All
	Governance of urban risks: Adaptation options for efficient governance of urban areas, services and communities under climate change; Early warning systems to ensure proactive governance of urban risks.	All
	Early warning systems and emergency services: Effectiveness of warning systems and understanding how emergency services should adapt to facing increased climate hazards, as well as the associated costs.	All

R&I challenge	R&I needs	With direct implications on
Data needs	**Data sharing:** Improved data sharing practices across regions and sectors, data on the impacts of past events on towns and cities including cascading impacts; Data on lived experience of climate change.	All
	Standardised adaptation monitoring: Consistent monitoring of adaptation actions and their effectiveness, including economic and health and wellbeing benefits of adaptation.	WS, E, TICT, T, Bd, H
	Monitoring asset deterioration: Consistent monitoring of infrastructure vulnerability over time.	WS, E, TICT, T, Bd, H
	Erosion monitoring: Consistent national-scale monitoring of erosion rates, losses and shoreline management plan implementation.	WS, E, TICT, T, Bd, H
	Green infrastructure asset registry: Centralised data on green infrastructure assets, including typology and quality metrics.	WS, E, TICT, T, Bd, H
	New service conditions and extreme events definition: New service conditions, compound risks and extreme events to be accounted for updated UK design codes for infrastructures.	All
	Effectiveness of adaptation: Long-term evidence with regards to the efficiency of adaptation options in improving climate adaptation.	All
	Data sharing and discussion: Platforms to enable communication and crosspollination between communities and climate risk reduction organisations on adaptation.	All

R&I challenge	R&I needs	With direct implications on
Data needs	**Displacement, migration and immobility:** Data on displacement, migration and immobility patterns of affected communities to inform planning on risk management practices and emergency preparedness.	All
	Systematic rapid evidence assessment: Critical appraisal of international literature and best practices, learning from regions with similar climate conditions and informing risks to health and wellbeing from high temperatures.	TCC, Bd, H

Buildings (Bd)

Buildings should be healthy and comfortable places to spend time in all year round. This means warm in winter, cool in summer and resilient to climate hazards such as flooding. The building stock includes residential and non-residential buildings, such as commercial buildings (offices and factories) and public buildings like schools, prisons and hospitals (CCC, 2023).

Overall goal

Buildings (fit for the future) adapted to the current and future climate.

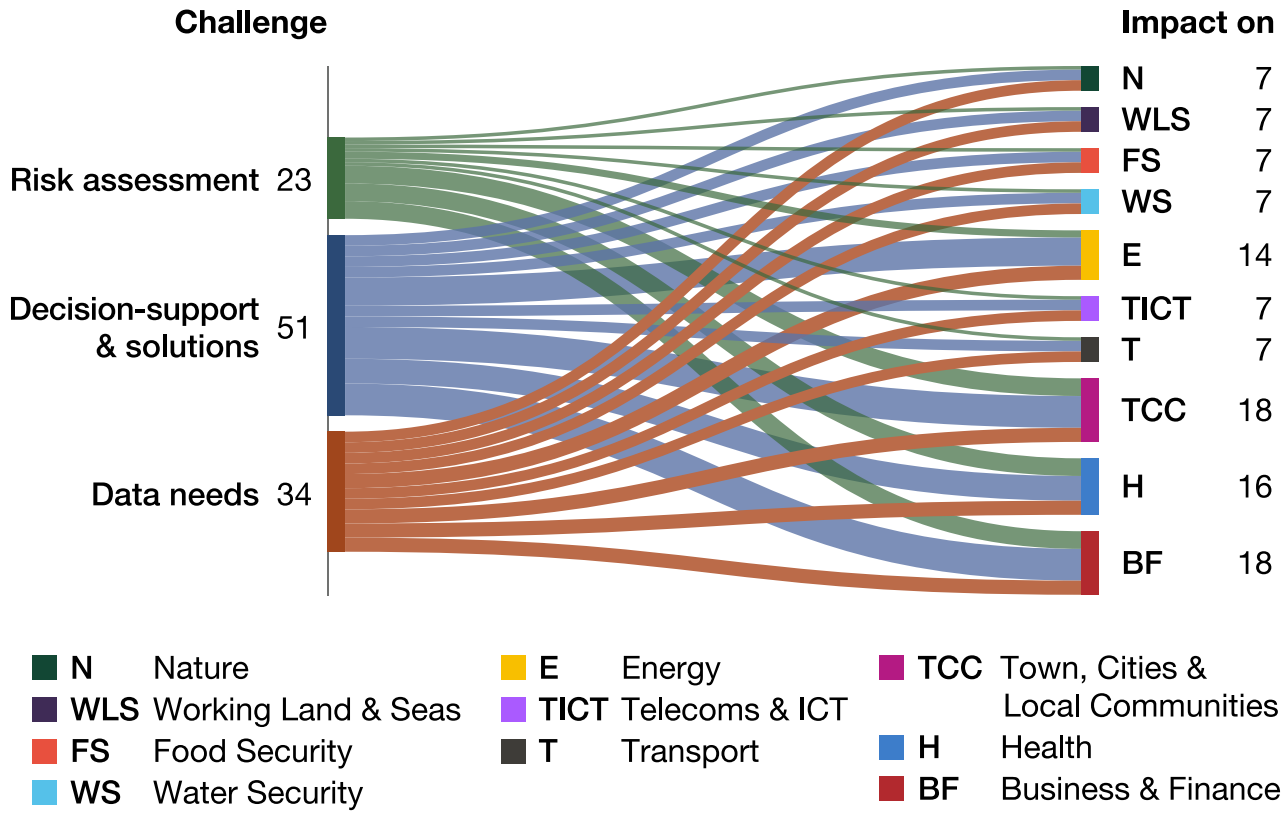
Main outcomes

- Buildings do not overheat
- Buildings are prepared for flooding
- Buildings are resilient to other climate risks

Key UK government department

Ministry of Housing, Communities and Local Government.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Hazards:** Likelihood and trends of future climate-related hazards affecting building stock, including flooding, wind-driven rain, subsistence and compound hazards.	H, TCC, BF
	Damage mechanisms: Damage mechanisms to building fabrics (including those of historic and heritage buildings) from climate-related hazards (e.g. precipitation, flooding and wind).	H, TCC, BF
	Overheating and air quality: Overheating risk in buildings, including UK government estates, adult and children's care homes, education settings, prisons and health facilities, food systems (e.g. livestock housing, processing and storage), and impacts on productivity and education (including research into threshold, overheating occurrences in building stock); Risk of overheating in very highly insulated and under-ventilated dwellings and identifying potential thresholds for insulation levels; Changes to indoor air quality (including indoor mould and yeasts) and other health risks under climate change; Impacts of increasingly wet, warmer winter weather on indoor humidity levels and air quality.	H, TCC, BF
	Vulnerability mapping: Higher resolution vulnerability mapping across risks; Building construction, age and location to assess sensitivity to climate-related hazards, including heatwaves; Mapping of future domestic air conditioning demand.	All
	Heat and moisture transfer: Impact of combined increases in ambient temperature and changes in rainfall patterns on heat and moisture transfer in buildings.	E, H, TCC, BF

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Adaptation measures:** Review of adaptation measures and adaptive capacity to climate-related hazards (including floods, wildfire, subsidence, wind-driven rain, extreme wind and biological hazards) as relevant to building fabric; Different adaptation action pathways for the building stock; Nature-based solutions for buildings and their efficiency.	All
	Repair, maintenance, retrofit and reuse of buildings: Best practice of repair, maintenance and retrofit of buildings to achieve co-benefits across energy efficiency, thermal comfort, air quality and ventilation; Extend service life and better understand synergies and trade-offs; Benchmarking adaptive reuse potential; Evidence base on the cost-effectiveness of passive and active adaptation retrofit measures (including cost of measures at household level); Guidance on retrofit for heatwaves; Ventilation requirements for air quality, and for passive cooling in response to overheating.	E, TCC, H, BF
	Traditional or vernacular building technologies: Ways in which traditional or vernacular building technologies can inform adaptation to climate in new building design.	E, TCC, BF
	Technological advances for better risk management in building stocks: Ways to best deploy sensor technology and digital twins to support sectors in risk management of buildings, reduce exposure and vulnerability to climate risk, and gauge the efficiency of adaptation interventions.	E, H, TCC, BF
	Costs and benefits: Improved understanding of benefits of adaptation and economic comparison of options, including costs of inaction.	All
	Opportunities: Ways in which potential opportunities can be maximised, for example benefits of a warmer climate to reduce energy demand or increase use of solar power.	E, TCC, BF

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**New design and construction practices in support of climate adaptation:** Design for durability; Design to be able to cope with changing normal and extreme weather events; Incorporate passive measures and adaptive management approaches for managing indoor environmental quality (including summer cooling and winter heating).	E, TCC, H, BF
	Heat strategies: The effectiveness of various strategies to tackle overheating, such as community cool rooms.	H, TCC, BF
	Behavioural adaptation: Effectiveness and reliability of behavioural adaptation measures to physical measures (passive or active cooling).	All
Data needs	**Accessible climate data:** Open access and accessible climate data for grassroots entities and other research base.	All
	Open database of adaptation options: Creating an open database of adaptation options including detailed data on the cost of adaptation for different assets across different sectors.	All
	Standardisation: Standardised risk mapping and data on location of corporate assets.	All
	Monitoring: Large-scale monitoring of overheating incidences and flood risk across the building stock; Improved monitoring of property flood resilience installations and their risk reduction benefits.	E, TCC, H, BF
	Public building stocks: Spatial data mapping across different major public building stocks.	TCC, H
	Health and wellbeing impacts of buildings: Health and wellbeing impacts on building occupants and service users including vulnerable cohorts – with particular focus on buildings that are also residential.	TCC, H

Case study

Advancing School Performance: Indoor Environmental Quality, Resilience and Educational Outcomes (ASPIRE) project

10 million children in the UK spend 30% of their life at school (70% of that time inside a classroom). There is significant evidence that poor indoor air quality and exposure to excess indoor temperatures can have detrimental impacts on the learning performance and health of pupils. This is particularly important because children breathe more indoor air pollutants than adults for their size and have a limited ability to thermoregulate, and their immune systems are still developing. The aims of the ASPIRE project were to:

- understand how energy-efficient building design strategies might affect the indoor environmental quality of schools in the UK and, as a result, pupils' learning performance and health
- provide recommendations for optimum low carbon and healthy school building design under climate change

Department for Education data was analysed to construct a library of school building archetypes that are statistically representative of the UK school building stock to simulate the energy, thermal and indoor air quality performance of each archetype under low carbon building design and operational strategies in the current and future climate. Various scenarios were co-created with a Project Advisory Board, consisting of project partners (Department for Education, Public Health England, Chartered Institution of Building Services Engineers, Architype Ltd and Atelier Ten) and stakeholders from the UK government, public health bodies, the construction industry and school communities.

Key outcomes

- Identified relationships between exposures to indoor air pollutants, temperature and ventilation rates and cognitive performance and health symptoms for a wide range of educational settings.
- Evaluated the impacts of building energy-efficient design and operational strategies, occupancy and climate change scenarios on educational attainment, and health costs at the national level.
- Improved understanding of the performance of low carbon, healthy school buildings
- Informed the development of best practice school design guidance under climate change.

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Yair Schwartz and others (2022), Modelling platform for schools (MPS): The development of an automated one-by-one framework for the generation of dynamic thermal simulation models of schools – Energy and Buildings

Sung Min Hong and others (2022), Characterising the English school stock using a unified national on-site survey and energy database – Building Services Engineering Research and Technology

Yair Schwartz and others (2021), Developing a data-driven school building stock energy and indoor environmental quality modelling method – Energy and Buildings

Health (H)

To be well-adapted to climate change, the population should be healthy under current and future climate scenarios, and the health and social care system should continue to operate during extreme weather events (CCC, 2023).

Overall goal

A healthy population and a resilient health system in current and future climates.

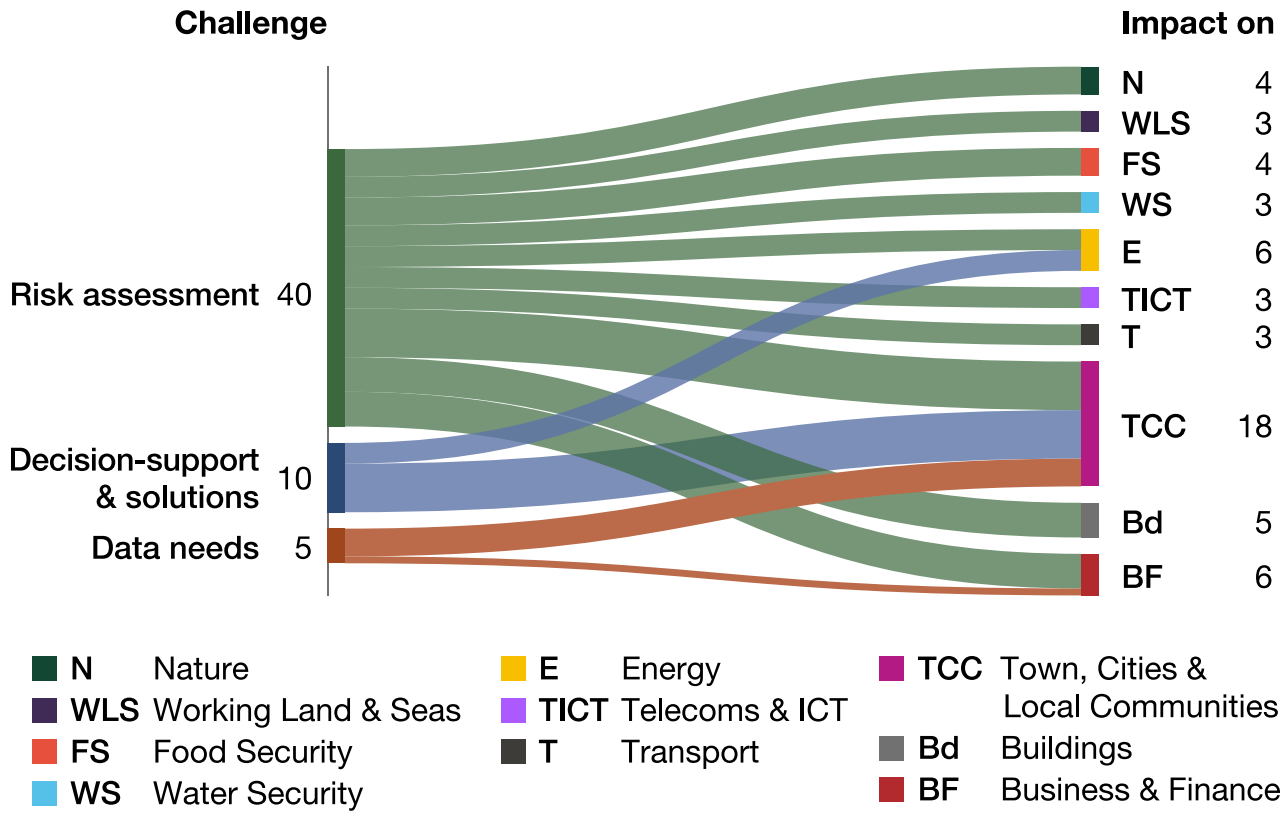
Main outcomes

- Protect population health from the impacts of climate change and utilise potential benefits
- High-quality and accessible healthcare delivery during extreme weather

Key UK government department

Department of Health and Social Care.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Climate impacts on health:** Impacts of climate change on health systems, including social care systems (including on future trends for changes in location of health and social care provision); Health equity under climate change; Climate change or climatic disaster-induced disruptions of critical health infrastructure, or impacts of changes to other sectors (such as transport, food/water and WLS) on health and wellbeing; Risks associated with pests, communicable diseases, natural disasters, and food/water/air quality under climate change; Understanding links between anti-microbial resistance and climate change; Impacts of climate change on chemical hazards and non-communicable diseases and conditions.	All
	Long-term heat exposure: Effects of long-term and multi-day heat exposure, accounting for changes in humidity on productivity and health.	TCC, BF , BI
	Impact of heat and extreme heat on vulnerable populations: Effects of heat and extreme heat on vulnerable populations (e.g. low-income settings, children, pregnant women and ethnic minority groups).	TCC, Bd, BF
	Interactions between heat and air pollution: Interactions between heat and air pollution, and their combined effects on health; Better projections of indoor air quality under future climates; Better understanding of air quality impacts from temperature-dependent emissions (e.g. ammonia, nitric oxide and volatile organic compounds), changes in atmospheric transport patterns, and wildfires.	TCC, Bd, N, FS
	Climate-induced migration: Impact of climate-induced migration on health and health system demand in the UK; Impact of changing burdens of disease globally as a result of climate-induced migration; Impact of climate-induced migration on the position of the UK as a development funder.	TCC

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Safe working temperatures:** Identifying and implementing maximum safe working and classroom learning temperatures in the UK.	All
	Costs: Cost of extreme weather to UK health system in the mid-to-long term, including the cost of inaction with respect to adaptation.	All
	Energy-efficient heat stress mitigation: Energy-efficient ways to mitigate and adapt to heat stress, including passive building designs, and wearable technology and materials.	E, TCC, BI
	Advanced technologies for public health: Best ways of exploiting advanced technologies and artificial intelligence to assist public health workers and emergency planners through early warning systems.	E, TCC, BI
	Healthcare resilience: Building resilience into the health and care system – e.g. via improvement packages for health and social care facilities, education settings and prisons for effective adaptation measures, including targeted heat management and flood protection.	E, TCC, BI
	Public health messaging: Ways to enable people to comply with heat stress advice and to deliver the right public health messaging.	TCC
	Better screening practices: Innovative and efficient screening technologies and practices for better monitoring and forecasting of health risks due to climate change; Best practice for public health workers and emergency planners.	TCC

R&I challenge	R&I needs	With direct implications on
Data needs	**Monitoring overheating, flooding and air quality:** Regular monitoring of overheating, flooding incidences, and air quality levels in health and social care settings, education settings and prisons.	TCC
	Monitoring vectors and infectious diseases: Continued and widened monitoring of vectors and infectious disease prevalence impacted by climate change.	TCC
	Tracking climate-induced mortality and morbidity: Data to track mortality, morbidity and disruption due to climatic impact including but not limited to flooding and heat.	TCC
	Health opportunities from outdoor activities: Data to track the mental and physical health opportunities from being outside; Data on changing opportunities for outdoor activities under climate change.	TCC
	Disruption of health and social care services: Data on the extent to which health and social care services have been and are likely to be disrupted by climatic hazards, such as heatwaves or flooding, including holistic understanding of costs incurred; Real-time data on climate impacts when they occur.	TCC, BF
	Passive cooling and flood protection measures: Indicators for health and social care facilities with passive cooling measures, flood protection measures, heat management plans or effective adaptation plans.	TCC , BI

Business and finance (BF)

Businesses must be able to function effectively in a changed climate. This will be through adapting their organisational practices, supply chains and physical sites, which in turn requires access to adaptation finance. The financial system is a highly connected network of financial institutions – such as insurance companies, stock exchanges and investment banks – that work together to exchange and transfer capital from one place to another. Through the financial system, investors receive capital to fund projects and receive a return on their investments. Financial services are a key element of the UK's national economy. The financial system is exposed to climate impacts directly through loans and investments that have exposure to physical impacts, and indirectly from its interaction with all parts of the economy.

Overall goal

Opportunities realised and a reliable supply of goods and services.

A stable financial system and which enables adequate investment in UK adaptation.

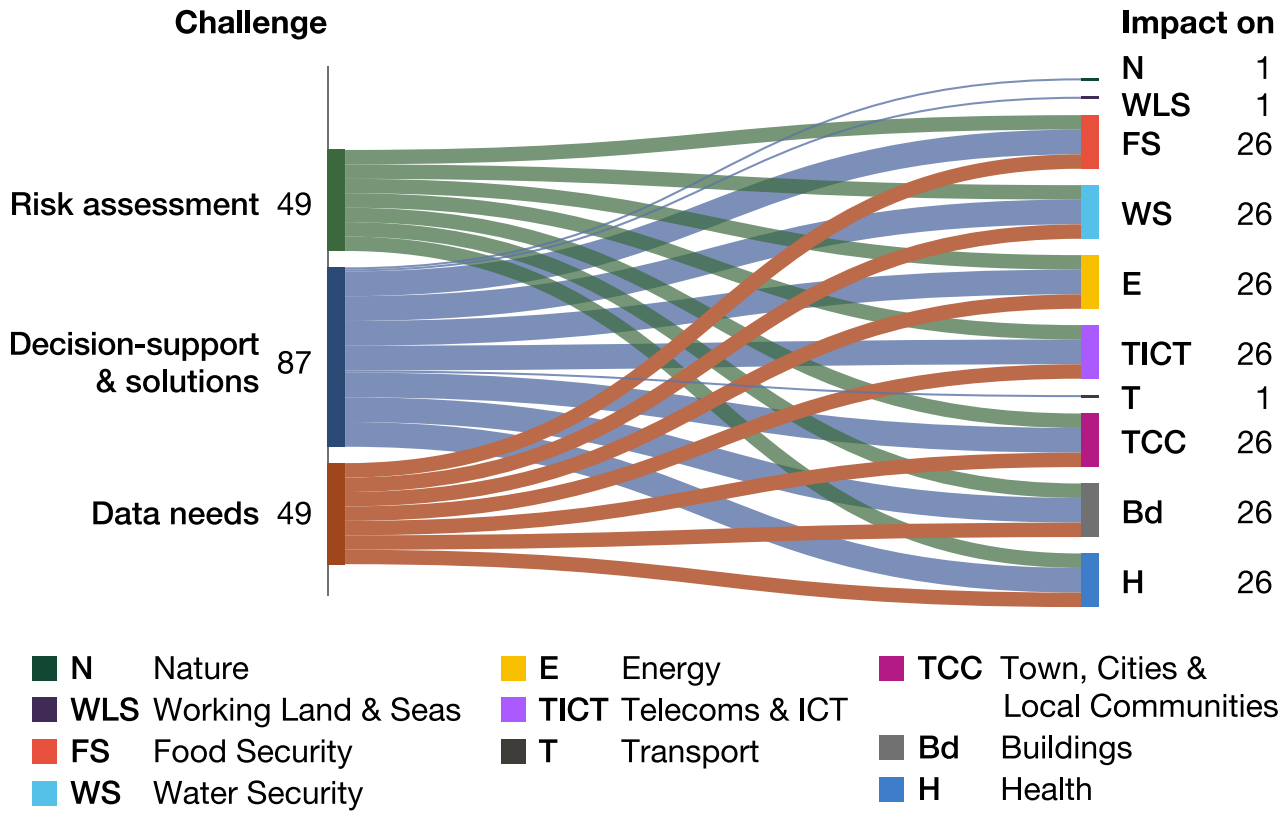
Main outcomes

- Public and private adaptation measures are implemented to minimise risks to business sites
- Businesses have access to insurance and capital, including for adaptation
- Productivity losses due to physical climate risks are minimised
- Supply chain risks are identified and managed
- Risks and actions are disclosed and managed by businesses and financial institutions
- All financial institutions incorporate physical risks into financial decision-making
- UK financial services are a global leader in adaptation
- No viable necessary adaptation project fails for lack of finance
- Risks and actions are disclosed and managed by financial institutions

Key UK government department

HM Treasury.

Systems interactions



R&I challenge	R&I needs	With direct implications on
Risk assessment	**Risk assessment:** Climate-induced and nature-related risks on businesses; Impacts on potential disruption to supply chains, shipping and scarcity of natural resources; Identification of international trade route architecture (e.g. ports and canals) and foreign supply chains into the UK that are most at risk from climate change.	FS, WS, E, TICT, T, TCC, Bd, H
	Workforce and jobs: Understand workforce groups vulnerable to climate disruption, e.g. lower paid workers who have to commute or who work outdoors; Likelihood and amount of job losses in various sectors and locations due to climate change and/or adaptation.	FS, WS, E, TICT, T, TCC, Bd, H
	Reduced employee productivity: Understand productivity losses (current and expected in the future) due to high temperatures across a range of sectors and contexts.	FS, WS, E, TICT, T, TCC, Bd, H
	Flooding risks: Assessment of flooding risks on businesses that incorporate infrastructure failure; Increased number of national climate change scenario-driven future flood risk maps.	FS, WS, E, TICT, T, TCC, Bd, H
	Water scarcity: Water scarcity risk assessment; Interdependencies between high temperature and drought events.	FS, WS, E, TICT, T, TCC, Bd, H
	Disruption to supply chains and distribution networks: Impact of UK supply chain loss due to links with impacted international supply chain components, and ability to identify the source of the disruption; Increased amount of UK-specific evidence to support analysis of risk to supply chains beyond the food system.	FS, WS, E, TICT, T, TCC, Bd, H
	Low likelihood, high impact and interacting risks: Improved understanding of low likelihood, high impact and interacting risks on financial systems.	FS, WS, E, TICT, T, TCC, Bd, H

R&I challenge	R&I needs	With direct implications on
Risk assessment	**Limits to insurability:** Risk thresholds for insurability under climate change.	All
Decision support and solutions	**Business planning and preparedness:** Strategies for businesses to plan for and reduce risks from climate induced disruption, e.g. staff shortages and supply chain disruption; Increased evidence on level of preparedness of businesses for flooding; Sharing information to understand climate risks and opportunities across the sector or geographical area in which a business is based.	FS, WS, E, TICT, T, TCC, Bd, H
	Commercial models: Viable commercial models to incentivise investors to finance businesses that wish to put adaptive measures in place.	FS, WS, E, TICT, T, TCC, Bd, H
	Skills: Identification of new skills that businesses will need to deliver adaptation measures, e.g. risk planning.	FS, WS, E, TICT, T, TCC, Bd, H
	Multi-criteria decision, cost-benefit and cost-effectiveness analysis: Assessment of the costs and benefits of climate stress-testing and adaptation, including cost of inaction.	FS, WS, E, TICT, T, TCC, Bd, H
	Opportunities: Identification of the comparative advantages that the UK or its regions will have in the future under climate change, e.g. being able to grow certain food crops, or tourism in a warmer climate; Scope and scale of opportunities for businesses and markets to positively respond to climate change to drive innovation in future-ready goods and services, business processes and supply chains; Identification of opportunities for businesses and financial services for new adaptation goods and services.	FS, WS, E, TICT, T, TCC, Bd, H
	Standards: Standards for climate risk assessment and preparedness assessment for businesses; Standards for climate risk assessment and preparedness assessment for financial instruments.	FS, WS, E, TICT, T, TCC, Bd, H

R&I challenge	R&I needs	With direct implications on
Decision support and solutions	**Insurance markets:** Ways to design insurance markets in the future and their remit, e.g. coastal flood insurance and fire insurance; Further evidence on physical climate factors being a risk to pricing.	FS, WS, E, TICT, T, TCC, Bd, H
	Financial models: New financial models to unlock finance for smaller organisations who need to deliver a climate adaptation project.	FS, WS, E, TICT, T, TCC, Bd, H
	Private investment: Ways in which businesses leverage private investment for adaptation (case studies, spending to save, wider benefits, learning from mitigation markets, standards, audit and indicators); Alignment of private investment for adaption with that for other objectives such as biodiversity, net zero and active travel.	FS, WS, E, TICT, T, TCC, Bd, H
	Verification methodologies for adaptation plans and actions: Ways to verify and certify adaptation plans, and quantify the effectiveness and return on investment of adaptation actions.	FS, WS, E, TICT, T, TCC, Bd, H

R&I challenge	R&I needs	With direct implications on
Data needs	**General:** More data and monitoring to enable robust risk assessment, tracking of effective actions, data on adaptation intervention costs and benefits, and understanding of interdependencies; Data to build greater evidence to quantify and monetise benefits of adaptation action hence to enable investment; Data on economic costs of past extreme weather events and climate impacts.	FS, WS, E, TICT, T, TCC, Bd, H
	Flooding: Improved reporting and assessment of indirect risks to businesses from flooding.	FS, WS, E, TICT, T, TCC, Bd, H
	Coastal change: Data on risk to businesses from coastal erosion; Data on areas of UK coast most at risk of storm damage and erosion.	FS, WS, E, TICT, T, TCC, Bd, H
	Water scarcity: Improved evidence on sufficiency of adaptation levels; Improved accuracy and timeliness of meter readings to inform management of water use efficiency.	FS, WS, E, TICT, T, TCC, Bd, H
	Case studies: Accessible case studies on costing and financing of adaptation solutions across different sectors and locations.	FS, WS, E, TICT, T, TCC, Bd, H
	Scenario analysis: Further standardisation and clarification on scenario analysis models.	FS, WS, E, TICT, T, TCC, Bd, H
	Corporate assets: Data on the location of corporate assets.	FS, WS, E, TICT, T, TCC, Bd, H
	Financial flows: Robust data collection to monitoring financial flows to adaptation.	FS, WS, E, TICT, T, TCC, Bd, H

Case study

GeoAsset project

The Spatial Finance Initiative's GeoAsset project creates and distributes open asset databases for high impact industries. It is building a digital footprint of the global economy by collecting openly available information on physical assets (such as location, ownership and capacity) and aggregating these in standardised templates. There are currently six GeoAsset sector databases: cement, iron and steel, petrochemicals, paper and pulp, waste management and beef abattoir.

The GeoAsset project uses a combination of manual and machine learning techniques to analyse satellite, geo-spatial and web-based datasets to extract asset-level information in a way that is transparent, repeatable and allows for open publication.

Key outcomes

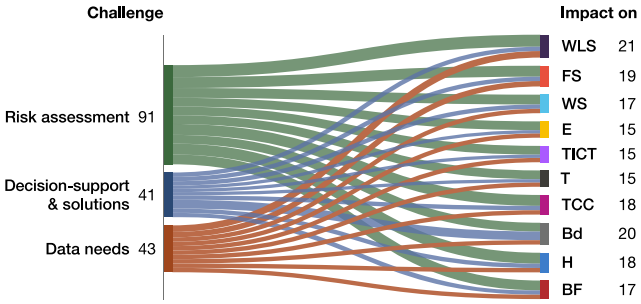
- The project benefits financial institutions as well as businesses, civil society and policymakers by creating a transparent dataset to enable access to geospatial insights to corporate entities and financial assets.
- The project enables assessment of environmental performance and financial or systemic risks by asset managers and owners.
- Banks and financial systems can be stressed-tested by regulators, sufficient capital flow can be ensured by policymakers, and all these stakeholders can be held accountable by civil society organisations.

References

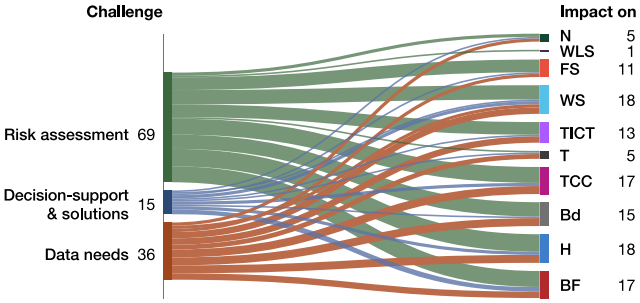
GeoAsset – Spatial Finance Initiative

Graph of all system interactions

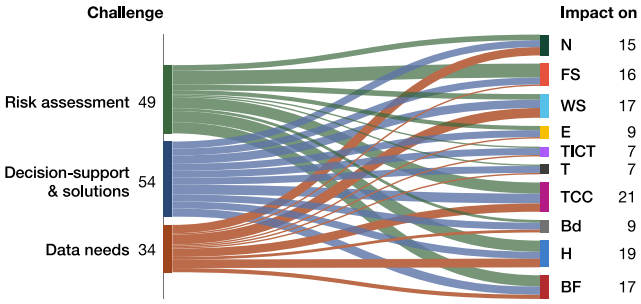
Nature (N)



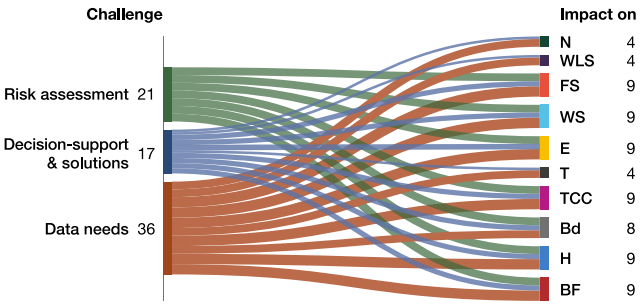
Energy (E)



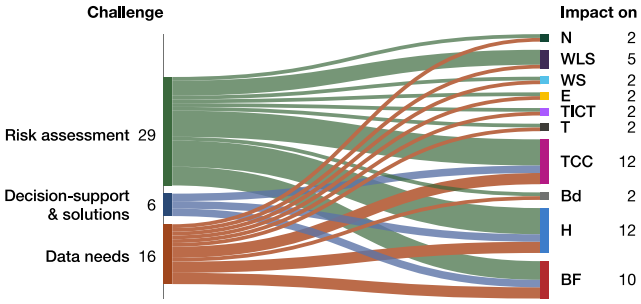
Working land and seas (WLS)



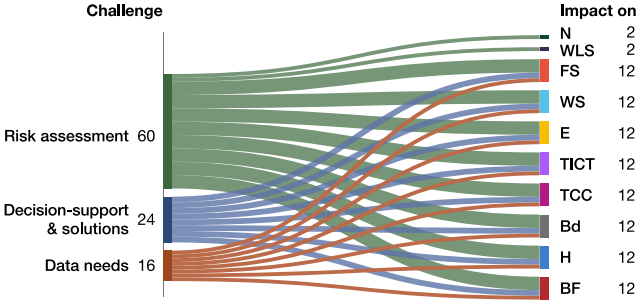
Telecoms and ICT (TICT)



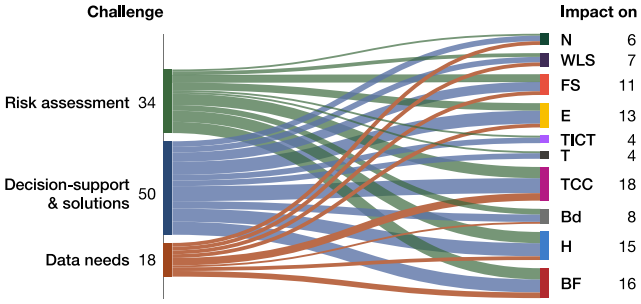
Food security (FS)



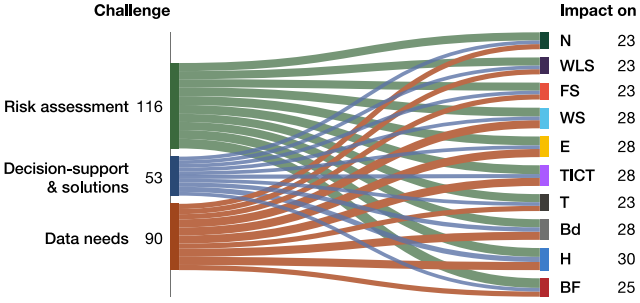
Transport (Tr)



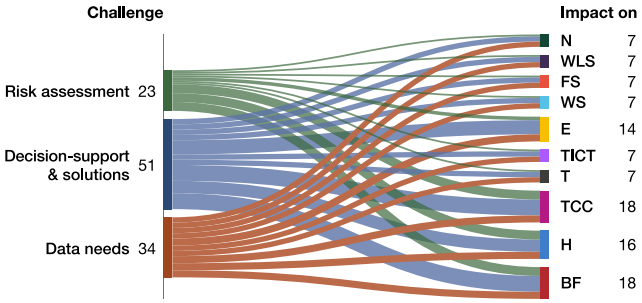
Water supply (WS)



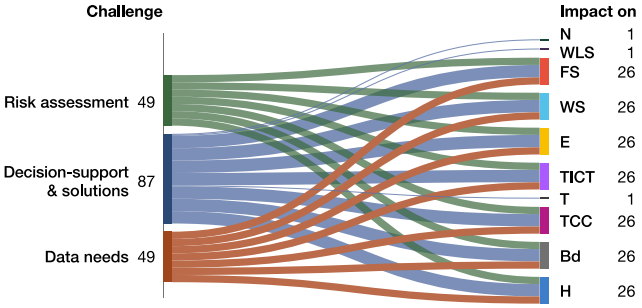
Towns and cities and community preparedness/response (TCC)



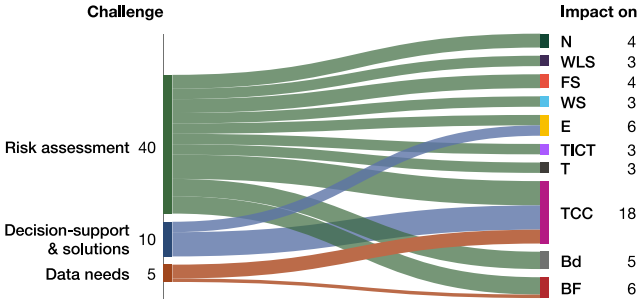
Buildings (Bd)



Business and finance (BF)



Health (H)



Using the framework

This Framework establishes a foundation for climate adaptation R&I planning within UK government and aims to provide a strategic tool to guide the R&I agendas within business and research communities.

We do not expect UK government programmes to cover all the R&I challenges identified. For publicly funded R&I, the UK government will publish a Delivery Plan outlining the programmes being prioritised within the scope of this Framework.

The Climate Adaptation Research and Innovation Board (CARIB), co-chaired by the Government Chief Scientific Adviser and the Department for Environment, Food and Rural Affairs' Chief Scientific Adviser, will serve as the primary forum for discussing prioritisation and monitoring progress. CARIB will play a central role in ensuring accountability and alignment with the broader objectives of this Framework.

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