UK CLIMATE RISK

UK Climate Risk Independent Assessment (CCRA3)

Technical Report
Chapter 2: Method

Lead Authors: Paul Watkiss, Richard Betts

Contributing Authors: Fai Fung, Paula Harrison, Alistair Hunt, Jason Lowe, Sari Kovats

Additional Contributors: Kathryn Brown, David Style, Matthew Bell, Rachel Warren

This chapter should be cited as:

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

Contents

Executive Summary 2

2.1. Introduction 5

2.1.1 Context and Objectives 5

2.1.2 Key Terms 8

2.2. Developments in the CCRA3 Methodology 11

2.2.1 Evaluation and Lessons from CCRA2 11

2.2.2 Lessons from other national climate risk assessments and academic literature 13

2.2.3 New Climate Science and UKCP18 15

2.2.4 New climate science: low-likelihood, high-impact scenarios and events 17

2.2.5 Additional Commissioned Research 18

2.3 The CCRA3 Approach: Using Risk Assessment to Inform Adaptation 18

2.3.1 The Framework for CCRA3 19

2.3.2 New focus areas in CCRA3 22

2.4. CCRA3 Process 25

2.4.1 Overview of the CCRA3 Process 25

2.4.2 Overview of the CCRA3 Evidence Process 26

2.5. CCRA3 Method Overview 27

2.5.1 Step 1: Assessment of risks and opportunities 29

2.5.2 Step 2: Analysis of Government and non-Government adaptation action 30

2.5.3 Step 3: Analysis of the need and urgency for additional adaptation 30

2.6 Detailed Description of the Method 31

2.6.1 Step 1. Assessment of Current and Future Risks and Opportunities 32

2.6.2 Task 1b Assess Future Risks and Opportunities 40

2.6.3 Task 1c Assessing Possible Thresholds and Lock-in 59

2.6.4 Task 1d Investigate Cross-Cutting and Interdependencies 59

2.7. Step 2 Assess Current and Planned Government and non-Governmental Adaptation 60

2.7.1 Task 2a Analysis of Current, Planned Government Adaptation 60

2.7.2 Task 2b Assess Non-Governmental Adaptation 65

2.7.3 Task 2c Analysis of Need for Further Adaptation and Barriers to Adaptation 67

2.8. Step 3 Assess the Benefits of Additional Adaptation Action 70

2.8.1 Task 3a Analysis of Possible Early Adaptation Options 71

2.8.2 Task 3b Costs and benefits of further action (Indicative) 73

2.8.3 Task 3c overall urgency score 74

2.8.4 Task 3d Learning and Evaluation – linking to CCRA4 77

2.9. References 78

Annex 1: Risk/Opportunity template (Round 1) 90

Executive Summary

This chapter sets out the methodology for the Third UK CCRA Technical Report (CCRA3). The Technical Report informs the CCRA3 Advice Report, which is written by the Climate Change Committee, and these two documents together are the core components of the CCRA3 Independent Assessment.

In line with the Climate Change Act 2008, the objective of the CCRA is to consider current and future climate-related risks and opportunities to the UK, and the extent to which current or planned policies address these. To help guide this, the CCRA3 Technical Report uses the following key question:

Based on the latest understanding of current and future climate risks and opportunities, as well as current and planned adaptation, what should the priorities be for the next National Adaptation Programme and adaptation programmes of the devolved administrations?

The aim of the CCRA3 Technical Report is to inform planned adaptation from government, agencies, regulators, etc., including both direct intervention and/or to create the enabling environment to help others adapt (e.g. the private sector, households). It seeks to inform the adaptation programmes of the individual countries of the UK (England, Northern Ireland, Scotland and Wales) and this determines the aggregation and reporting level. The priority for the Technical Report is, therefore, to identify where action is needed in the next five years to manage climate change risks or opportunities that may arise over the short, medium and longer-term.

As with CCRA2, the CCRA3 Technical Report uses a synthesis approach. It draws on a large body of peer-reviewed scientific literature and other quality-assured literature on climate change, risks and adaptation, complemented by new research studies in key areas. This requires a harmonised and consistent approach to consider and collate evidence from different sectors and source material: this chapter sets out this approach.

The method developed in CCRA3 builds on requirements set out by Defra and the devolved administrations and an initial method statement developed by the Climate Change Committee (CCC). This was developed further by the CCRA3 Evidence method team authors. It uses the same broad approach as CCRA2, but with some evolution to reflect lessons from CCRA2 and the second round of national adaptation programmes, as well as developments in the climate risk assessment and adaptation literature over the past five years.

The CCRA3 Evidence method is based on the prioritisation of risks and opportunities using an analysis of urgency. This seeks to identify where action is most urgently needed over the next five-year period using three questions:

1. What is the current and future level of risk/opportunity?
2. Is the risk/opportunity being managed, based on government commitments and other adaptation actions?
3. Are there benefits to further action in the next five years, over and above that already planned?

For the CCRA3 Technical Report, we have aligned the methodology to the three questions above, thus there are three steps:

- Step 1) Analysis of the magnitude of current and future risks and opportunities;
- Step 2) Analysis of the benefits of current and planned adaptation;
- Step 3) Analysis of overall urgency and the benefits of additional adaptation.

For the third of these steps, the CCRA3 uses a complementary framework to help to identify adaptation priorities, as well as what type of additional action could be useful. This approach builds on a well-established literature that was also included in CCRA2. It aims to identify three types of early adaptation priorities that can help address risks and opportunities within the next five-years:

- To address any current adaptation gap by implementing ‘no-regret’ or ‘low-regret’ actions that reduce risks associated with current climate variability, as well as building future climate resilience.
- To intervene early to ensure that adaptation is considered in near-term decisions that have long lifetimes and therefore reduce the risk of ‘lock-in’, such as for major infrastructure or land-use developments.
- To fast-track early adaptive management activities, especially for decisions that have long lead times or involve major future change. This can enhance learning and allows the use of evidence in forthcoming future decisions.

These three priorities are not mutually exclusive, and a combination of all three is often needed as part of a portfolio at the national level.

At the end of this analysis, based on the evidence, each risk or opportunity is ranked into one of four urgency scores: i) “more action needed”; ii) “further investigation”; iii) “sustain current action”; or iv) “watching brief”.

A number of updated or new elements have been included in the CCRA3 Evidence method. These include the following:

- A new set of UK Climate Projections were published in 2018, 2019 and 2020, called UKCP18. However, it takes several years for the risk and impact literature to use these projections in published studies, and much of CCRA3 is therefore based on literature that uses the previous set of projections, UKCP09. CCRA3 has therefore assessed what has changed from UKCP09 to UKCP18, and has produced guidance on how to interpret exiting literature using the new UKCP18 results (see also Chapter 1 (Slingo, 2021) and section 2.2 of this chapter).

- There is a greater focus in CCRA3 on looking at changes in climate variability (volatility) and new methods for considering unprecedented events that could occur in the current climate. CCRA3 has also considered the potential risks of low-likelihood, high-impact outcomes, which includes High++ scenarios and major discontinuities (globally or regionally) (see Chapter 1 (Slingo, 2021) and section 2.2 of this chapter).

- CCRA3 has considered interacting risks and interdependencies for each risk / opportunity, rather than as part of a cross-cutting chapter (as in CCRA2). There is also consideration of the inequalities associated with risks and opportunities.

- There is a greater focus on considering the type of further adaptation that could be possible, and on the benefits of additional action. A lesson from CCRA2 is that evidence to inform adaptation needs to be collected and assessed earlier in the analysis. CCRA3 therefore has a greater emphasis on the risks of lock-in and thresholds, as part of step 1 (see section 2.3). There is also more emphasis on adaptive management, encouraging the consideration of evolving risks over time, including a more explicit linkage to CCRA4 (see section 2.3).
- There has been more consideration of the economic costs (or benefits) of individual risks and opportunities (reported in a separate monetary valuation analysis) and an analysis of the indicative costs and benefits of further adaptation. n the indicative costs and benefits of further adaptation.
- Finally, during the period that the analysis for the CCRA3 Technical Report was undertaken, the UK, Scottish and Welsh Governments adopted Net Zero greenhouse gas emissions targets into law. The measures needed to achieve Net Zero may be sensitive to climate hazards, particularly in the buildings and land use sectors. To investigate this, CCRA3 has considered possible relevant climate risks or opportunities for different types of mitigation measures, and also considered synergies and trade-offs between mitigation and adaptation actions (see section 2.5).

2.1. Introduction

2.1.1 Context and Objectives

The UK's Climate Change Risk Assessment (CCRA) aims to analyse the risks and opportunities from climate change to the UK, with the goal of informing the priorities for the UK Government's National Adaptation Programme (NAP) as well as the adaptation programmes of the devolved administrations (DAs).

The UK CCRA is undertaken on a five-year rolling cycle and is now on its third cycle. This chapter sets out the approach used for the **Third CCRA Technical Report**, to be published in 2021. The objective of the Technical Report is to review and analyse the evidence on priority risks and opportunities for England, Northern Ireland, Scotland and Wales and by doing so, to help provide information of relevance for the next round of Government-led adaptation programmes. The Technical Report informs the CCRA3 Advice Report, which is written by the Climate Change Committee, and these two documents are core components of the CCRA3 Independent Assessment. This Assessment informs the CCRA3 Government Report (due for publication in 2022) and the third NAP and the third adaptation programmes of the devolved administrations (DAs), due to be published from 2023. The information in the CCRA3 Technical Report is, however, also likely to be of interest to a wider audience.

For practical purposes, the CCRA3 Technical Report sets out to address the following key 'exam' question:

Based on the latest understanding of current and future climate risks and opportunities, as well as current and planned adaptation, what should the priorities be for the next National Adaptation Programme and adaptation programmes of the devolved administrations?

These adaptation programmes may include direct public sector action (by government, agencies, regulators, etc.), but also interventions that create the enabling environment for others to adapt, i.e. for utilities, the private sector and households. To provide this information, the CCRA focuses on the urgency of risks and opportunities. Urgency is defined as a measure of the level of action that is needed in the next five years to reduce a risk or realise an opportunity from climate change, noting that these near-term actions may address risks or opportunities in the short, medium or long-term. To ensure that the information provided is relevant for the respective adaptation programmes, the assessment is undertaken for each individual country (England, Northern Ireland, Scotland and Wales), rather than for the UK.

In addition, unless it conflicts with the primary aim, the CCRA3 Technical Report also has a set of secondary goals, which are:

- To inform investment and policy decisions where there are material climate risks for other organisations or actors, e.g. for the private sector (including small to medium sized businesses) or households. This has links to recent initiatives on financial climate risk disclosure and reporting (TCFD, 2017; NGFS, 2019) and also the UK Green Finance Strategy (HMG, 2019);

- To show progress from CCRA1 (HRW, 2012a) and from CCRA2 (CCC, 2016) on how our understanding of the level of current and future risk, as well as the management of these risks by Government, has changed; and
- To act as a stepping-stone to CCRA4 in terms of the approach, framing and information needs.

The CCRA3 Technical Report draws on a well-informed practitioner community and a rich legacy of previous climate risk assessments. It updates the previous CCRA2 by drawing on evidence produced in the intervening five years. It also includes an update to the methodology used for the assessment, taking advantage of the fact that the five-year UK CCRA cycle allows for a process of evaluation and learning. This has led to an evolution in the method used for successive assessments, i.e. from CCRA1 to CCRA2, and CCRA2 to CCRA3.

In the first and second CCRAs, the assessment of risks was presented in an Evidence Report. In CCRA3, the Independent Assessment consists of a substantial set of reports and other document including this Technical Report and the CCC's Advice Report. As with the CCRA2 Evidence Report, the CCRA3 Technical Report is based on a synthesis exercise, rather than a new national quantified assessment. It draws on the large body of peer-reviewed scientific literature and grey literature on climate change, risks and adaptation in the UK, complemented with new CCC commissioned research in key areas. It uses this evidence alongside expert judgement in assessing risks and opportunities, building on expertise in the international context (e.g. Mach et al., 2017) as well as previous CCRAs. However, this synthesis approach means that the CCRA3 draws on literature that has used different methods, scenarios and assumptions.

The key aim of the CCRA3 method chapter is to set out a harmonised approach to: gather evidence from the wide range of source material; to analyse this evidence consistently; and to present it in ways that make it easier for the UK Government and the devolved administrations to respond. This chapter sets out this approach.

The method developed for the CCRA3 Technical Report responded to requirements set out (in a document) by Defra and the devolved administrations (produced in 2018).

It was further developed by the CCRA3 Evidence method team authors, working in partnership with the Climate Change Committee, who led the overall programme to produce the Independent Assessment, and with inputs and comments from the peer review process. The method development drew on lessons from the second CCRA Evidence Report (CCRA2), published in 2016 (CCC, 2016), the latest climate science including the new UK Climate Projections (UKCP18), and the updated approaches to climate change risk and adaptation assessment presented in the IPCC Fifth Assessment Report (IPCC, 2014a), the Special Reports on Global Warming of 1.5°C (IPCC, 2018a) and on the Ocean and Cryosphere in a Changing Climate (IPCC, 2019). A summary of the methodological development of the three CCRAs over time is presented in Table 2.1 below, followed by discussion of a number of key updates of relevance in CCRA3.

Table 2.1 Evolution of the CCRA method over time.

	CCRA1	CCRA2	CCRA3
Objective and aims	Quantification of risks / opportunities (impacts)	Assessment of risks / opportunities to inform adaptation	Assessment of risks / opportunities to inform adaptation and initial steps towards adaptive management
Approach	New analysis of all risks using standardised approach	Synthesis, supported by targeted new research	Synthesis, supported by targeted new research and inclusion of new climate projections
Direct funding available*	Approximately £3.5 million	Approximately £0.7 million	Approximately £1.8 million
Method to assess risk / opportunities	Quantitative or semi-quantitative impact assessment	3 step urgency framework	3 step urgency framework, with additional method development
Identification of risks / opportunities	Very wide initial review, with focus down on 100 or so most important	Initial list provided by Government and DAs, reviewed and extended based on evidence to ~55 risks and opportunities	Initial list provided by Government and DAs, reviewed and extended based on evidence to ~65 risks and opportunities
UK climate Projections	UKCIP02 and UKCP09	UKCP09	UKCP09, UKCP18, EuroCORDEX
Global climate projections	N/A	CMIP5	CMIP5, CMIP6, HELIX, UKCP18 global
Economic analysis	Indicative valuation of risks and opportunities	Not included	Indicative valuation of risks and opportunities, plus initial consideration of costs and benefits of further adaptation

* It is highlighted that all three CCRAs, but especially the synthesis assessments undertaken in CCRA2 and CCRA3, benefited from considerable levels of in-kind support. This included the time contribution of the CCC secretariat, as well as the inputs from contributor authors which were unpaid. The total costs of undertaking CCRA2 and CCRA3 is therefore much higher than shown in the table.

Climate Science. Since CCRA2, there has been the publication of new climate projections for the UK (Lowe et al., 2018; Murphy et al., 2018; Palmer et al., 2018). The CCRA3 Technical Report makes use of UKCP18 as far as possible, and bespoke analysis was carried out to help teams re-assess existing published evidence on future impacts (which is often based on UKCP09) in light of the new projections (see Chapter 1: Slingo, 2021). However, the Technical Report also draws on scenarios and studies that are not based on UKCP18 in order to ensure evidence is drawn from the widest possible base of research.

Identification of risks and opportunities. There are a very large number of potential risks and opportunities from climate change in the UK, indeed, the CCRA1 Evidence Report (HRW, 2012a) identified almost 1,000 of these following a series of stakeholder workshops to come up with a 'long list'. This was then reduced down to the most important 100 or so based on a set of evaluation criteria. The approach adopted in CCRA3 is the same as the second CCRA (CCC, 2016) and focuses on the most important risks and opportunities as identified by the UK Government and devolved administrations, with some additions from the Technical Report authors and inputs from stakeholder workshops. This approach is therefore selective (rather than comprehensive). Although driven by the end user, this approach to risk selection runs a risk that some risks or opportunities (including unknowns) are poorly addressed, though CCRA3 has paid greater attention to the consideration of low-likelihood, high impact scenarios and events than previous CCRAs (see later section).

Consideration of Adaptation. The role of the CCRA3 Technical Report – as part of the analysis of urgency - is to assess whether current and planned adaptation is managing risks and opportunities, and what adaptation gaps might be present. For the CCRA, an adaptation gap is considered to exist if risks (or opportunities) are not being managed (see section 2.7). This provides a clearer sense of where action is most urgently needed. Following a specific request from Government, a greater emphasis is given in CCRA3 to identifying where adaptation action is likely to be most 'urgent' between 2022 and 2027. This includes an indicative analysis of what form this additional adaptation could take, and possible costs and benefits, while noting it is not the role of the CCRA3 Technical Report to identify adaptation policies or make recommendations.

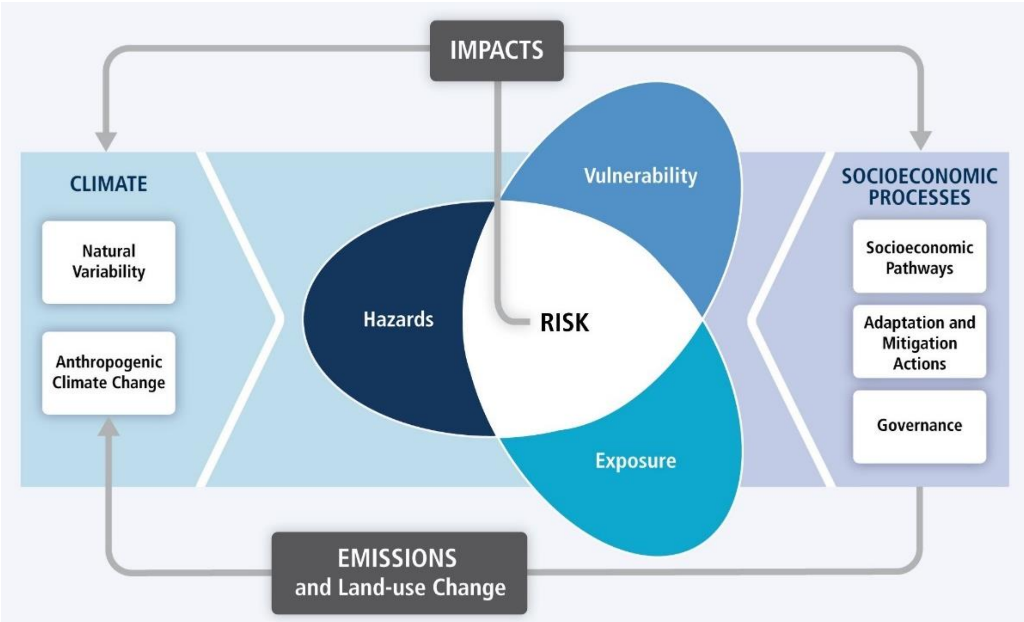
Net Zero. During the time period that the CCRA3 was being undertaken, the UK Government adopted a Net Zero greenhouse gas emissions target, as an amendment in the Climate Change Act. The Scottish Government committed to a target of Net Zero emissions of all greenhouse gases by 2045 and the Welsh Government has announced a 95% reduction in greenhouse gas emissions by 2050 with an ambition to reach Net Zero. This has important implications for future socio-economic scenarios and mitigation-adaptation linkages. To respond to this, an additional analysis was included in the second round of the CCRA3 evidence analysis. This undertook an initial analysis on the possible influence of climate risks on Net Zero measures, and considered mitigation-adaptation linkages.

2.1.2 Key Terms

In the context of the CCRA3 Technical Report, 'risks' are defined in line with the climate change literature (IPCC, 2014a), i.e. the potential for adverse consequences of climate-related hazards, based on their likelihood of occurrence, and taking account of exposure and vulnerability. In CCRA3, the term 'risk' is used to identify negative consequences from climate change, and the term 'opportunity' to identify positive consequences. A full glossary has been developed for CCRA3 and a number of the key terms are presented in Box 2.1. This draws primarily on the IPCC 5th Assessment Report (AR5) Core Concepts (IPCC, 2014a), the IPCC Glossary (IPCC, 2014b) and the IPCC Special Report on Global Warming of 1.5 °C (SR1.5) (IPCC, 2018b), but with additions on the new elements introduced in CCRA3. It has been reviewed and agreed by the CCRA3 technical team, peer reviewers and Government stakeholders.

Box 2.1 Key concepts and terms used in CCRA3.

The main definitions in CCRA3 draw on the IPCC 5th Assessment Report (IPCC, 2014b) and the IPCC core concepts (IPCC, 2014a) and key terms are summarised below.



Box 2.1 Figure 1. Core Concepts of the IPCC 5th Assessment Report WG II. Reproduced from IPCC, 2014a.

Risk - The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence. Source IPCC SR1.5. Note that in CCRA3, the term risk is used for negative consequences (i.e. threats).

Opportunity - The potential for a beneficial consequence, as a result of a changing climate (the propensity to be beneficially affected). Source: CCRA3 Method Chapter Authors.

Exposure - The presence (of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets) in places and settings that could be adversely affected. IPCC, AR5.

Vulnerability - The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Source IPCC, AR5.

Hazard - The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. In the IPCC, hazard refers to climate-related physical events or trends. Source IPCC AR5.

Impacts - Effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health status, ecosystems, economic, social, and cultural assets, services (including environmental), and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. Source IPCC AR5.

Adaptation - The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. Source IPCC, AR5. This includes: Incremental adaptation - Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale. Transformational adaptation - Adaptation that changes the fundamental attributes of a system in response to climate and its effects. Source IPCC AR5.

Autonomous adaptation - IPCC AR5 defined this as adaptation in response to experienced climate and its effects, without planning explicitly or consciously focused on addressing climate change (spontaneous adaptation). However, CCRA3 does not use the term autonomous adaptation. Instead, it considers two elements: reactive adaptation, i.e. a response to the changing climate experienced rather than a pro-active planned approach, as well as non-governmental planned adaptation (i.e. anticipatory adaption undertaken by other organisations, e.g. private sector).

Resilience - IPCC AR5 defines as: the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation. However, the term resilience is now used very widely, in different ways, and as a consequence in CCRA3 we try and avoid the term due to the lack of a commonly applied definition. The exception is where it is used in existing Government policies, or in plans or actions as stated by the private sector or other groups, noting in such cases the specific definition should be included.

Adaptation pathway - A generic term that involves the analysis of adaptation options over time to changing risk levels. This term has been applied in a number of different ways, which include: i): Adaptation roadmaps or pathway frameworks, which consider portfolios of adaptation that change over time, to allow analysis of the timing and sequencing of adaptation and identify priorities; ii) Adaptive management, which is an iterative cycle of monitoring, research, evaluation and learning, i.e. a process, that is used to improve future management strategies (also called iterative risk management); iii) Dynamic adaptation route-maps, which focus on decision making under uncertainty and identify adaptation tipping points (or turning points), the point at which a particular action is no longer adequate for meeting the plan's objectives, that act as triggers for a change in adaptation. Source: CCRA3 Method Chapter Authors.

Socioeconomic scenario - A scenario that describes a possible future in terms of population, gross domestic product, and other socioeconomic factors relevant to understanding the implications of climate change. Source, IPCC AR5.

Lock-in - Early actions or decisions that involve long lifetimes or path dependency, which will potentially increase future risk or vulnerability and that are difficult or costly to reverse later (irreversibility). This can be from a 'business-as-usual' action or decision, from a lack of an action or decision, or from a maladaptive action or decision. Source: CCRA3 Method Chapter Authors.

2.2. Developments in the CCRA3 Methodology

The UK Climate Change Act (2008) set out the requirement to complete a Climate Change Risk Assessment (CCRA) every five years, followed by a National Adaptation Programme. This repeat cycle provides the opportunity to review and learn, and thus iteratively improve each CCRA (and subsequent NAP). In line with this, a number of methodological updates have been included in this CCRA Technical Report. These improvements have drawn on the lessons from CCRA2, as well as changing practices on risks and adaptation assessment from the literature. Alongside this, there was the publication of UKCP18 and a new set of CCC commissioned research was published. These developments are set out in this section.

2.2.1 Evaluation and Lessons from CCRA2

Following the first CCRA, a number of formal evaluations of the Evidence Report were undertaken (Wilby, 2012; HRW, 2012b; Watkiss and Hunt 2012). These provided recommendations that were used in the methodology update and subsequent implementation of CCRA2 (see Table 2.1). There were also several academic reviews of CCRA1 (Tangney, 2017; Tangney and Howes, 2016).

There was not a formal evaluation of the CCRA2 Evidence Report. However, the CCC produced a lessons report, based on feedback from its Adaptation Committee, as well as Evidence Report authors and the Customer Group of the CCRA. This concluded that distilling the evidence into urgency scores was an effective way to communicate the results in a meaningful way for Government. It also reported that the governance arrangements worked well, i.e. the use of an IPCC-like synthesis approach, with lead contributors and a larger group of contributing authors, overseen by the CCC's Adaptation Committee, acting to coordinate the whole project with independence from Defra. The approach, combined with a two-stage peer and stakeholder review process, delivered an Evidence report that was authoritative and usable. However, the lessons report identified that the success of the project relied heavily on goodwill (given that most authors were not paid), and that the length of the process created challenges. It was also difficult to differentiate risks by scenario (i.e. between the 2°C and 4°C global temperature increase by 2100, relative to pre-industrial), due to the evidence available and the resource constraints. There was also insufficient information on common socio-economic scenarios for the UK. The synthesis approach also made it difficult to assess the magnitude of risks with little evidence or inconsistent assumptions from different evidence sources. There was considered to be insufficient cross-sectoral analysis in the report. Finally, some chapters struggled to get buy-in or material from Government Departments, indicating a need for an improved Government review process. There has also been some academic literature that has compared and evaluated CCRA1 and CCRA2 and made suggestions on future risk assessments (e.g. Howarth et al., 2018), particularly on some aspects of method, operationalisation and better communication.

The CCC consulted with Government (the key users of the Evidence Report), to get feedback on improving the CCRA method. This led to a CCRA3 Requirement Document, produced by Defra and the devolved administrations, and also represented the views of other government departments as fed in using a consultation process. This included the following key requests for CCRA3:

- To inform the adaptation plans of the UK Government and the devolved administrations, and to help this, make the outputs and key messages more accessible (e.g. greater use of infographics, guidance on entry points for outputs, shorter, crisper and less technical summary reports);
- To use a more systems-based approach than CCRA2 to take better account of interdependencies and interactions;
- To take account of new evidence on climate projections (namely UKCP18, most of which was published in November 2018, with a further set of high-resolution projections published in September 2019);
- To consider different future global warming scenarios, including those associated with a 2°C and a 4°C increase in global mean temperature by the end of the century, relative to pre-industrial.
- To use the urgency framework developed for CCRA2, refining it to identify a smaller number of specific priorities for the next five-year period;
- To avoid recommendations about the risk appetite for addressing risks, or on how to adapt, since those are policy or operational decisions. However, where appropriate, and for consistency with CCRA2, to include consideration of some adaptation scenarios that go beyond planned adaptation.
- There was also a subsequent request, as part of discussions with Defra and the DAs, to assess risks and opportunities in monetary terms, and to consider the indicative costs and benefits of adaptation, i.e. to include more economic analysis than in CCRA2.

As part of the CCRA3 methodology development, a rapid evaluation of CCRA2 was also undertaken by the methodology chapter team. This found that the smaller number of risks in CCRA2 (56) allowed a more focused assessment. However, while the use of literature review and synthesis did provide a good evidence base, there was not the same quantitative information of magnitude as generated in CCRA1, and less direct comparability between risks, although this was not considered to be detrimental to the final Evidence Report. The use of the urgency framework was considered a particularly useful addition, as this focused the evidence towards a policy-first approach (Ranger et al., 2010) that informs adaptation – as compared to a science-first approach that focuses on the climate projections and impacts (as in CCRA1). The success of CCRA2 was particularly noteworthy given the much lower resources available than for CCRA1.

Alongside this there was also some analysis of the uptake and use of the CCRA2 Evidence Report in policy, i.e. in the subsequent five-year adaptation policy period and the 2nd National Adaptation Programme for England (Defra, 2018), as well as the Adaptation Programmes of the DAs. The CCC Adaptation Progress Report (CCC, 2019a), and supporting research (Watkiss et al., 2019) found that the coverage of the risks and opportunities from the CCRA2 Evidence Report in the 2nd NAP (Defra, 2018) was partial. A similar finding (Watkiss et al., 2019) was found for the use of CCRA2 Evidence material in the UK Government 25 Year Environment Plan (25 YEP) (HMG, 2018), which set out the long-term strategy for the environment, including climate change. For the latter, the analysis identified that there was not a systemic analysis to integrate climate risks across the 25YEP objectives and goals (i.e. a climate adaptation mainstreaming exercise).

CCRA2 undertook a very high-level assessment of the benefits of further action (step 3 of the method), consistent with the resources available. The reviews above identified that in many cases, this step identified future research priorities. A greater focus on potential interventions, rather than research gaps, was therefore identified to offer more relevant information for the development of planned adaptation by the Government.

Finally, as noted above, after CCRA1 a number of formal evaluations were undertaken. This process step was not repeated in the same depth after CCRA2, reducing the opportunity for learning. A stronger component of evaluation and learning was therefore identified, to be undertaken after the publication of CCRA3.

2.2.2 Lessons from other national climate risk assessments and academic literature

The UK is not the only country undertaking climate risk assessments. Most European countries have undertaken these types of climate risk assessments and have published national adaptation plans, and globally, many countries are undertaking similar exercises as part of the UNFCCC National Adaptation Plan process. These other assessments provide potentially valuable lessons, and a rapid review of other national risk assessments was undertaken to help inform CCRA3. The review concentrated on those countries that have already undertaken multiple assessments (and thus include learning cycles). Some of the key findings are summarised in Box 2.2. The lessons from this review were used to update the CCRA3 method, so as to reflect current good practice (see section 2.3).

There are also other climate change risk assessments at different scales emerging in the UK, such as the recent climate risk and opportunity assessment for Glasgow City Region (CRC, 2019) and the analysis of the Climate Risk Assessment by Kent County Council on behalf of the Kent Climate Change Network. This highlights that national level assessments can cascade down to local risk assessment, either using similar approaches or assessing what the national level implications mean for the local area.

Box 2.2 Review of other Climate Change Risk Assessments.

A number of other national climate change risk assessments were rapidly reviewed. The focus was to identify additional methodological aspects as compared to CCRA2, and look for lessons on application in national risk assessment. Some key insights are highlighted below that were considered particularly relevant.

The US 4th National Climate Assessment (USGCRP, 2018) is a mandated risk assessment, which is delivered every four years, with the requirement to analyse the effects of global climate change (on the USA). The assessment is an extremely comprehensive analysis, and has benefited from several successive assessment cycles. It provides some useful lessons on how to raise interest in climate risks in a challenging climate policy landscape. Methodologically, it has many aspects that are similar to CCRA, but the most recent analysis also refined the goal to focus on key messages using a series of questions:

- What do we value? What is at risk?
- What outcomes do we wish to avoid with respect to these valued things?
- What do we expect to happen in the absence of adaptive action and/or mitigation?
- How bad could things plausibly get?
- Are there important thresholds or tipping points in the unique context of a given region, sector, and so on?

The aim was to address the overarching question of 'what keeps you up at night?' There was also a stronger focus on:

- Impacts and losses on the economy;
- Extreme impacts (Impacts from changes in extreme statistics of key climate variables) that are less likely but have severe consequences;
- Communicating cascading effects among and within complex systems;
- Quantification of risks that could be avoided by taking action.

The Netherlands has been one of the leaders in climate risk and adaptation planning globally. The most recent National Climate Adaptation Strategy 2016 (NAS, 2016), while it has different objectives to the UK CCRA, does include a risk assessment and this uses four diagrams ('Hotter', 'Wetter', 'Drier' and 'Rising Sea Level') to visualize the effects of climate change within nine sectors: water and spatial management; nature; agriculture, horticulture and fisheries; health and welfare; recreation and tourism; infrastructure (road, rail, water and aviation); energy; IT and telecommunications; public safety and security. From this it sets out six climate effects which call for immediate action to be identified. The diagrams provide a useful way of trying to communicate climate information and have been reviewed alongside other international examples to help design the CCRA3 summary products.

There is also a literature on climate change risk assessment associated with the large flows of finance being spent internationally on adaptation, which provides valuable new insights. In 2017/18, global public finance flows for adaptation were estimated at US$30 billion (CPI 2019). A very large proportion of this ($7.4 billion: MDBs, 2017) was financed by the large multi-lateral development banks (MDBs) and International Financial Institutions (IFIs) including those in Europe. Of high relevance, these organisations have implemented climate risk management systems (CRMs) as part of their due diligence processes, and they undertake routine climate change risk assessment of investments, especially for infrastructure (MDBs, 2017). These assess the level of climate risk during the project appraisal cycle, and if needed, include adaptation (resilience) measures. They provide an existing and applied evidence base on processes and implementation practice for climate risk analysis of major investments, as well as lessons on improving risk assessments over time (ADB, 2020) that have relevance for national assessments.

The academic literature on climate risk assessment and adaptation has also developed considerably since the last CCRA. A rapid review to inform CCRA3 identified a number of relevant themes that were subsequently incorporated where possible into the CCRA3 method:

- A greater focus was included to encourage iterative risk management (Jones et al., 2014) in CCRA3 (also called adaptive management), to help prioritise and sequence adaptation over time. These approaches are sometimes called adaptation pathways, though this term is used for several different approaches (see key terms Box 2.1).
- The lessons from new decision support approaches for adaptation, including decision making under uncertainty (DMUU), were included in CCRA3. While most of the formal DMUU methods are more applicable at the project scale, rather than at the national level, the concepts that these approaches advance, e.g. robustness, diversity, flexibility, learning, and minimizing regret (Watkiss et al., 2014), are useful to help identify potential additional adaptation action.
- An additional method component (in Step 2 on adaptation) was added to recognise that there are barriers (constraints) to adaptation (for both risks and opportunities) (Klein et al., 2014), and

that addressing these barriers is important for implementation of adaptation. This also aligns to the traditional policy appraisal framework in UK Government (set out in the UK Green Book, HMT, 2018), and can help the subsequent justification for adaptation policy and programming.

- There was a greater focus on the consideration of climate risks in private sector decisions in CCRA3, reflecting developments on the financial reporting of climate risks. This aligns to the initiatives of the Task Force on Climate-related Financial Disclosures (TCFD, 2017) and the Network for Greening the Financial System (NGFS, 2019). These frameworks identify physical climate risks (the risks which are the focus of CCRA3) as well as transition risks (associated with policy or technology change as the world reduces greenhouse gas emissions, which are not considered in CCRA3). There has also been a recent recognition of liability risks, which arise from people or businesses seeking compensation for losses they may have suffered from physical or transition risks (BoE, 2018). These initiatives are likely to stimulate greater interest from the private sector in the CCRA3 results. In response, the CCRA3 Expert Advisory Panel strengthened private sector involvement and interest in CCRA3, though the main audience for the Independent Assessment (including the Technical Report) remains Government.
- Reflecting the government request, the CCRA3 method considered, in indicative terms, the monetary valuation of risks and opportunities (presented in a separate economic report), and the indicative costs and benefits of further adaptation (included in Step 3).
- The CCRA3 method and its implementation have also adopted a stronger emphasis on co-design and co-production - i.e. the participatory development of the project with stakeholders (end-users) (Hegger et al., 2012; Beier et al., 2016) than previous cycles. This drew on recent review work which has identified the key success factors for co-production for climate change and adaptation (COACCH, 2018). Additional co-production activities were undertaken as part of the Technical Report chapter research and analysis, while noting there were some limits due to the need to respect the governance arrangements for CCRA3, i.e. to produce a report that is independent of Government while at the same time undertaking co-production of research with Government as a key end-user.
- There is growing recognition that climate risks will not be distributed evenly (among groups as well as places) (JRF, 2016) and thus additional consideration of distributional effects and inequalities was included.
- There is more focus on the potential synergies and trade-offs between adaptation and mitigation (OECD, 2017; IPCC, 2018a), and this became even more relevant area during the time-period of CCRA3 with the announcement of Net Zero targets and analysis (CCC, 2019b).
- Finally, there is a growing focus in the literature on the need for transformational adaptation (Field et al., 2014; Lonsdale et al., 2015: CRC, 2020), which requires fundamental change, as compared to incremental adaptation (see Box 2.1) and this is reflected in the final method step and greater linkages to CCRA4.

2.2.3 New Climate Science and UKCP18

A new, comprehensive set of state-of-the-art climate projections for the UK were released in November 2018 by the Met Office and its partners (Lowe et al., 2018; Murphy et al., 2018; Palmer et al., 2018), commissioned by Defra. The UKCP18 projections provided important new information of relevance to CCRA3 and were taken into account as much as was practically possible. For example, they were used in the supplementary analysis undertaken by the research projects.

A key part of the CCRA3 methodology was to take advantage of the new UKCP18 information, while acknowledging that due to the timing of release, it has not fed into the risk and opportunity literature. Reflecting this, the Technical Report has drawn on scenarios and studies that are not based on UKCP18 in order to ensure evidence is drawn from the widest possible base of research.

Although a number of studies have already been carried out using UKCP18, most of the literature on future UK climate risks assessed in CCRA3 is inevitably based on the previous set of climate projections, UKCP09 (Murphy et al., 2009). It is noted that some climate risk-related quantities in UKCP18 are quite different to those in the previous projections, while others are similar (see Chapter 1: Slingo, 2021). It has been important to assess where these differences are extensive enough to affect the advice previously provided by the CCRA, and thus affect CCRA3 findings.

UKCP18 contains some projection tools that are similar in nature to those in UKCP09, such as the probabilistic projections, the regional climate model projections and the sea-level rise projections. As an update from UKCP09, UKCP18 includes the more recent emissions scenarios linked to the Representative Concentration Pathways (RCPs). The probabilistic projections considered four RCP scenarios, ranging from RCP2.6 (which is consistent with extensive mitigation of emissions) through to RCP 8.5 (which has future emissions considerably higher than pathways considered consistent with current worldwide energy policies). The intermediate scenarios RCP4.5 and RCP6.0 were also included: these are within the range of possible emissions futures considered consistent with current worldwide policies, and RCP6.0 is used to define the higher climate change scenario used in the CCRA3 Technical Report (see Box 2.5 and also the Introduction chapter: Betts and Brown, 2021).

An important feature of both the UKCP18 and UKCP09 probabilistic projections that is different to most other projections with General Circulation Models of climate is that they are driven by scenarios of emissions scenarios rather than concentrations. For example, the widely-used models in the 5th Coupled Model Intercomparison Project (CMIP5) apply the RCPs as pathways of greenhouse gas concentrations in the atmosphere, but in contrast, UKCP18 uses emissions scenarios aligned to the RCPs but calculates its own concentration pathways accounting for uncertainties in carbon cycle feedbacks to be explored and quantified. The latter approach results in a range of concentration pathways, most of which rise faster than the standard RCP concentration pathways. This is an important influence on the differences in projected rates of warming between UKCP18 and CMIP5 (Murphy et al., 2018).

As a further advance from UKCP09, information from the UKCP18 probabilistic scenarios has been used to quantify the effects of natural climate variability on the spread of future outcomes (Murphy et al., 2018).

As well as the UK and global probabilistic projections, UKCP18 provided a 28-member perturbed parameter ensemble (PPE) of global (60km resolution), and PPEs of regional (12km) and local (2.2km) projections over UK land areas, driven by a range of concentration pathways arising from the standard RCP8.5 emissions scenario. The 12km resolution of the regional projections is higher than the 50 km resolution of the equivalent projections in UKCP09, and in some cases these project larger changes in weather extremes such as heavy precipitation – a comparison of this was carried out in support of the CRA3 Technical Report (Johns et al., 2021). The high-resolution (2.2km) Convective Permitting Model used in the local projections has been shown to simulate extreme precipitation events more realistically than lower-resolution models so the changes in the local projections provide further important context for the assessment, as discussed in Chapter 1.

60km-resolution projections were also provided for global warming levels of 2°C and 4°C global warming above pre-industrial, and for the RCP2.6 emissions scenario (Gohar et al., 2018).

UKCP18 also includes probabilistic projections with one of the same emissions scenarios (SRES A1B) as used in UKCP09, so that a direct comparison can be made with previous probabilistic projections (Murphy et al., 2018). The method used for assessing the implications of the new regional climate projections in the UKCP18 projections for conclusions derived from UKCP09-based regional projections is described in Box 2.4.

Like UKCP09, UKCP18 also includes marine projections including the rise in long-term average sea level, changes in short-term extreme water levels from storm surges, and changes in wave height (Palmer et al., 2018). Since these were developed in parallel with the new climate modelling system used for the UKCP18 land projections, the marine projections used existing climate projections from CMIP5. Although this inevitably results in potential inconsistencies between the UKCP18 land and marine projections, this does not pose a difficulty for CCRA3 as the Technical Report already draws on literature from a wide range of very different sources and has applied a framing of future projections which groups these together appropriately.

2.2.4 New climate science: low-likelihood, high-impact scenarios and events

It is important for a risk assessment to consider high-impact outcomes even if they are considered to be of low likelihood. This includes responses of the climate system outside of the ranges considered “likely”, and also potential abrupt climate changes and the passing of “tipping points” in the Earth System (see Chapter 1: Slingo, 2021). Examples of the former include high values of equilibrium climate sensitivity or carbon cycle feedbacks strength which are facilitated by the use of probabilistic projections. Regarding climate tipping points, also known as earth-system tipping points, and sometimes as climate tipping elements (Lenton et al., 2008; Lenton et al., 2019), some of these are now included in mainstream climate projections and other studies related to these, but many are still not.). Nevertheless, they are increasingly recognised as a very important component of climate change risk assessment, and modelling and theoretical work has been performed to explore them outside of the mainstream climate projections.

These earth system climate tipping points elements were not included in depth in CCRA1 or CCRA2, and this was considered an important omission. They have therefore been included in CCRA3. Some are included either explicitly or implicitly in the UKCP18 projections: the marine report considers the implications of marine ice shelf instabilities which could lead to more rapid sea level rise, and the probabilistic land projections include uncertainties in carbon cycle feedbacks based on a model which simulates die-back of the Amazon forest in some of its simulations (Boulton et al., 2017). The high-emissions RCP8.5 scenario can also serve as a proxy for climate projections with much stronger carbon cycle feedbacks than in current Earth System Models, which could be used to represent the effects of permafrost thawing and other biospheric sources of carbon dioxide or methane emissions. A scenario of shutdown of the Atlantic Meridional Overturning Circulation (AMOC) has also been examined with a version of the main climate model used in UKCP18 (Jackson et al., 2015), and although this is not included in the UKCP18 projections themselves, it has been used for assessing some impacts on the UK (Ritchie et al., 2020). The implications of some of these has been considered for a limited number of risks, and an additional study was performed for CCRA3 to examine these and other tipping points from a UK perspective (Hanlon et al., 2021). Since this showed that information on the implications of other climate tipping points for UK climate risks remains limited, it was not possible to include an assessment of tipping points at the level of all individual risks and opportunities. Instead, they are considered through a separate cross-cutting analysis in each chapter following the discussion set out in Chapter 1 (Slingo, 2021).

2.2.5 Additional Commissioned Research

Following the CCRA2 Evidence report, an evidence gap analysis was commissioned by the CCC. This identified over 200 evidence gaps. Following a stakeholder engagement period in 2016 – 2018, the CCC commissioned six research projects to inform the CCRA3 Technical Report, using funding provided by Defra, the devolved administrations and research councils (NERC, ESRC and EPSRC). These projects were:

1. Updated projections of future water availability for the UK (HRW, 2020);
2. Updated projections of future flood risk for the UK (Sayers et al., 2020);
3. Understanding how behaviours can influence climate change risks (Power et al., 2020);
4. Climate driven threshold effects in the natural environment (Jones et al., 2020);
5. Interacting risks (WSP, 2020);
6. A consistent set of socioeconomic projections dimensions for the CCRA3 Evidence Report research projects (Cambridge Econometrics, 2019).

These projects have fed into CCRA3 in a number of ways. The flood risk and water availability studies provided updated quantified risk estimates for CCRA3, using the new UKCP18 products. They also used the new socio-economic projections provided by the sixth research project. Some of the other studies have provided information of relevance to the update methodology in CCRA3. The threshold study helped to provide information for the new pathways thinking in CCRA3, while the interacting risks project was used to help assess the interacting and cross-cutting risks (which are undertaken for each risk/opportunity in the chapters in CCRA3, rather than as a separate cross-cutting chapter as in CCRA2).

Work was also commissioned in support of the CCRA3 Technical Chapters to assess the impacts of climate change on agricultural land use and associated greenhouse gas emissions (Mancini et al., 2021), again using UKCP18 projections. Further additional work was carried out by the research community on implications of climate change for wildfire risks in the UK (Belcher et al., 2021). This had been identified as an area where the evidence base had not advanced substantially between CCRA1 and CCRA2.

The results of these studies and the CCRA3 research described in sections 2.2.3 and 2.2.4 are included throughout the Technical Report chapters and referenced as such.

2.3 The CCRA3 Approach: Using Risk Assessment to Inform Adaptation

2.3.1 The Framework for CCRA3

The CCRA3 Evidence method is based on the prioritisation of risks and opportunities, using an analysis of urgency. This seeks to address the issue of 'where is action needed most urgently over the next five-year period'? This is complemented by a second framework (applied in Step 3) that helps to identify early adaptation priorities to respond to the identified risks and opportunities, i.e. that seeks to address the issue of 'what type of action is most urgently needed?'

2.3.1.1 Establishing urgency

The analysis of the urgency of risks and opportunities was undertaken in CCRA2 through an urgency framework (Warren et al., 2016). This high-level framework has been carried over into CCRA3, with minor refinements. It prioritises risks and opportunities using three questions:

1. What is the current and future level of risk/opportunity?
2. Is the risk/opportunity going to be managed, taking into account Government commitments and other non-Government adaptation?
3. Are there benefits to further action in the next five years, over and above what is already planned?

These three questions are shown within the decision flow diagram in Figure 2.2.

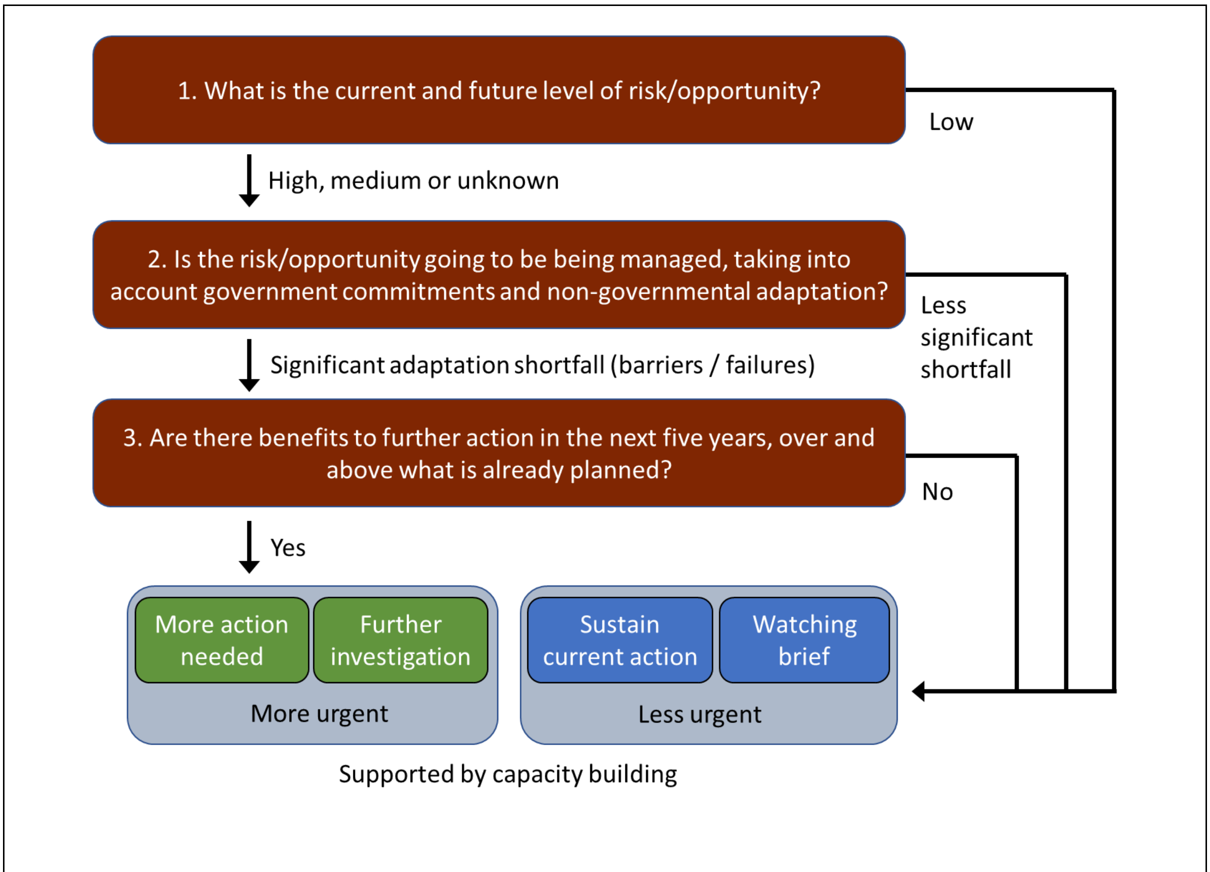


Figure2.2 Urgency Scoring Framework. Updated from CCRA2 (Warren et al., 2016).

2.3.1.2 Identifying possible priorities for early adaptation

The CCRA Technical Report aims to provide evidence to inform adaptation. Following from the urgency diagram above, it seeks to provide additional information on what type of adaptation action might be beneficial in a case where more action is needed. This is influenced by the type of decision, noting that for many risks and adaptation responses, there is a need to address the challenge of deep uncertainty, i.e. where the probability of risks is not known (Hallegatte et al., 2012). An initial adaptation framework was set out in CCRA2 (Warren et al., 2016; Warren et at., 2018). This built on a well-established literature and existing frameworks for identifying early adaptation priorities, using a portfolio or 'building block' approach (drawing on Fankhauser et al. (1999); Ranger et al. (2010); Watkiss and Hunt (2011)). This framework has been updated in CCRA3, and identifies three main priorities for early adaptation activities, which are to:

- Address any current adaptation gap by implementing 'no-regret' or 'low-regret' actions[1] to reduce risks associated with current climate variability as well as building future climate resilience, or to enhance opportunities.
- Intervene to ensure that adaptation is considered in near-term decisions that have long lifetimes, such as major infrastructure developments, in order to avoid 'lock-in' (see key terms). This can include the use of decision making under uncertainty (DMUU) concepts (i.e. flexibility, robustness).
- Fast-track early adaptive management activities, especially for decisions that have long lead times or involve major future change, including planning, monitoring and research. This can enhance learning and allows the use of evidence in forthcoming future decisions, for either risks or opportunities.

These are shown in the adaptation priority framework in Figure2.3, along with the decision characteristics involved. It is stressed that at the national level, all three of these adaptation priorities or building blocks (shown in the green boxes) are needed, and this requires portfolios of interventions for each individual risk or opportunity. Indeed, the three activities above can be part of an overall adaptive management process or adaptation roadmap (see section 2.3.2).

The differences between the three 'building blocks' of early adaptation in Figure 2.3 are quite subtle, but important. Each involves a different combination of the time-scale of climate risks and the time period of the adaptation decision. On the left of Figure 2.3, there are some current decisions or actions that can be taken now to address current climate risks. These lead to an immediate benefit. An example is to improve weather and climate services to reduce current weather-related impacts from heatwaves. Moving to the centre of Figure 2.3, there are some near-term decisions which will be exposed to future climate change risks, and there is a one-off opportunity to adapt now. For example, to change the design of a major new infrastructure project (e.g. a major bridge or hydroelectric-power plant) to make them more resilient to future climate change, noting later major retrofits could be expensive or impossible. Finally, on the right of Figure 2.3, there are some future decisions that may need to be implemented to address major climate change in the future. Some of these will take time to develop, and some will benefit from improved information and learning. In these cases, it makes sense to start planning now (especially if lead times are long or the potential for learning is large). The Thames Estuary 2100 project (Ranger et al., 2013) is such an example,

[1] No-regret adaptation is defined as options that 'generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs' (IPCC, 2014b). A variation of no-regret options are win-win options, which are options that have positive co-benefits, which could include wider social, environmental or ancillary benefits. These are differentiated from low-regret options, which may have low costs or high benefits, or low levels of regret, or may be no-regret options that have opportunity or transaction costs in practice.

where early planning and monitoring has been put in place now to prepare for the possibility that a new Thames Barrier might be needed in the long-term. The key point is that all of these involve some actions in the next five years, i.e. in the next NAP period.

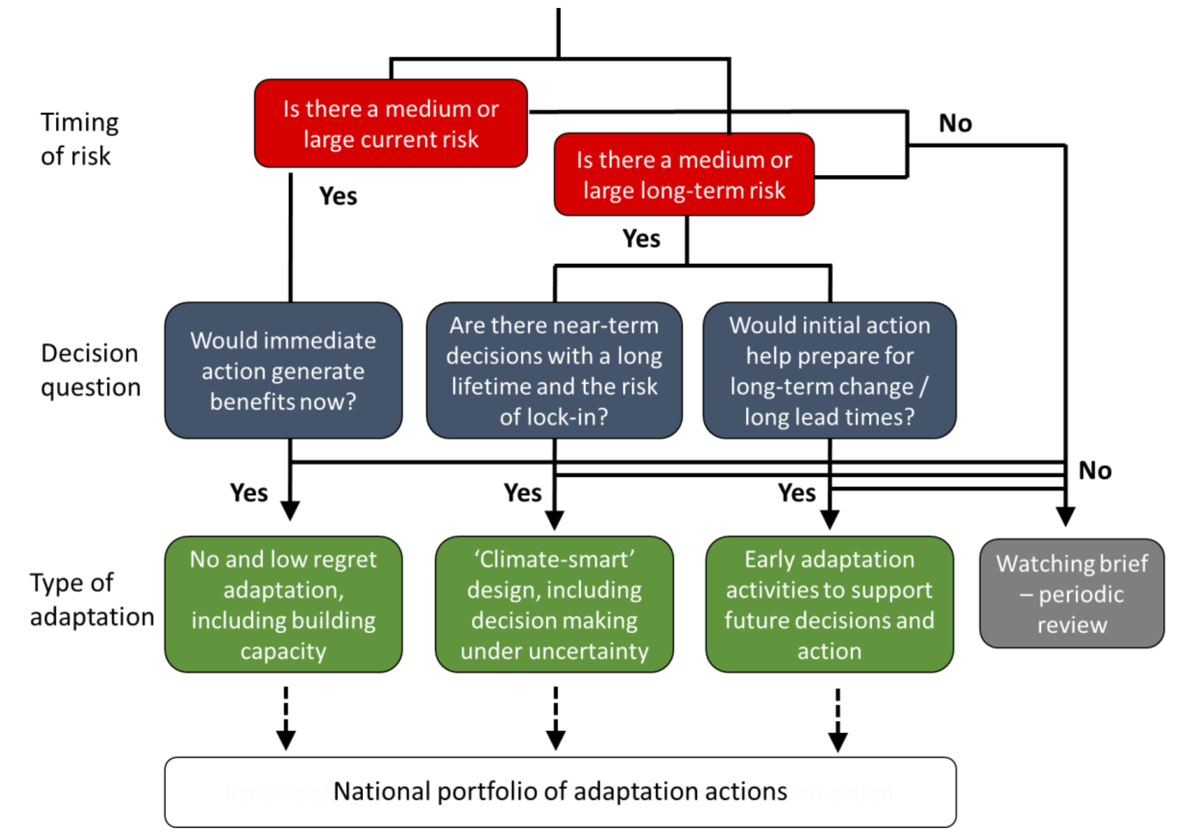


Figure 2.3 Early adaptation priority framework in CCRA3. Updated from CCRA2 (Warren et al., 2016).

This adaptation framework is applied in Step 3 of the urgency method (see Figure 2.2). However, a lesson from the review of CCRA2 was that this requires particular evidence to be gathered in Steps 1 and 2, to allow the subsequent application of the framework in Step 3. For this reason, additional information requirements (to inform adaptation) were added early in the CCRA3 method - this includes a greater emphasis on lock-in, thresholds, and adaptive management – and are discussed in the next section.

It is noted that while this methodology has been applied to all risks and opportunities in CCRA3, it is more challenging to apply this approach to international risks (Chapter 7: Challinor and Benton, 2021). Additional information on how this has been addressed is presented in that chapter.

This method was applied to all risks and opportunities, at the level of each of the four countries (England, Northern Ireland, Scotland and Wales) as set out in the CCRA3 Requirement Document. It is highlighted, however, that risks and opportunities vary across regions and populations. In practice, for adaptation decisions, greater dis-aggregation may be needed.

2.3.2 New focus areas in CCRA3

A number of additional developments – related to the frameworks above - are included in CCRA3. These encourage more adaptive management thinking in the CCRA, although there are limits to what is possible given that CCRA3 is a synthesis exercise, rather than new analysis of future impacts and adaptation. These are described briefly below.

2.3.2.1 Risks of Lock-in

The first area that is given greater weight in CCRA3 is the risk of **lock-in.** The adaptation literature on lock-in has generally focused on decisions that 'lock-in' the potential for future climate change risks that are difficult or costly to reverse or change later (Fankhauser et al., 1999; Ranger et al., 2010; Fankhauser et al., 2013) and this term was included in CCRA2 (Warren et al., 2016). It is recognized that lock-in is an important issue for early action, and it has been considered in recent CCC progress reports (e.g. CCC, 2015; 2017; 2019a). The term lock-in has also appeared in the IPCC glossary for recent special reports (IPCC, 2018b), which defines it as *a situation in which the future development of a system, including infrastructure, technologies, investments, institutions, and behavioural norms, is determined or constrained ('locked in') by historic developments*. CCRA3 investigated these issues in more detail, with an updated literature review on lock-in, including a consideration of the use of the term in the mitigation literature (see Seto et al., 2016).

Based on this, a new definition was developed for the CCRA3 (see Box 2.1). This captures the relevant focus on lock-in that could arise in the next NAP period (i.e. the next five years or so) and relates to actions or decisions that could potentially increase future risk or vulnerability and that are also difficult or costly to reverse later (quasi-irreversibility / path dependency). This can be from i) action or decision taken that is business-as-usual', ii) from a lack of an action or decision, or iii) from a maladaptive action or decision.

An example where business-as-usual actions or decisions could involve lock-in (i) is the building of new infrastructure, which has a long life-time. Where this does not consider future climate risks, this may experience large future climate impacts, and/or could be expensive or difficult to retrofit later. This could be large projects that do not consider future floods risks or building large numbers of houses that do not consider future overheating risk. It can also involve land-use decisions, as these tend to lock-in development patterns irreversibly, e.g. developing new areas that may become at risk under future climate related flooding. At the same time, lock-in could also include policy decisions associated with these investments (e.g. building standards or development policy) and even new policy or market based instruments that increase exposure, sensitivity or vulnerability. An example of (ii) could include a case where peatlands are not restored in the short-term, leading to further degradation that is irreversible, which removes its coping capacity to future climate shocks. It could also include a failure to manage other drivers of stresses, such as rising demand for water, that increase susceptibility to future climate change. Finally, examples of maladaptation (iii) could include a major investment today that involves a sunk cost for an adaptation measure that may not be needed, or implementing costly adaptation without considering uncertainty (noting also that lock-in may constrain future adaptation decisions). In the CCRA3 method, a decision that involves a potential risk of lock-in is given a higher magnitude score, and assigned a higher urgency score requiring action sooner.

2.3.2.2 Thresholds

The second area of greater focus in CCRA3 is around **thresholds.** These represent levels or states beyond which there is step-change in risks and which may necessitate much greater levels of adaptation (or even may reach the limits of adaptation, Klein et al., 2014). This draws on the literature on adaptation decision-making under uncertainty (DMUU) and adaptation pathways (e.g. Ranger et al., 2013; Dittrich et al., 2016). CCRA3 has included more adaptive management thinking, with a more explicit consideration of thresholds and the potential differences for these between 2 and 4°C pathways. In considering these elements, authors were asked to consider a number of different types of thresholds:

- Biophysical thresholds. Typical examples are the suitability or lethal threshold limits for crops, temperature thresholds for heat and daily mortality, or thresholds for heating or cooling demand. These thresholds are sometimes translated into current policy, e.g. the Heat Health Watch heat-wave temperature thresholds, or occupational temperature thresholds.
- Engineering thresholds. These are often associated with design standards and tolerance levels for various climate parameters, e.g. rail buckling temperature thresholds, maximum water flows for drainage channels etc.
- Performance thresholds. These thresholds are linked to the adaptation tipping points literature (also known as adaptation turning points) (Haasnoot et al., 2013; Werners et al., 2013), and they relate to points beyond which a particular action is no longer adequate for meeting a plan's objectives and a different adaptation option or strategy is required, including sometimes more transformational measures. These can include a wide range of types of thresholds, e.g. service levels, economic returns.
- Policy thresholds. These may be policy levels that are set to politically determined levels of acceptable risk or economic optimality, e.g. the use of 1 in 100 year level of flood protection, or policies that define unacceptable risks.

It is noted that for the first of these, there may be natural or intrinsic thresholds, which may be immutable. For the other three, these thresholds are often set by decision makers, and thus reflect policy choices.

The consideration of thresholds (particularly performance thresholds) has been used widely in the adaptation tipping points literature and adaptation pathways (see definition Box 2.1). However, these pathway approaches and threshold analysis are more often used at the project level, and there are challenges to implement them at the national level. Nonetheless, there is a value to exploring potential risk (or opportunity) thresholds, to help inform the CCRA3 and to encourage more pathway thinking. It is also highlighted that there is a separate literature on global (Earth System) thresholds (often called climate tipping points), discussed in section 2.6., which should not be confused with the thresholds or adaptation turning points discussed above.

2.3.2.3 Sequencing adaptation, adaptive management and transformational adaptation

While the focus of CCRA3 is to identify where further adaptation is needed in the next reporting period (to address priority risks and opportunities over the short, medium and long-term), these early priorities need to be seen as part of a longer-term **adaptive management process**, i.e. that encourages a cycle of evaluation, learning, and revision (of possible actions).

CCRA3 therefore includes more emphasis on iterative adaptive management. The aim is to encourage more consideration of risks and opportunities – and adaptation - over time and across scenarios (including uncertainty). This is particularly important because of the regular repeat cycle of the CCRA process every five years, and thus the opportunity to learn and update over time.

In the national context, this could extend to adaptation roadmaps, i.e. generic adaptation pathways. These are not to be confused with detailed dynamic adaptation route-maps, which are a decision support method used primarily at the project level (e.g. as in Thames Estuary 2100, see Reeder and Ranger, 2013), which are often called dynamic adaptation pathways (see Box 2.1).

However, while an adaptive management process is inherent in the CCRA and NAP process due to the five-year repeat cycle, operationalising this in practice is very challenging at the national scale. There are some examples, notably in the Netherlands with the Delta Committee and plans (Marcel et al., 2011) but these tend to focus on sea-level rise, which lends itself more easily to such analysis. Following the CCRA1, Defra funded an Economics of Climate Resilience study (Frontier Economics et al., 2013; HMG, 2013) which developed national level adaptation roadmaps. While this approach was informative, and identified actions over time (for successive CCRA cycles), it was found to be difficult to implement the findings at the sectoral level, because there are multiple risks (and opportunities). This indicates adaptive management (roadmaps) is more applicable at the level of individual risks or opportunities. However, developing a national adaptation roadmap for every CCRA3 risk and opportunity would be a major undertaking and has not been possible given the resources available and synthesis nature of CCRA3. Nonetheless, recent national level analysis (for the CCC) did develop indicative analysis for ten specific risks and opportunities (Watkiss et al., 2019) and found it was possible to identify lock-in and thresholds, and to include some general suggestions on moving to an adaptive management approach. CCRA3 authors were therefore asked to try and incorporate a similar discussion in Step 3 of the CCRA method, i.e. to try and consider some of the implications of lock-in and thresholds, as well as to include adaptive management suggestions for further action.

Looking forward, it would be useful to maximize the linkages between successive CCRAs (see Figure 2.4) to try and encourage a more formal iterative approach into national risk assessment. As a first step towards such an approach, CCRA3 included an additional question for authors to address in the analysis on ‘what evidence or learning would help to inform CCRA4?’

This recognises that the CCRA4, which is due for completion in 2027, will inform the fourth NAP and DA adaptation programmes for the period 2028-2032. By this time, the UK’s climate is projected to be significantly different as compared to the last century, and could be entering a period of very major climate change in the decade that follows, especially if global international mitigation efforts are below the levels needed to deliver the Paris Agreement. Therefore, authors were asked to consider what additional information might be useful to help inform CCRA4 and NAP4 decisions and they were also asked to explicitly consider where transformational adaptation might be needed.

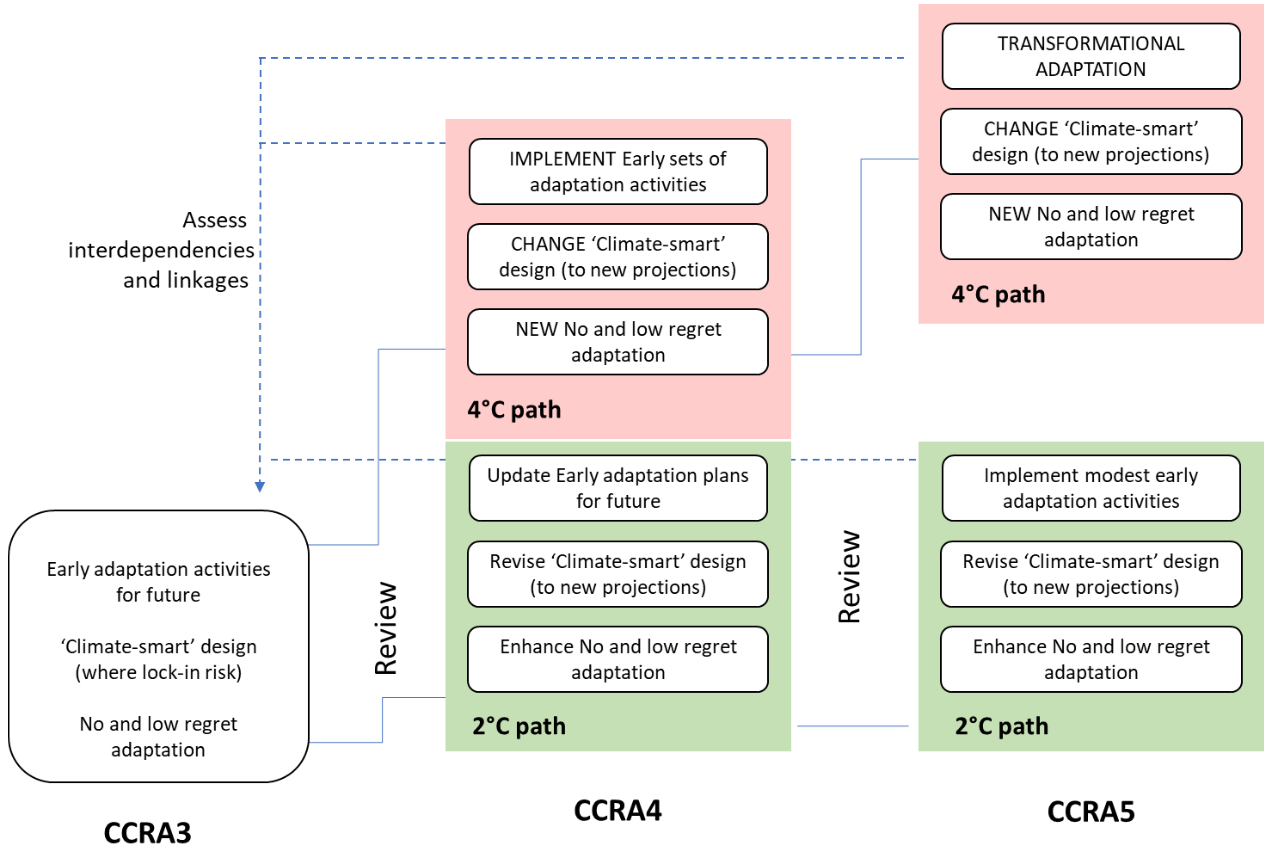


Figure 2.4 Idealised Adaptive management under different future CCRA cycles.

2.4. CCRA3 Process

2.4.1 Overview of the CCRA3 Process

This section sets out the process involved in the development of the CCRA3 method. Building on the CCC method statement, as well as the early review work (on other national risk assessments and the academic literature), a first draft of the CCRA3 Technical Report Methodology Paper was produced in April 2019. This was reviewed internally by the CCRA3 Technical Report team and by the CCC secretariat. Following updates, a second draft of the method paper was produced and was shared with the Chapter teams for discussion, and a methodology workshop was held with this group in May 2019. The resulting changes and updates were used to produce a third version, which was reviewed by an external Expert Advisory Panel (EAP, in June 2019) and presented to the CCRA3 Project Board for comment (July 2019). The comments received were used to produce an updated version of the methodology, which went out for detailed external peer review during August and September 2019. This included review by the Government, the EAP and the external peer review panels. A large number of comments were received from this review, and these were used to produce a fifth version of the methodology chapter (along with a logged response to all 350 comments).

This version was used by Chapter teams for the first round of the CCRA Evidence analysis and urgency scoring. The methodology was operationalised through the development of a CCRA3 Risk/Opportunity template, which set out the questions that chapter teams should address (and record) for each of the three urgency method steps, along with worked examples. The template is attached in Annex 1. To support this process, a slide presentation pack on 'how to' implement the method was produced.

During the autumn of 2019, a number of activities (method authors or working groups) further developed the methodology. This included consideration of socio-economic scenarios including the UK Net Zero target, adaptation pathways, interacting and cross-cutting risks and equity/distributional impacts. A revised methodology chapter was produced in January 2020, along with an updated template, and discussed at a CCRA3 meeting with the chapter teams in February 2020. This was finalised for the second round of CCRA Evidence analysis in March 2020, and was also sent out for a final peer review in May 2020 by the Government, the EAP and the external peer review panel. The comments from this review were used to produce a draft final version of the methodology chapter in October 2020, which was circulated with other chapters for a final round of peer review in November 2020, but with instructions for comments to focus on updates only.

2.4.2 Overview of the CCRA3 Evidence Process

The CCRA3 method was applied using a three-round approach to derive the magnitude and urgency scores. This iterative process is set out in Figure 2.5.

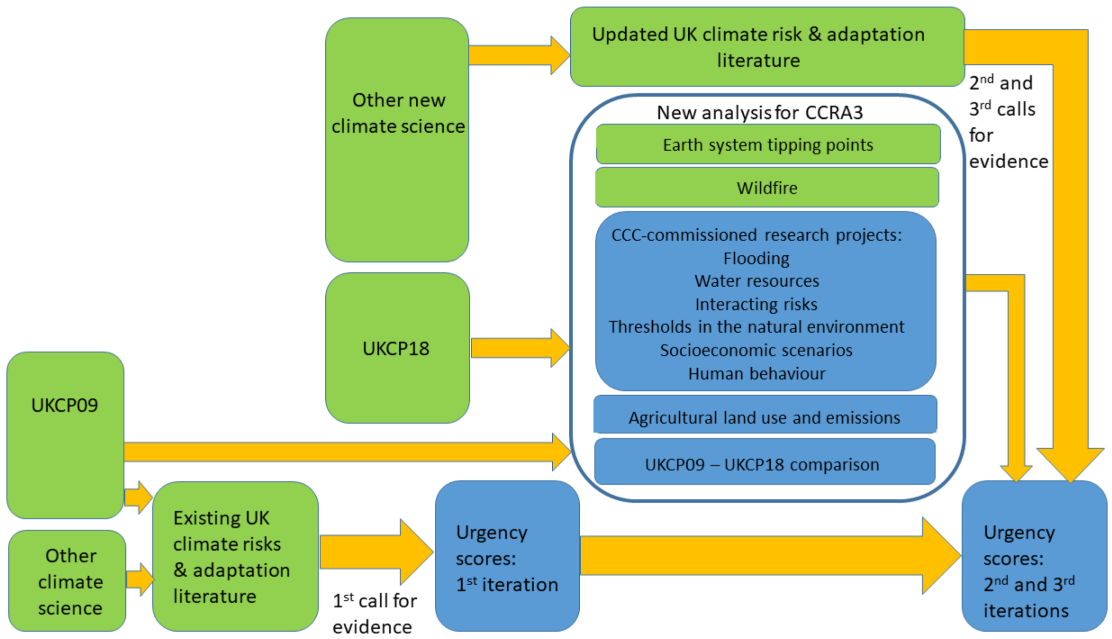


Figure 2.5 Combination of existing literature and new analysis in urgency scoring using iterative approach. Blue: activities resourced directly by the CCRA3 work programme. Green: additional activities.

The initial pass of the urgency scores was undertaken during late 2019, based on existing literature. A second iteration of the urgency scores was made in early 2020, following the evidence from the UKCP09-UKCP18 comparison, the outputs of CCRA3 research projects, the outputs of CCRA3-focussed research in other programmes, and new literature published later in the CCRA3 analysis and writing period. A final iteration was made in late 2020 to ensure an up-to-date assessment reflecting the latest literature.

2.5. CCRA3 Method Overview

The final methodology is summarised in Figure 2.6, showing the **three urgency steps** (in red) and associated questions, along with the **tasks** (in blue) that are undertaken at each of these steps. This is presented as a flow chart, which shows how the evidence at each stage progresses through towards the analysis of urgency. The key outcomes are shown in green, and include the magnitude scores (Step 1) and the urgency scores (Step 3).

The method is designed to treat evidence consistently, irrespective of the sector or system affected, creating a balanced assessment representative of the available literature. The three steps are briefly described below and then outlined in detail in the subsequent sections.

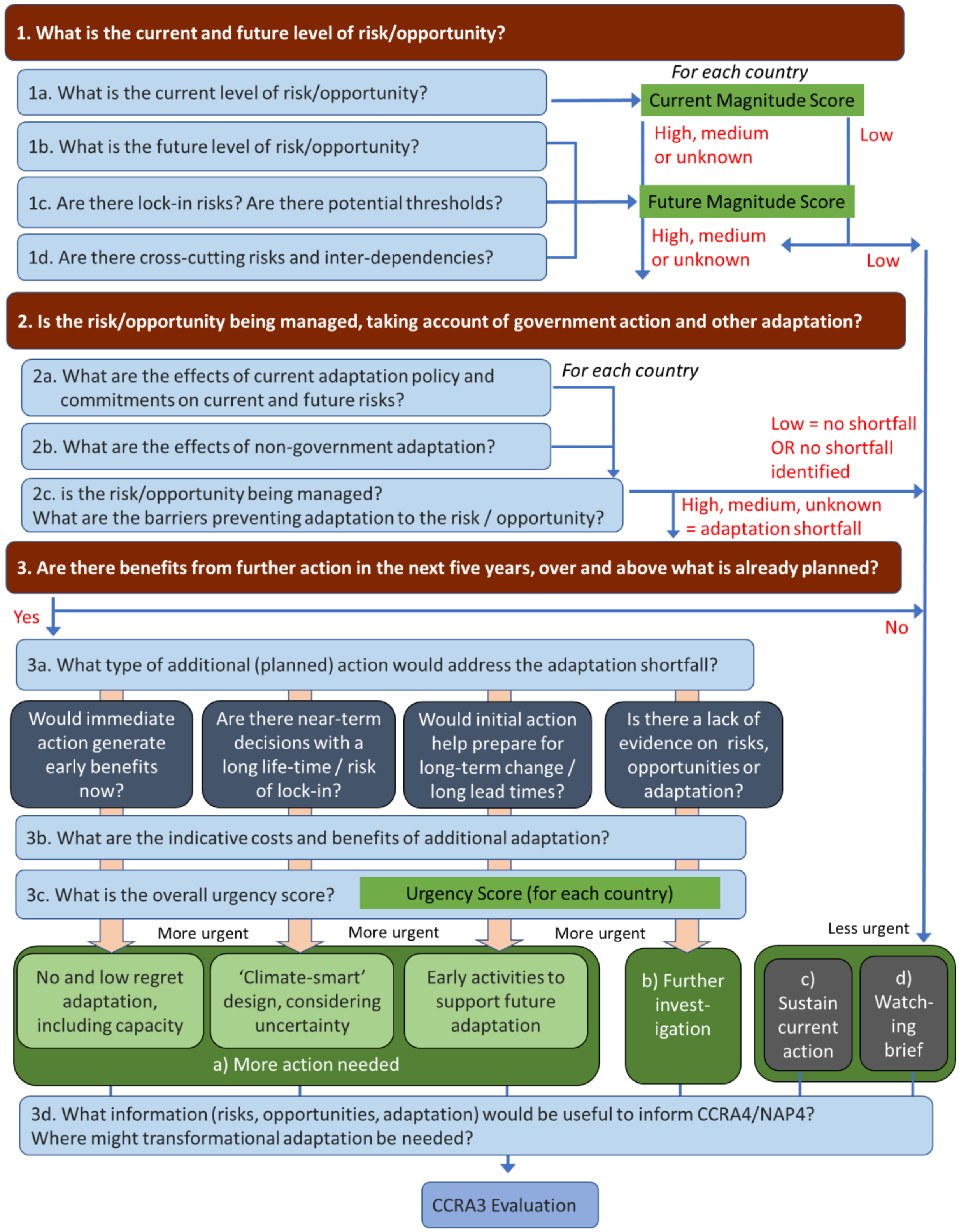


Figure 2.6 Overall CCRA3 Methodology.

2.5.1 Step 1: Assessment of risks and opportunities

This step undertakes the analysis of current and potential risks and opportunities, and undertakes an initial scoring of their magnitude. It is stressed this scoring is undertaken at the national level, i.e. individually for all four countries. This first step includes the following tasks:

Step 1a. Current risks and opportunities. This task sets out to understand and assess present-day current climate-related risks and opportunities, with a quantitative or qualitative assessment of their magnitude (see magnitude scoring Tables 2.2 and 2.3). For risks, it assesses how vulnerability, exposure and hazards affect current risks, including the influence of socio-economic drivers. For opportunities, as the IPCC hazard-exposure-vulnerability framework does not apply, the focus is on understanding the current influence of climate. This task also considers the distributional effects and potential inequalities associated with risks and opportunities. An analysis of the magnitude for risks and opportunities is made (individually) for each of the four countries (England, Northern Ireland, Scotland and Wales) (see Table 2.2 and 2.3, below), along with an analysis of the confidence in this score, based on the quality of the evidence and the level of agreement in the evidence between studies and authors (see Tables 2.4 and 2.5).

Step 1b. Future risks and opportunities. This task extends the analysis above to understand and assess how climate and socio-economic change may alter risks and opportunities in the future. This assesses the magnitude of future risks and opportunities for two time periods, associated with the mid-century (2050s) and late-century (2080s), and for two scenarios, broadly consistent with 2°C and 4°C warming by the end of the century (globally, relative to pre-industrial – see Chapter 1: Slingo, 2021). It also considers ranges of uncertainty, where relevant information is available. The analysis considers the changes from extreme events and variability, as well as average (slow-onset) change. The relative importance of climate change as compared with other drivers of risk (i.e. socio-economics) is reported where possible, as well as distributional effects and potential inequalities. At the end of this task, the magnitude of future climate risks or opportunities is assessed using the categories set out in Table 2.2, in the absence of planned adaptation (the 'no additional adaptation' scenario), for each of the four countries. It also assesses the quality of the evidence and level of agreement, i.e. confidence (see Tables 2.4 and 2.5). This task also considers the evidence on low-likelihood, high impact scenarios, which are reported but not used to assess the likely magnitude, as well as the potential linkages with Net Zero from the risk/opportunity.

Step 1c. Lock-in and thresholds. This task identifies the potential risks of lock-in, i.e. where decisions (or inaction) in the next five years or so could 'lock-in' exposure or vulnerability to future climate risks that are difficult or very costly to address later. The risk of lock-in is identified and reported in Step 1 and then used during the consideration of the benefits of further adaptation in Step 3. This task also considers possible thresholds associated with risks or opportunities, and if the exceedance of these might necessitate different adaptation interventions (for either the 2°C or 4°C warming pathways by end of century globally, and also across uncertainty ranges for each of these scenarios). The potential for lock-in and threshold risks is reported alongside the magnitude scoring table, and in the adaptation and the urgency analysis. It is noted that lock-in and thresholds can also be relevant for opportunities.

Step 1d. Interacting and cross-cutting risks. This task investigates cross-cutting risk linkages and interdependencies for each risk and opportunity. The analysis of interdependences is considered in the magnitude scoring and has the potential to increase the score. For opportunities, the potential for interdependent and cross-cutting effects, as well as co-benefits or trade-offs, are also considered.

2.5.2 Step 2: Analysis of Government and non-Government adaptation action

This step assesses the influence of adaptation in reducing current and future climate change risks, or enhancing potential opportunities, and therefore if risks and opportunities are being managed. This second step includes the following tasks:

Step 2a. Analysis of current adaptation policies. This step assesses the potential benefits of current and announced adaptation policy in reducing risks or enhancing opportunities. It starts by identifying the policy landscape, identifying organisational responsibilities, and existing adaptation policy and plans from Government and other agencies. This is used to produce a current adaptation policy scenario. The analysis assesses the potential impact of existing adaptation (in place) in reducing total current risks or enhancing opportunities. It then assesses the potential impact of current and announced planned adaptation in reducing future risks or enhancing opportunities, for the same time periods as step 1b (medium-term and long-term) for different future scenarios (2°C and 4°C future warming by 2100 globally) taking account of uncertainty. This analysis is undertaken for each country as well as overall UK actions for non-devolved issues. This also assesses the quality of the evidence associated with adaptation (see Tables 2.4 and 2.5).

Step 2b. Non-Governmental adaptation. In cases where there are still medium or high magnitude risks in any of the likely climate/socioeconomic scenarios considered (not the low likelihood, high impact scenario), or further opportunities, the analysis considers the potential impact of other forms of adaptation. This includes spontaneous and reactive adaptation (e.g. in natural systems, from acclimatisation, or in markets) in response to the changing climate, but also planned adaptation by non-government actors, e.g. proactive, planned private adaptation. The aim is to establish whether risks will be managed in the absence of further government intervention. The analysis also considers if this adaptation is likely to be beneficial, defined through the lens of overall social welfare. For opportunities, the analysis considers whether non-governmental adaptation is likely to lead to benefits being fully realised without planned Government action, or whether additional action may be needed, including creating the enabling environment for this to happen.

Step 2c. Analysis of Adaptation Gap and Barriers to adaptation. At the end of this task, there is a re-analysis of the magnitude of future risks or opportunities, taking into account planned and non-governmental adaptation. This identifies if these risks/opportunities are being managed or if there is still an adaptation gap (an adaptation deficit, see section 2.7 for criteria). This analysis is undertaken for each of the four countries. Where an adaptation gap exists, the analysis considers the barriers or constraints to adaptation, i.e. what might be stopping government, private sector, households, etc. from adapting.

2.5.3 Step 3: Analysis of the need and urgency for additional adaptation

In the case where an adaptation shortfall is identified in Step 2 (i.e. the risk has a residual high, medium or unknown magnitude score in any of the likely climate/socioeconomic scenarios considered), the final step considers the potential benefits of additional adaptation, over and above what is currently happening or planned. This includes the following tasks:

Step 3a. Identify and assess possible additional adaptation action. This identifies an additional adaptation scenario to consider further adaptation to reduce risks or enhance opportunities. It considers the type of adaptation that could be taken (aligned to Figure 2.3), whether individual areas or as a portfolio or pathway. The aim is to identify where further action would be beneficial in managing risks or opportunities, whether through direct Government intervention or by creating the enabling environment for others, but it does not identify or suggest specific adaptation policies. While the focus is on the additional action in the next adaptation reporting period, this task also considers what action might be needed now in the context of longer-term pathways. For opportunities, the task considers what additional planned adaptation might be beneficial to fully realise potential benefits from climate change.

Step 3b. Assess the indicative costs and benefits of additional action. This task assesses the economic rationale for, and the indicative costs and benefits of the identified further action (including wider co-benefits or trade-offs), primarily in qualitative terms. This information helps to identify the possible areas for action (aligned to Figure 2.3) and to provide some context on the possible benefits of further action as compared to costs. This task also checks if there are any synergies or trade-offs with mitigation.

Step 3c. Analysis of overall urgency scores. At the end of this step, an analysis is made of the overall urgency score of each risk or opportunity. This categorises risks and opportunities into one of four scores: ‘more action needed’; ‘further investigation’; ‘sustain current action’ or ‘watching brief’. Alongside this ranking, the assessment describes what type of action might be beneficial to manage the risks or opportunities, particularly in the context of the next National Adaptation Programme and adaptation programmes of the DAs. The urgency scores are set out in each chapter and summarised in the Advice Report. This step also assesses the quality of the evidence for the urgency ranking (see Tables 2.4 and 2.5).

3d. Learning and Evaluation. The last step is to move beyond the five-year focus of the CCRA3 cycle and ask the question of where additional information or analysis would be useful to inform CCRA4 and subsequent adaptation programmes, i.e. with respect to risks and adaptation. Teams were also asked to explicitly consider if/where transformational adaptation might be needed.

Finally, following the publication of the CCRA3 Evidence and Government Report and the next set of national adaptation programmes, it is recommended that a formal evaluation of CCRA3 should be undertaken prior to the CCRA4. This would need to be undertaken in 2023, after the publication of the CCRA3 Technical Report, Advice Report, Government Report and the National Adaptation Programme. As yet, resource has not been allocated to this task and will need to come from the UK Government.

2.6 Detailed Description of the Method

The detailed methodology for CCRA3 Technical Report is set out below by task and step.

2.6.1 Step 1. Assessment of Current and Future Risks and Opportunities

The first step in the overall method is the assessment of risks and opportunities (see Figure 2.7). This step starts with the analysis of current and potential risks and opportunities, and undertakes an initial scoring of their magnitude, then considers how these may change in the future.

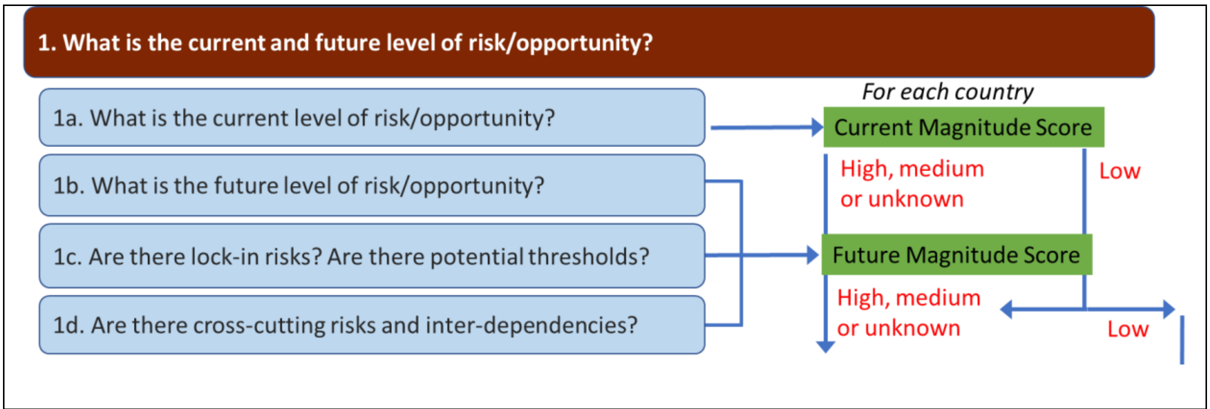


Figure 2.7 First step in the overall method and urgency analysis.

These steps are described in more detailed below.

2.6.1.1 Task 1a. Understand Present Day Risks and Opportunities

The purpose of the first task is to provide a summary of the current risks and opportunities from climate and non-climate stressors. An understanding of how hazard, exposure and vulnerability to the current climate (including climate change that has already taken place) allows for a better understanding of how risks and opportunities may change in the future. It also provides inputs to help assess the size of the current adaptation deficit.

The key terms for defining risks in CCRA3 (see Box 2.1) are based **on the IPCC definition of risk, and the components of hazard, exposure and vulnerability** (IPCC core concepts, IPCC, 2014a: IPCC, 2014b). This is worth being clear about as definitions of 'risk' – and methodological approaches - do vary across UK government (see Introduction Chapter: Betts and Brown, 2021). To assess current climate-related risks, CCRA3 authors were asked to assess the following:

- The current risks of climate on economic, social and environmental systems. This includes the consideration of year-to-year variability and extreme events, as well as from average climate.
- The key socio-economic factors that influence vulnerability, how these interact with climate and what is their relative importance or contribution. To support this task, an additional CCC research project was commissioned to update UK socio-economic data to use in the other research projects and across the report.
- Given the above, what the magnitude of the risks and opportunities is at present. This uses the magnitude table shown in Table 2.2. This scoring was undertaken separately for each UK country (England, Northern Ireland, Scotland and Wales), including the adjustment factors in Table 2.3.
- Assesses the quality of the evidence and level of agreement, i.e. confidence (see Tables 2.4 and 2.5)

A key focus for authors was to identify and document additional changes in the current risk or opportunity observed since CCRA1 or CCRA2. This included any weather-related thresholds, geographic 'hotspots' or types of event that pose a specific risk.

It is noted that the climate of the UK has already changed since pre-industrial times, and significant changes have occurred since the 1961-1990 period in both mean climate and extremes (Kendon et al., 2018), as outlined in Chapter 1 (Slingo, 2021). These changes become more important with each successive CCRA. This includes evidence of warming in annual mean temperature, the hottest and coldest days of the year, changes in annual precipitation, the most intense rainfall events, and the length of warm spells, dry spells and growing season length.

An additional element that was included in CCRA3 is the evidence that even in the present day, there is a higher probability of climate events that could happen but have not yet occurred in the observational records (Thompson et al., 2017 and Smith et al., 2019), as an example, temperatures exceeding 40°C. This has been considered using new methods that consider the likelihood of extreme and unprecedented weather events under the current climate, using. a technique known as "UNSEEN" (UNprecedented Simulation of Extremes with ENsembles), as outlined in Chapter 1 (Slingo, 2021). Information on these events were compiled, and chapter authors were encouraged to consider the implications of these results, i.e. whether they affect their assessments of present-day climate impacts and risk. Additional information is given in Box 2.4 in the next section below.

For opportunities, the focus was also on understanding the current influence of climate on economic, social and environmental systems. However, the IPCC hazard-exposure-vulnerability framework does not work well for opportunities. Instead, the focus was on the magnitude of potential beneficial consequences (using the same categories of magnitude as for risks, but opposite in sign). This can involve the positive existing influence of the climate (i.e. as a baseline to allow comparison of rising future benefits under climate change) or the current negative impact of extremes to allow analysis of future decreases from climate change, such as for cold-related extremes.

At the end of this task, an analysis of the magnitude of current risks or opportunities was made (see section and Table 2.2 below). It is stressed that this magnitude score is undertaken for each individual country (England, Northern Ireland, Scotland and Wales), see also Table 2.3. The assessment also considers the confidence of the risks or opportunity, based on the level of agreement combined with the quality of the evidence used.

An interesting finding from the application of this approach is that adaptation is influencing current risks and opportunities. This creates new methodological challenges. In cases where the analysis of current risks (or opportunities) is based on observed information, these will reflect current levels of adaptation. However, any observed changes will also be influenced by other drivers, e.g. from changes in exposure or vulnerability, plus non-climate policy. This makes it extremely difficult to attribute the benefits of current adaptation in reducing current risks (without more detailed counterfactual analysis). Furthermore, to analyse the benefit of current adaptation, it is necessary to go through the tasks in Step 2 (identify who is responsible, what current adaptation policy is, and how effective it is). For these reasons, the analysis of the role of current and future adaptation was included in Step 2.

More information on the magnitude and confidence scoring, and supplementary activities on economic valuation and distributional effects and inequalities, is given below.

2.6.1.1.1 Magnitude scoring

The final task in the first step of the method is to assign a magnitude score to each risk and opportunity. This is undertaken for both current and future time periods.

Most risk assessments seek to assign an overall magnitude using a combination of likelihood and impact. For example, the UK National Security Risk Assessment and the National Risk Register (NRR) (HMG, 2020) - which consider risks (national-scale emergencies) assuming a reasonable worst case - assesses the combination of likelihood (within the next five years) and the impact severity to provide an overall ranking of risks. CCRA3, however, is working with a broader defined set of risks (see Box 2.1 key terms), which include long-term trends as well as probabilistic events, over a much longer-time frame.

A magnitude scoring approach was developed in CCRA2 to capture potential impact of trends and probabilistic events, and this has been applied again in CCRA3. The impact levels were set based on a review of the NRA.

This magnitude table has been updated in CCRA3. This extended the table with a larger number of categories, particularly to capture potential magnitude for the natural environment and natural capital, see Box 2.3 below (as these are not captured in many existing risk frameworks, such as the NRR). The new table added additional categories (rows), but also undertook a re-analysis to improve the cross comparability between magnitude rankings (columns) and between categories (rows) using a valuation and benchmarking exercise. This resulted in some changes in the magnitude descriptions as compared to CCRA2. The updated categories and magnitude scores used in CCRA3 are shown in Table 2.2.

Where possible, the evidence was matched to the relevant category and magnitude in the table. However, in some cases such evidence does not exist, and the analysis allows for expert judgement to be used. To make this process robust, this was based on the consensus (through consultation and discussion) of Technical Report authors, the CCC, and the CCRA peer reviewers.

A further change in CCRA3 has been to provide different magnitude tables for each UK country (England, Northern Ireland, Scotland and Wales). This aims to provide an equivalent relative magnitude score of risks or opportunities for each country, i.e. to provide consistent relative scores of what is important for each DA. This approach was used because the use of a single scoring table led to important omissions (of magnitude) for the three DAs. This does, however, mean that risks or opportunities in each country do not have the same absolute risk or opportunity level. For England and the UK, Table 2.2 was used without adjustment. For other DAs, the values were adjusted using the information in Table 2.3. Note that scoring below the level of the DAs (at a more disaggregated level or for hotspots) has not been undertaken.

The evidence from the review was used with Table 2.2 and 2.3 to assign a low, medium or high magnitude to each risk or opportunity - there is also an option of an ‘unknown’ score in case there is insufficient evidence. Opportunities were assessed using the same magnitude level, but with opposite sign.

It is stressed that these categories are not mutually exclusive, but are a set of options from which chapter authors could choose based on the evidence available. They were asked to choose from the categories to score a risk in the fullest way possible with the evidence available. It is acknowledged that in some cases, the available evidence will represent an underestimate of the total scale of risk or opportunity, thus a logarithmic scale is used to reduce the sensitivity to gaps in the evidence.

The other main development in CCRA was the consideration of future risks across different future time periods and scenarios, in line with the customer request. The resulting scoring table is presented in section 2.6.2.

Box 2.3 Natural Environment and Natural Capital.

In considering the size of risks or opportunities in the natural environment, different types of quantification are possible depending on what is being measured. This could be the size of a natural capital asset (see below), the size of an area containing different assets, the change in the quality or quantity of a natural asset, the services it provides to people, or the value of those services. CCRA2 only provided magnitude categories for the area or size of habitats and species affected, but when looking at the definition of natural capital, it is clear that these measures do not capture the total risk. The additional categories in Table 2.2 are intended to allow for a fuller analysis depending on the evidence available. While the terms natural environment and natural capital are both included here to ensure comparability between this and past CCRAs, going forward (including in CCRA4), it would be useful for these terms to be consolidated.

Natural capital is defined by NCC (2017) as follows: Natural capital are the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. Natural capital is a broad term that includes many different components of the living and non-living natural environment, as well as the processes and functions that link these components and sustain life. Natural capital assets include all biotic and abiotic assets (e.g. species, ecological communities, soils, freshwaters, land, atmosphere, minerals, sub-soil assets and oceans) and include both designated and undesignated habitats and species. The magnitude of a risk on a natural capital asset can be measured using any of the quantitative or qualitative indicators in Table 2.2, and not just those described using the term 'natural capital'.

Table 2.2 CCRA magnitude categories for UK and England.

	High Magnitude	**Medium Magnitude**	**Low Magnitude**
Quantitative evidence	*Major annual damage and disruption or foregone opportunities:*[1]	*Moderate annual damage and disruption or foregone opportunities:*	*Minor annual damage and disruption or foregone opportunities:*
	-£hundreds of millions damage (economic) or foregone opportunities, and/or	-£tens of millions damage (economic) or foregone opportunities, and/or	-Less than £10 million damage (economic) or foregone opportunities, and/or
	-Hundreds of deaths[2], thousands of major health impacts, hundreds of thousands of people affected / minor health impacts, and/or	-Tens of deaths, hundreds of major health impacts, tens of thousands of people affected / minor health impacts. and/or	-A few deaths, tens of major health impacts, thousands of people affected / minor health impacts, and/or
	-Tens of thousands of hectares land lost or severely damaged[3], and/or thousands of km of river water/km^2 of water bodies affected, and/or	-Thousands of hectares of land lost or severely damaged, and/or hundreds of km of river water/km^2 of water bodies affected, and/or	-Hundreds of hectares of land lost or severely damaged, and/or tens of km of river water/km^2 of water bodies affected, and/or
	-Major impact (~10% or more at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	-Intermediate impact (~5% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	-Minor impact (~1% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or
	-Major impacts on or loss of species groups, and/or	-Intermediate impacts on or loss of species groups, and/or	-Minor impacts on or loss of species groups, and/or
	-Major impact (10% or more at national level) to an individual natural capital asset and associated goods and services[4,] and/or	- Intermediate impact (1 to 10% at national level) to an individual natural capital asset and associated goods and services, and/or	- Minor impact (~1% or less at national level) to an individual natural capital asset and associated goods and services, and/or
	-Major loss or irreversible damage to single nationally iconic heritage asset (e.g. Stonehenge, Giants' Causeway)	-Medium loss or irreversible damage of nationally iconic heritage asset (e.g. Stonehenge, Giant's Causeway)	-Low loss or irreversible damage to nationally iconic heritage asset (e.g. Stonehenge, Giants' Causeway)
Qualitative evidence	Expert judgement of chapter authors, confirmed with agreement across authors, CCC and peer reviewers suggest there is a possibility of impacts of the magnitude suggested above.		

[1] This could be an annual average or expected annual damages. Where evidence is only related to a single event, authors should make a judgement on the magnitude and state this in their assumptions.

[2] The implied value of number of deaths is broadly in line with the value of prevented fatalities used by Government in the appraisal of policies (see DfT, 2019). It should be noted that this applies to an 'average' prevented fatality, i.e. someone of average age and who is otherwise healthy. The number of major injuries / major health outcomes, and minor injuries / minor health outcomes / people affected, are also in line with values used in appraisal.

[3] These values are based on the average value for an agricultural hectare of land in England that is estimated to be £22k (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/710539/Land_Values_2017.pdf) It is noted that the average value for residential, commercial and industrial land is much higher, and thus if urban land areas are affected, these scoring categories might be adjusted, i.e. so that a lower number of hectares would be equivalent to a low, medium or high ranking.

[4] The areas of natural capital assets are based on the definitions and reported values in the ONS Natural Capital Accounts and expert analysis of equivalence, https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalaccounts/2019.

<table>
<tr><td colspan="5">Table 2.3 Adjustment factors for scoring magnitude for devolved administrations.</td></tr>
<tr><th></th><th>England</th><th>Northern Ireland</th><th>Scotland</th><th>Wales</th></tr>
<tr><td>Economics</td><td>As table above</td><td colspan="3">Metrics in table above adjusted for gross value added[1], thus to give relative importance, values in table are reduced by 1 order of magnitude, and applied equally to Northern Ireland/Scotland/Wales.
• £tens of millions damage or foregone opportunities,
• £ millions damage or foregone opportunities
• Less than £1 million damage or foregone opportunities.</td></tr>
<tr><td>Health</td><td>As table above</td><td colspan="3">Metrics in table above adjusted for population[2], factoring down levels in table by 1 order of magnitude, and applied equally to all DAs.
• Tens of deaths, hundreds of major health impacts, tens of thousands of people affected / minor health impacts, and/or
• A few deaths, tens of major health impacts, thousands of people affected / minor health impacts, and/or
• No deaths, a few major health impacts, hundreds of people affected / minor health impacts, and/or</td></tr>
<tr><td>Land</td><td>As table above</td><td>Metrics in table above adjusted for land[3], factoring down levels in table by 1 order of magnitude.
• Thousands of hectares land lost or severely damaged,
• Hundreds of hectares of land lost or severely damaged,
Tens of hectares of land lost or severely damaged.</td><td>Given high land area of Scotland (approx. one third of UK) values in table above are used.</td><td>Metrics in table above adjusted for land[3], factoring down levels in table by 1 order of magnitude.
• Thousands of hectares land lost or severely damaged,
• Hundreds of hectares of land lost or severely damaged,
Tens of hectares of land lost or severely damaged.</td></tr>
<tr><td>Habitat / Natural capital</td><td>As table above</td><td colspan="3">As table above.</td></tr>
</table>

[1] Economics. Gross Value Added (GVA) is taken from Office for National Statistics https://www.ons.gov.uk/economy/grossvalueaddedgva/bulletins/regionalgrossvalueaddedbalanceduk/1998to2017

	GVA (2017 £M)	%
England	1,562,707	86.7%
Northern Ireland	39,613	2.2%
Scotland	138,231	7.7%
Wales	62,190	3.4%
UK	1,802,741	

[2]Population is taken from the Office for National Statistics – National population projections https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2018based#table-1408dbb6

2018	Million	%
England	56.0	84%
Northern Ireland	1.9	2.9%
Scotland	5.4	8.1%
Wales	3.1	4.7%
UK	66.4	

[3] Land area is taken from the Office for National Statistics using latest land cover accounts.https://www.ons.gov.uk/economy/environmentalaccounts/articles/uknaturalcapitallandcoverintheuk/2015-03-17

	Thousand Hectares	
England	13,043	53.4%
Northern Ireland	1,415	5.8%
Scotland	7,881	32.3%
Wales	2,078	8.5%
UK	24,417	

2.6.1.1.2. Quality of Evidence and Level of Agreement (Confidence)

In the IPCC AR5 synthesis process (Mach et al., 2017), assessment findings are evaluated against (a) evidence and agreement, (b) confidence, and (c) likelihood. For CCRA3, a formal method was used to assess the quality of the evidence used in terms of evidence and agreement, and thus confidence.

In terms of the quality of evidence, there is a requirement that evidence be from:

- Published papers in academic and professional journals;
- Papers *in press* in academic and professional journals (*copies of these should be made available to the reviewers, and have been published by the time the CCRA3 Technical Report is published*);
- Published (or publicly available, including at cost) reports from research institutions, Government agencies, Government committee reports, papers and minutes (and responses to consultations), third-sector organisations or private sector companies (including contract research reports), as well as grey literature that has been through a review process and is published.

These sources of evidence were recommended *not* to be used:

- Papers that have been ‘submitted’ or are ‘in preparation’ at the time of the publication of the CCRA3 Technical Report:
- Reports that are not publicly available, even at cost.

To assess the confidence a simplified version of the IPCC AR5 approach is used, looking at the combination of the quality of evidence as set out above (from high to low), along with the level of agreement between studies and experts (high to low). These are combined to give the overall confidence ranking. Note that the confidence is a measure of the strength of evidence and agreement, and is different to the likelihood that the risk or opportunity will occur. Table 2.4 provides the criteria used to assign a confidence score to each risk and opportunity in Step 1. There is also a similar quality of evidence and agreement included for assessing the effect of adaptation in Step 2 and if additional action would be beneficial in Step 3. Additional supplementary information for assessing the quality of evidence is included in Table 2.5.

Table 2.3 Quality of Evidence and Level of Agreement (Confidence) – Criteria.

	High	**Medium**	**Low**
Step 1: Assessment of current and future risk	Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement between studies and experts.	Several sources of high-quality independent evidence, with some degree of agreement between studies, and/or widespread agreement between experts.	Varying amounts and/or quality of evidence and/or little agreement between experts, or assessment is made using only expert judgement.
Step 2: Assessment of the effect of planned and non-Governmental adaptation	High quality evidence of the effects of future adaptation in managing the risk and high agreement between experts.	Some evidence on the effects of future adaptation in managing the risk and/or high agreement between experts.	Little/no/contrasting evidence of the effects of future adaptation in managing the risk and little agreement between experts, or assessment is made using only expert judgement.
Step 3: Assessment if additional action would be beneficial	High quality evidence of benefits of future adaptation on risk and high agreement between experts.	Some evidence on benefits of future adaptation and/or high agreement between experts.	Little evidence of the benefits of future adaptation and little agreement between experts, or assessment is made using only expert judgement.

Table 2.4 Supplementary information for assessing Quality of Evidence.		
High quality evidence	**Some evidence**	**Little evidence**
• Multiple sources of evidence that contain similar results • Evidence of validation using different datasets • Based on robust techniques • Data used is of a high quality • Evidence has been peer reviewed • Remains relevant • Use of relevant indigenous and local knowledge	• Some elements of "high quality evidence" and "little evidence"	• No, or very few, sources of evidence • Based on only one dataset • Based on weak methodologies (e.g. anecdotal evidence) • Poor quality data • Evidence has not been peer reviewed • No longer relevant • No use of relevant indigenous and local knowledge

2.6.2 Task 1b Assess Future Risks and Opportunities

The second task undertakes an analysis of the future risks and opportunities of climate change, repeating the steps above but for future time periods. This step also considers risks in terms of hazard, vulnerability and exposure. However, it involves the additional challenge of different future climate projections, uncertainty and future socio-economic change. The task applied the IPCC Core Concepts to assess future risks, while noting that the components of hazard, exposure and vulnerability are dynamic and change over time. For opportunities, the focus was on the magnitude of potential consequences. The CCRA authors were asked to consider the following issues:

- How relevant climatic factors, and risks or opportunities, may change in the future, including an assessment of the uncertainties.
- How socio-economic factors could influence the risk/opportunity in the future and their influence on magnitude.
- To record evidence for the risks and opportunities in the mid-century (2050s, i.e. 2041-2060) and late-century (2080s, 2070 – 2099), including the uncertainties associated with the climate evidence. This also included the differences in future risks or opportunities for pathways to warming of 2°C and 4°C by the end of the century, globally, relative to pre-industrial, where available, including quantification of uncertainty. Authors were asked to record the reference period used (noting UKCP18 is now using 1981-2000). They were also asked to document the assumptions on socio-economic scenarios and to document the relative importance of climate versus socio-economic (if available). When evidence was based on global warming levels, the teams were asked to document the Global Warming Level (GWL) and time period (e.g. 2°C GWL global mean temperature (GMT), relative to preindustrial, exceeded in time period centred on 2070).
- To capture and report on any low-likelihood high-impact extremes or scenarios. This included High++ runs, tail-end risks, higher warming scenarios (e.g. > 4°C by 2100) and earth system tipping points.
- To identify any potential risks of lock-in (see section 2.3), or loss of opportunities, particularly where decisions might be taken in the next reporting period (the next 5 years). They were also

asked to document important thresholds (whether biophysical thresholds, engineering, performance or policy thresholds, see section 2.3) and consider if the exceedance of these varied over scenarios or across projections (including uncertainty). Authors were also asked to assess the potential synergies and trade-offs with Net Zero, as part of a separate set of questions.

- To assess the magnitude of the risks and opportunities in the future and how important climate change is in the realisation of a risk.

At the end of this task, the same magnitude scoring approach as for Task 1a (Tables 2.2 and 2.3) were used to score future risks and opportunities. This was undertaken separately for each UK country (England, Northern Ireland, Scotland and Wales).

For the first round of magnitude scoring (in early 2020), authors were asked to assess future magnitude (High, Medium, Low or Unknown) as one single score, which reflected the highest score across different time periods, scenarios or pathways, and across the uncertainty range. Note that this approach is inherently precautionary, and followed the approach used in CCRA2.

For the second round of scoring (summer to autumn 2020), authors were asked to assess magnitude in line with the request from Government. This included information on potential risks and opportunities under different time periods (mid-century and late century) and different future pathways, defined broadly in terms for 2°C and 4°C pathways by the end of the century (globally, relative to pre-industrial levels)[2] as well as for each DA. Authors were asked to provide the highest score across the uncertainty range in each cell. This is shown in Table 2.6 below.

An assessment of the quality of the evidence and level of agreement, i.e. confidence, was also undertaken and included in brackets after the magnitude score (Tables 2.4 and 2.5).

A number of additional aspects to consider were also requested. Authors were asked to consider the implication of different rates of climate change between the two scenarios, not just the absolute change, as this is extremely important in determining adaptation potential. They were also asked to consider the distributional effects and potential inequalities associated with risks and opportunities (see section in 2.6.1.).

[2] This did not include a scenario that limits warming to 1.5°C, i.e. to consider an additional scenario that was closer to the Paris Agreement text of pursuing efforts to limit warming to 1.5°C relative to pre-industrial. This 1.5°C scenario has received more attention following the recent IPCC Special Report on Global Warming of 1.5 °C (IPCC, 2018). CCRA3 has not considered such a 1.5°C scenario, see Chapter 1. This is primarily due to the lack of information to inform a risk assessment at this level. However, it is noted that global emissions are still rising and current pledges for reducing emissions, as set out in the Nationally Determined Contributions, indicate warming of above 3°C (UNEP, 2019; UNEP, 2020). This analysis has also identified limiting warming to 1.5°C would require global emissions to fall by 7.6% per year from 2020 to 2030. The progress towards such reductions will become clearer during the Global Stocktake (in 2020, now delayed to 2021), which will review the implementation of the Paris Agreement and assess collective progress and updates towards achieving the Paris Agreement and its long-term goals.

Table 2.5 Magnitude Scoring summary table in CCRA3. Each cell was assigned a score of low (L), medium (M), high (H) or unknown (U).

	Present Day	**2050s**		**2080s**	
Country		**On a pathway to stabilising global warming at 2°C by 2100***	**On a pathway to 4°C global warming at end of century#**	**On a pathway to stabilising global warming at 2°C by 2100***	**On a pathway to 4°C global warming at end of century#**
England	L/M/H/U	L/M/H/U	L/M/H/U	L/M/H/U	L/M/H/U
Northern Ireland	L/M/H/U	L/M/H/U	L/M/H/U.	L/M/H/U	L/M/H/U
Scotland	L/M/H/U	L/M/H/U	L/M/H/U	L/M/H/U	L/M/H/U
Wales	L/M/H/U	L/M/H/U.	L/M/H/U.	L/M/H/U	L/M/H/U

*This scenario is defined as the global mean temperature rise stabilising at 2°C ± 0.5°C by 2100. This includes pathways that align to the Paris Agreement and the goal of limiting global mean temperature rise to well below 2°C above pre-industrial levels, and also pathways that slightly exceed this global warming level, including "overshoot" pathways.

This scenario is defined around outcomes that lead to a 4°C global mean temperature rise above pre-industrial levels at the end of the 21st century (2080 to 2100). This is considered an upper bound of global warming rates that could occur with current policies, considering various combinations of emissions scenarios and climate system feedbacks (see Introduction chapter: Betts and Brown, 2021.

A supplementary analysis was undertaken to investigate the indicative monetary impacts of future risks and opportunities (see section in 2.6.1.). Alongside this magnitude score, authors were also asked to consider possible low likelihood, high impact extremes and scenarios (including high warming outcomes that reach 4°C before 2070, High++, tail-end risks and earth system tipping points). However, the evidence (on low likelihood, high impact) was not used in the magnitude scoring.

It is stressed that the primary aim of this task was to identify the magnitude of future risk and opportunities in the absence of planned adaptation - the analysis of adaptation in managing these future risks is undertaken in step 2. However, for studies that undertake modelling of risks and adaptation, including the CCRA3 research projects, it was necessary to define no adaptation baselines. To address this, CCRA3 defined a Step 1 future 'no additional adaptation' scenario. This included 'common sense' assumptions on what might happen in the absence of planned policy. This is the same approach that was used in CCRA2.

One lesson from the application of the method for opportunities was that in most cases, these are complicated by the presence of potential risks alongside benefits, e.g. where there were potential benefits identified from a warmer average climate, there were often still potential impacts from changing variability or extremes, or other factors such as water availability limiting the ability for enhanced crop growth in warmer temperatures. In such cases, authors were asked to document both aspects.

More information on key elements of this task – on climate projections, socio-economic scenarios, the Net Zero analysis, and tail-end risks - are given below.

2.6.2.1 Climate change projections, including uncertainty

The starting point for the assessment of future risks and opportunities are the climate projections, set out in Chapter 1 (Slingo, 2021). There are different ways to use these projections in climate risk assessments, and to ensure consistency of reporting for different risks and opportunities. However, these consistency issues are a particular challenge for a synthesis exercise, such as CCRA3, because it must draw on various evidence that uses different projections and approaches.

In previous CCRAs, and in most impact studies, analysis or evidence is assessed for future scenarios and time periods. In CCRA1, a consistent set of projections and time slices from UKCP09 were used and applied to every risk or opportunity. This used the UKCP09 time slices[3] for the 2020s (represented by the mean climate for 2010-2039), 2050s (2040-2069), and 2080s (2070-2099) relative to a baseline period of 1961-1990 and considered the UKCP09 low, medium and high UKCP09 projections, as well as sampling the probabilistic projections[4],[5]. CCRA2 was a synthesis exercise, but asked contributors to report evidence for the 2050s, and 2080s, including a discussion on the uncertainties associated with the climate evidence used. The authors considered climate projections on a country-by-country basis, for the subsequent risk and opportunity assessment. In CCRA2, this was based on country averages, but with commentary around how this varied spatially.

As set out in Chapter 1 (Slingo, 2021), and earlier in this Chapter, the UK has now published a new set of climate projections, the UK Climate Projections 2018 (UKCP18). The UKCP18 overview report (Lowe et al., 2018) reported changes for two future time periods (of twenty years) – the 2050s (2041-2060) and 2080s (2080 – 2099), relative to a baseline period of 1981-2000, though the UKCP18 projections also provide a time series that runs continually from pre-present through to 2100. The UKCP18 products allow analysis of projections with the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 emissions scenarios, and also some potential to extract information specifically for 2°C and 4°C global warming levels relative to pre-industrial (Gohar et al., 2018). The latter allows for an alternative approach to reporting results, using global warming levels (GWL), rather than for time periods for emission / forcing scenarios. However, it is stressed that for adaptation, the time period when risks or opportunities occur and the rate of adaptation needed are important, and therefore approaches that use GWL need to document time, as has been done here. It is also possible to extract subsets of the projections that follow pathways that reach these global warming at specific times such as at the end of the 21st Century, and this has been done in some of the CCRA3 supporting research (Sayers et al., 2021) and in other literature drawn on for the CCRA3 assessment (e.g. Arnell et al., 2021)

---

[3] Note that projections are generally presented as averages for twenty-year or thirty-year time periods, not as decadal or yearly averages, because decadal periods are still subject to significant natural variability and may not give a good indication of the long-term climate.
[4] CCRA1 sampled across the p10, p50 and p90 for the UKCP09 low medium and high projection and focused on nine combinations (results) as follows: 2020s: p10 Medium, p50 Medium, p90 Medium; 2050s: p10 Low, p50 Low, p50 Medium, p50 High, p90 High; and 2080s: p10 Low, p50 Low, p50 Medium, p50 High, p90 High.
[5] It is interesting to note that the CCRA3 Independent Assessment and the next national adaptation programme period (2023-2027) is at the mid-point of the UKCP09 2020s time period.

In gathering existing information on the evidence in CCRA3, authors were asked to understand and assess how climate and socio-economic change may alter climate-related risks and opportunities for the mid-century (the 2050s, often represented by the mean climate for 2040 -2060) and late-century (2080s, or 2070 – 2100), for 2°C and 4°C warming pathways by the end of the century (globally, relative to pre-industrial levels), where possible. Authors were asked to be explicit about the reference (baseline) periods used for evidence.

As highlighted earlier, much of the literature on future UK climate risks assessed in CCRA3 is based on UKCP09. In practical terms, this raised an issue on how to use information from UKCP09 in CCRA3, given the different baseline and future periods[6], as well as the updated information from UKCP18. To address this, the UK Met Office produced new information for authors, based on the key metrics of relevance for the identified risks and opportunities (see Chapter 1: Slingo, 2021). A summary is provided in Box 2.4.

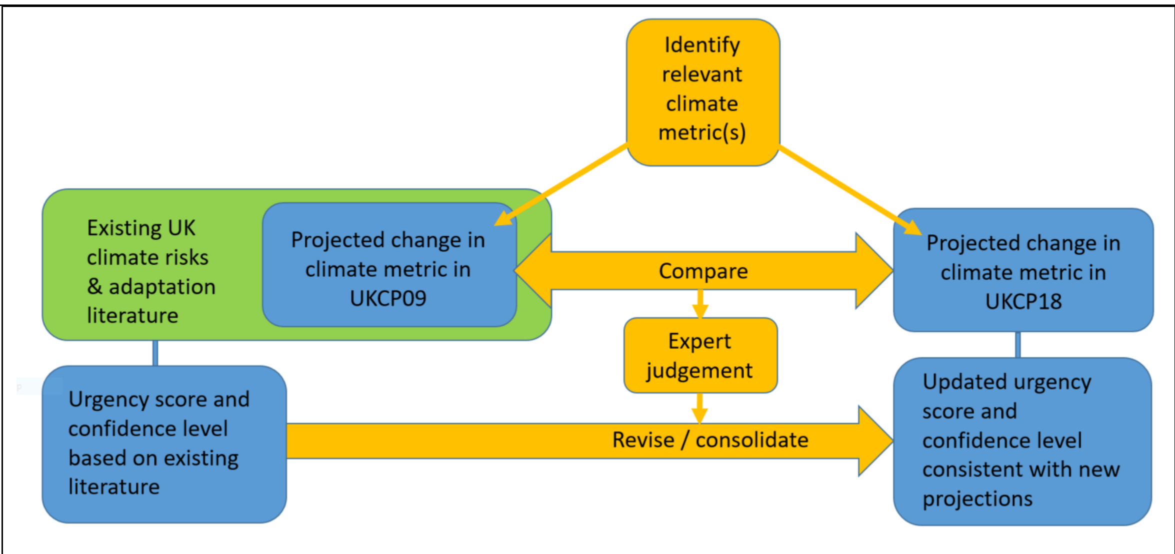
In collecting this information, and assessing adaptation, it is important to consider uncertainty. This involves two issues. The first is that there are alternative future emission pathways, which is addressed by using several sets of projections sampling the emissions scenarios associated with the Representative Concentration Pathways, RCPs, as in UKCP18. The second issue is that different climate models do not all give the same results for UK climate for a given emissions scenario or even at the same global warming level. This can be considered by using different models in an ensemble, or as in UKCP18, with the derivation of a conditional probability range, with outputs of (for example) 10^{th,} 50th and 90th percentiles. It is essential to recognise this uncertainty, not to ignore it.

Box 2.4. Supporting Climate Analysis for CCRA3.
UKCP09 to UKCP18. As noted in Chapter 1 (Slingo, 2021), some of climate risk-related quantities in UKCP18 are quite different to those in previous projections, while others are similar. Analysis by the UK Met Office for CCRA3 assessed key climate metrics (of relevance to the CCRA3 risks and opportunities) and provided information on when these differences were extensive enough to affect the advice previously provided by the CCRA around estimates of magnitude drawn from UKCP09, and also to take account of similarities when assessing confidence. To do this, the analysis in CCRA3 has used the following procedure for each Risk, (illustrated earlier in Figure 2.1). • Produce an initial magnitude score based on the existing UKCP09-based literature where relevant. • Identify the key climate variables or metrics used to quantify the hazard component of the risk or opportunity in the existing UKCP09-based literature. • Compare the projected changes in these variables and metrics from UKCP09 with the equivalent changes in UKCP18. • Using expert judgement, assess whether the differences between the changes projected by UKCP18 and UKCP09 are substantial enough to justify a different magnitude score. • If a different magnitude Score is justified by the UKCP18 projections, critically examine the underlying reasons for the difference in the projected climate variable / metric and form a

[6] Earlier impact studies, such as those based on UKCP09, use an earlier reference period (usually 1961-1990), but this is now out of date with respect to the current time (i.e. the year 2020). It is stressed that the magnitude does vary depending on whether risks compared with 1961-1990, 1981-2000 or the current.

judgement on which is the most robust. Reflect this change by use of an appropriate confidence statement. If a different magnitude Score is not justified, again critically examine the reasons for the similarity in in the projected climate variable / metric, and assign an appropriate confidence level.
- Ascertain if the change in magnitude warrants a change in the urgency score.

The UKCP09-UKCP18 comparison used the UKCP09 regional climate model (RCM ensemble) and was performed most systematically with the UKCP18 12km projections, but the 2.2km projections were also considered. Furthermore, the UKCP18 60km global simulations were also used to provide further context. The results were examined to assess whether the changes in key metrics – and subsequent risks and opportunities where relevant - were substantial enough to justify a different magnitude and urgency score.



Box 2.4 Figure 1. Comparison of old and new climate projections for assessing robustness of existing literature in the context of new projections and revising / consolidating urgency scores and confidence levels.

Volatility, extremes and UNSEEN. The climate of the future can be viewed as a long-term climate trend with natural variability superimposed on to it and providing volatility, which will be experienced as future weather. UKCP18 focuses more than UKCP09 on capturing climate volatility, with the conditional probability range including natural variability down to the monthly scale and the ensembles of realisations from global and regional climate models providing a tool to examine sub-monthly volatility (Lowe et al., 2018). Additionally, other tools are now available in the climate literature that focus on present day volatility and the possibility of seeing unprecedented events not captured in the relatively short observational record. These include the UNSEEN approach (Thompson et al., 2017), which uses many historical simulations to provide additional realisations of the events that might occur in the current climate. When assessing climate impacts, it is important to go beyond the long-term mean changes and to take account of volatility and extreme events, including unprecedented events. This can significantly widen the distribution of potential climate outcomes as Lowe et al. (2018) describe when showing probability distributions based on annual averages and multi-decade averages. From an impacts perspective it is useful for chapter authors to consider the time over which a threshold might be exceeded, relating this to natural climate variability where possible. There is also the potential to consider event-based extremes, including the analysis of preparedness, based on previous analogues, e.g. as used in the National Flood Resilience Review for Storm Desmond.

As discussed in Chapter 1 (Slingo, 2021), the projected temperature and precipitation changes are broadly similar until the 2040s across all the scenarios (i.e. with similar results for RCP2.6, RCP4.5 and RCP6.0 and to a slightly lesser extent in results for RCP8.5). There is also only a small difference between the climate outcomes of these emissions scenarios even at mid-century (the 2050s). However, there is a much larger difference in the results between or within models at this time (in the 2050s). This means that the main uncertainty at mid-century is due to differences between (and within) the climate models - or to put another way – projections for the mid-century are broadly similar irrespective of the emissions scenario being assumed. This is illustrated by, for example, the 10th to 90th percentile range from UKCP09, or the 5th to 95th percentile range from UKCP18. As shown in Chapter 1 (Slingo, 2021), this leads to a considerable range, and for some parameters (e.g. summer rainfall), it can even lead to a change in the sign, from an increase to a decrease in the projected change.

As CCRA3 has the primary goal of informing adaptation, it is just as important to sample model uncertainty as it is to sample emission pathway uncertainty, especially for the medium term (2050s), which is of most interest for informing early adaptation. Authors were asked to consider the conditional probability range, specifically the 10th to 90th percentiles in the UKCP09 or UKCP18 projections, but in practice it was extremely difficult to do this in a synthesis exercise such as CCRA3, though authors considered ranges of uncertainty where relevant information was available.

Towards the late-century (2100) the RCPs diverge significantly, as shown in Chapter 1. At the end of the century (2100) there are large differences between the central estimate pathways, although the very large differences across the percentile ranges mean that there is still a large overlap between the outcomes for the different RCPs, especially for precipitation changes at the UK scale (see Chapter 1).

A further issue is that different sets of climate projections use different emissions scenarios and different approaches for implementing these in climate models. For example, UKCP09 used the SRES emissions scenarios. The 5th Coupled Model Intercomparison Project (CMIP5) projections for IPCC AR5 used the Representative Concentration Pathways (RCPs) which were defined in terms of concentrations of CO_2 and the resulting radiative forcing, as opposed to emissions. UKCP18 used yet another approach – it used emissions scenarios that were designed to align with the RCP concentration pathways based on a specific assumption of the strength of climate-carbon cycle feedbacks, but then made its own calculations of the future concentrations accounting for uncertainties in the feedbacks. The evidence base available to CCRA3 included studies using all these different approaches.

To account for these uncertainties in both future emissions and the responses of the climate to these emissions, whilst avoiding reliance on specific methods and hence excluding important bodies of evidence in the literature, CCRA3 characterises future climate change in terms of two pathways. These are defined as broad pathways to approximately 2°C and 4°C global warming at the end of the 21st Century (Box 2.5). This allows the use of more evidence, as it can include scenarios or emissions (or radiative forcing) and time slices, as well as warming levels. The assessment considers risks and opportunities on the basis of studies using climate projections consistent with these 2°C and 4°C pathways. The uncertainty range across each pathway is considered as far as possible, and the Step 1 assessment uses the highest resulting magnitude score for across each scenario (across the uncertainty range) and time period. The analysis of whether the risks and opportunities are being managed across both the 2°C and 4°C pathways is considered in the subsequent Step 2.

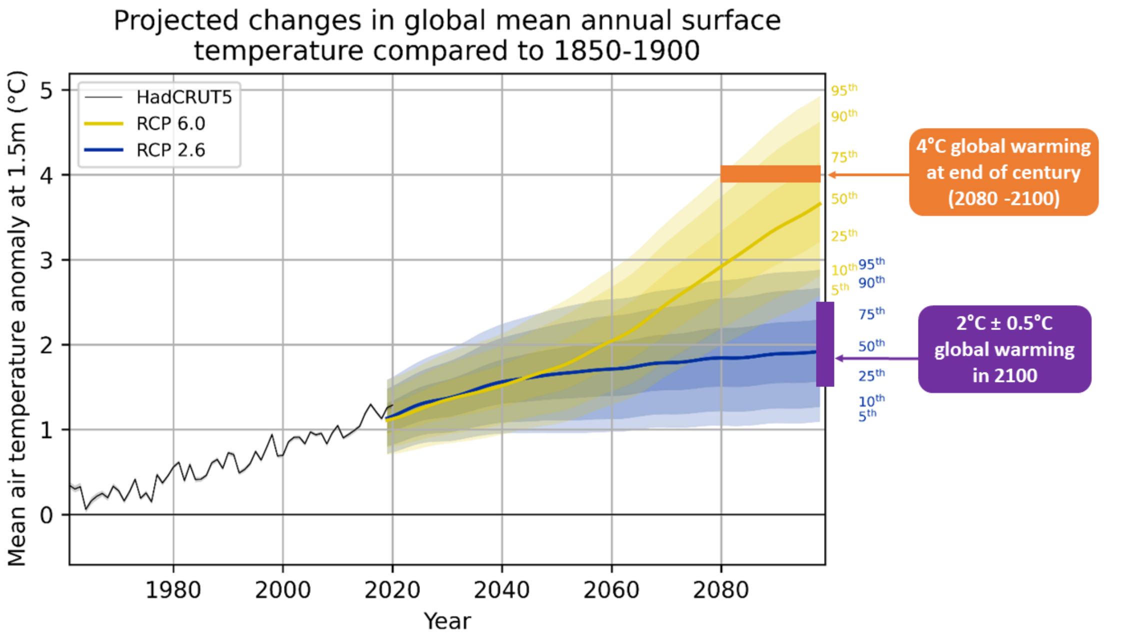
Box 2.5. Characterising future climate change: pathways to 2°C and 4°C global warming at the end of the 21st Century.

In the mitigation domain, the characterisation of 2°C and 4°C warming pathways is a useful proxy for considering the costs of inaction, and the possible benefits of global emissions reductions e.g. in line with the Paris Agreement goals. However, the aim of the CCRA3 is to inform adaptation and a different framing is used. This centres on the urgency of short-term action that is needed in the next five-year period to help adapt to uncertain futures. It is therefore wrong to frame adaptation as two different alternative levels of effort that might be needed for 2°C vs 4°C global warming, but rather to identify what is needed today, given a wide range of outcomes are possible that span this range. Furthermore, there is an additional level of uncertainty associated with the climate models, quantified with percentile ranges such as the 5th or 95th or 10th to 90th percentiles from UKCP18 for each RCP or pathway. In the 2050s, the uncertainty from this uncertainty range is generally larger than between different emissions scenarios. Finally, it is stressed that for adaptation, time matters, i.e. it makes a big difference if 2°C warming is exceeded in 2050 or towards late century. For this reason, two time periods are considered, the 2050s and 2080s.

In the adaptation literature, this uncertainty is usually comprehensively sampled using decision making under uncertainty approaches. However, this approach is challenging for a synthesis exercise like CCRA3. Instead CCRA3 characterises the future in terms of pathways to approximate levels of global mean warming by the end of the century (2°C vs 4°C) and considers the uncertainty in the climate projections for each of these pathways. This allows sampling of scenario and model uncertainty. This broad approach is important because the evidence base for CCRA3 consists of studies that have used a number of different approaches, including different emissions scenarios and based on different climate models or projections. In order to make maximum use of the available evidence, an approach is used that allows evidence from a wide range of relevant sources irrespective of the details of specific scientific approaches. It is also stressed that any particular UK climate state could arise from a range of different emissions scenarios, depending on feedbacks in the climate system and the responses of regional climate processes within global-scale changes. For simplicity and clarity, CCRA3 uses two broad pathways to help sample the evidence. The lower pathway represents, approximately, the level of climate change if the goals of the Paris Agreement are met. The higher pathway represents the upper end of climate outcomes consistent with current worldwide policies.

The pathway to 2°C global warming by 2100. This is representative of stabilisation of global warming at approximately 1.5°C to 2.5°C above pre-industrial by the end of the 21st Century. This aligns to the goal of the Paris Agreement to limit warming to "well below" 2°C and "pursue efforts" to limit warming to 1.5°C. However, given the large uncertainties in regional climate outcomes related to any specific level of global warming, and the large overlap in the ranges of possible UK climate states consistent with 1.5°C to 2°C warming, a single Paris-compliant scenario is used in CCRA3, labelled the "2°C warming by 2100 pathway". This deliberately imprecise definition of the 2°C pathway has the advantage of allowing the use of a large body of literature on climate change impacts and risks under the RCP2.6 emissions scenario, which stabilises global warming in the range of approximately 1°C to 3°C at the 5th and 95th percentiles in the UKCP18 probabilistic projections (Box 2.5 Figure 1). The CMIP5 projections with the RCP2.6 concentration pathway stabilise at slightly lower temperatures (Murphy et al., 2018).

The pathway to 4°C global warming at the end of the century. The higher pathway reaches global warming of 4°C at the end of the 21st Century (2080 - 2100). This represents the upper end of climate projections consistent with current worldwide policies, with the upper bound being the 95th percentile of the UKCP18 global probabilistic projections driven with the RCP6.0 emissions scenario (Box 2.5 Figure 1). RCP6.0 emissions are within the range of 21st Century emissions pathways consistent with current worldwide policies (Hausfather and Peters, 2020; also see discussion in the Introduction Chapter: Betts and Brown, 2021). NB “current policies” are distinct from the pledged Nationally Determined Contributions (NDCs) under the Paris Agreement, which would give lower emissions but which are not yet enacted in practice. When the RCP6.0 emissions scenario is used with the UKCP18 global probabilistic projections, 4°C is reached in 2080 at the 95th percentile of the projections, and in 2100 at around the 70th percentile.



Box 2.5 Figure 1 Definition of 2°C and 4°C global warming pathways, compared with probabilistic projections of global warming with the RCP2.6 and RCP6.0 emissions scenarios from UKCP18 global projections (Murphy *et al.*, 2018), showing the 5th, 10th, 50th, 75th, 90th and 95th percentile changes. Source for projections data: Met Office

2.6.2.2 Socio-economic scenarios

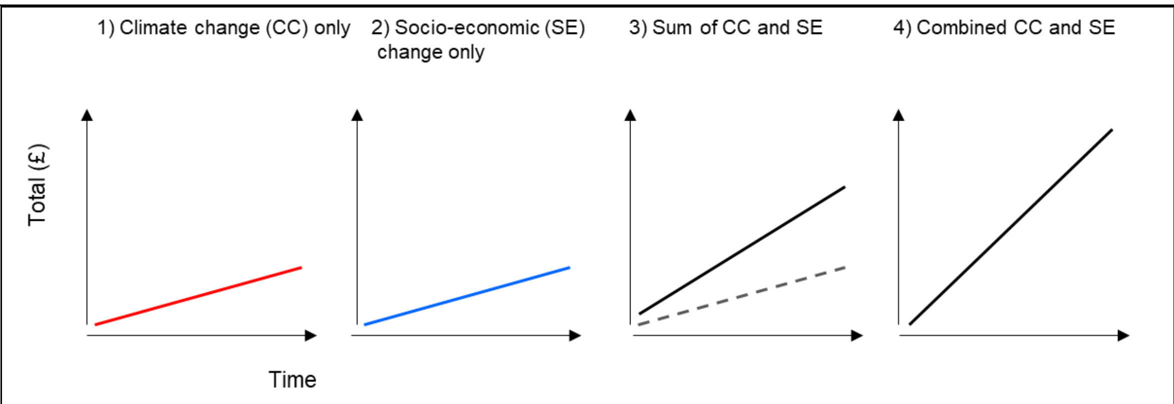
Future risks and opportunities are not just influenced by climate change, they are also influenced significantly in the future by socio-economic change (see Box 2.6). In theory, therefore, both should be considered in a national climate change risk assessment. These considerations are not trivial. Studies (e.g. Rojas et al., 2013; Brown et al., 2011) typically find that socio-economic change such as population or economic growth is at least as important as climate change in determining the overall magnitude of climate impacts in future periods. While the influence of socio-economics is often dominant at mid-century, it is still very large in the late century, as shown by studies that compare Shared Socio-economic Pathways (SSPs) (e.g. see Hinkel et al., 2014).

Box 2.6. Climate and Socio-economic Change.

CCRA3 should ideally take account of socio-economic change, as well as climate change, in the assessment of future risks and magnitude. A failure to do so implies that future climate change will take place in a world similar to today. The primary drivers of modelled socio-economic change include economic growth, demographic change (population) and land-use change, but there are also a wide range of other potential factors, including policy, societal and behavioural change, that are relevant, but more difficult to consider in quantitative terms. Future socio-economic change makes a very large difference to future risks, because climate and socio-economic factors can act together as risk multipliers (although it is also possible that socio-economic change can dampen impacts). There is also another dimension when considering adaptation interventions, because socio-economic change affects adaptive capacity, and therefore adaptation can be targeted to socio-economic aspects, in addition to or as well as climate risks. However, the consideration of these issues considerably complicates analysis.

Some studies look at the effect of future climate change alone, assessing the risks on the current stock (and exposure and vulnerability). This is shown using a simplified illustration (Box 2.6, Figure 1), starting with panel 1 (far left). However, in practice, even in the absence of climate change, there will be changes in exposure and vulnerability in the future, for example with the growing population projected in the UK, as well as the projected increase in economic growth. Panel 2 shows that even in the absence of climate change, future impacts could rise due to a greater stock at risk (all else being equal). However, it is not sufficient to add climate change and socio-economic together (Panel 3) because the two acting together can lead to larger cumulative risks (Panel 4, far right), e.g. climate change acts on a larger number of people or a greater value at risk (e.g. see Rojas et al, 2013). Ideally, therefore, studies should look at the future impacts of climate and socio-economic change individually as well as together, in order to separate out the relative importance of each, though in practice this is rarely considered in national risk assessments due to the difficulty of conducting this analysis across a wide range of risks.

It is also highlighted that there is considerable uncertainty around the socio-economic scenarios themselves, which adds another uncertainty dimension to risks, especially when combined with climate drivers. This can lead to a cascade of uncertainty (see Wilby and Dessai, 2010).



Box 2.6 Figure 1 Conceptual illustration of the impact of climate and socio-economic change, individually and in combination.

When undertaking new risk or impact assessment, it is possible to include consistent socio-economic scenarios. This approach was used in CCRA1, and it was also included in the CCRA3 research projects. However, such an analysis is impossible for a synthesis exercise such as CCRA3. Furthermore, there is very little consistency on socio-economics in the underlying literature that CCRA3 synthesises, with studies using very different approaches. Some impact studies only analyse climate change effects, i.e. they assume static socio-economic conditions. Others consider both climate and socio-economic change together, but they do this differently, e.g. some consider population growth only while others also include economic growth. Only a handful of studies split out the relative contribution of climate and socio-economic change, to allow analysis of the relative contribution of each. In theory it might be possible to use UK socio-economic projections to retrospectively adjust risk and opportunity scores, but in practice, this would be extremely challenging.

For CCRA3, authors were asked to report risks and opportunities transparently and consistently from different sources used in the evidence analysis, and to document the assumptions on socio-economic change (e.g. whether UKCP09 and UK socio-economic scenarios are used, or SSP scenarios, and which parameters were considered). However, this does not address the challenge of consistently scoring risks and opportunities in the magnitude tables. Ideally, all risks and opportunities should either consistently include or exclude socio-economic factors.

For CCRA3, the recommendation was to initially identify and score the total risk (the combination of climate and socio-economic change) where possible, on the basis that it is the total risk that the UK has to adapt to, provided climate change is a major factor[7], for example, the combined total effect of increased population and increased flood hazard. The exception to this is when a risk is dominated by other factors and not climate, e.g. as is the case for air pollution. In this case, authors were asked to score the incremental risk from climate change (and in the subsequent adaptation step, to only consider if the risks of additional climate-related risks were not being managed).

However, it was also recommended to split out (where possible) the contribution from climate change versus socio-economic change. In cases where risk information is only given in terms of the climate change signal alone, authors were asked to give some consideration (for future periods) of the potential change in risks (or opportunities) that might arise from the combination of socio-economic change. Most importantly, authors were asked to be transparent and document exactly what had been used, i.e. whether climate change only, or climate change and socio-economic change, and if the latter which metrics.

To help inform CCRA3, the CCC commissioned a new set of UK socioeconomic dimensions from Cambridge Econometrics (CE) (2019) as one of the CCRA3 research projects. These provided consistent projections out to 2100 for the following priority indicators: Population; Gross Domestic Product (GDP), Gross Value Added (GVA); Employment; Labour productivity (calculated from GVA

[7] A different issue arises if the CCRA3 Evidence Report was to be used to provide detailed information on the benefits of domestic mitigation policy, as part of global policy commitments towards the Paris Agreement. In this case, the focus is on the difference in the total risk between alternative climate and socio-economic outcomes, e.g. between 2 and 4°C, which provides the net benefit of mitigation. However, when reporting the marginal risk of climate change impacts for an individual scenario, this should - strictly speaking - only include the marginal increase over and above the socio-economic counterfactual, as only that marginal increase is directly attributable to climate change.

and employment projections); Land use; and Households occupancy rate. It is noted that this set of data is not a set of UK socioeconomic scenarios and is not aligned to the IPCC Shared Socio-economic Pathways (SSPs). Instead, the CE projections provide a central estimate along with an upper and a lower bound estimate for each of the indicators, to use across the CCRA analysis where appropriate. The low and high socio-economic data presented are based on the ranges from the national data sets, e.g. around UK population projections. This mirrors the approach used in previous CCRAs, which have focused on stand-alone national projections, in order to make sure that these are compatible with official Government projections. The CE projections do consider some mitigation elements for energy use, where the central scenario is based on the National Grid FES 'Two Degrees' scenario, and for land-use, where the high scenario includes an ambitious mitigation policy. It is noted that socioeconomic dimensions related to the adoption of the Net Zero emissions target was not factored into the CE report as quantified scenario data was not available, and does have some major implications, see section below. The CE socio-economic data sets were used in the CCC commissioned CCRA3 research projects on floods and water availability. However, they could not be used to adjust existing studies in the literature for the Technical Report chapters, because this would have required the primary studies to have presented future impacts for socio-economic change alone.

A final issue on the socio-economic scenarios is the linkages with the international climate change literature. In earlier studies (circa the time of the IPCC 4th Assessment Report), there was a set of self-consistent and harmonised scenarios for both socio-economic and climate change (the SRES scenarios). Future socio-economic pathways and associated Greenhouse Gas (GHG) emissions were first assessed, then fed into global and regional climate models.

For the IPCC 5th AR, a new family of scenarios was defined, the Representative Concentration Pathways (the RCPs) (van Vuuren et al., 2011). These include a set of four climate (forcing) pathways (now extended to five), which cover futures that are broadly consistent with the 2°C goal through to high-end (>4°C) scenarios. However, these were originally not aligned to specific socio-economic scenarios (as in the SRES). The RCPs were designed to be combined with a set of global Shared Socio-economic Pathways (SSPs) (O'Neill et al., 2014). The SSPs provide a set of socio-economic data for alternative future pathways. Five alternative SSPs are currently provided (SSP1 to SSP5), each with a unique set of socio-economic data and assumptions (available for each country). The SSPs are presented along the dimensions of challenges to mitigation and adaptation. This provides the flexibility to combine alternative combinations of future climate and socio-economic futures. Combining RCPS and SSPs gives a large matrix of combinations (though not all RCP-SSP combinations are considered possible, Riahi et al., 2017). This amplifies the uncertainty envelope, and there is a need to sample possible future combinations to make analysis manageable. The RCP-SSP approach has been used in much of the International climate literature when undertaking new impacts analysis (e.g. see IPCC 2018a; IPCC, 2019). The SSPs have not been used in CCRA3, as this is not possible in a synthesis exercise, and were not considered in the CE study. However, there has been recent work that has developed Shared Socio-economic Pathways for the UK (UK-SCAPE: SPEED project) (Pedde et al, 2020). These provide downscaled and enriched versions of the SSPs for the UK as narratives and tables of trends and provide additional relevant information, which could be used as an underpinning dataset for CCRA4. These are summarised in Box 2.7 below: these descriptions are from the SPEED project itself and are presented as an illustration of this type of approach: they were not used in CCRA3. There are also similar SSPs that have been developed specifically for Scotland (Kok et al., 2016).

Box 2.7. Example of Shared Socio-economic Pathways for the UK.

The UK-SCAPE project has developed UK SSPs. The summaries of these are presented below (Pedde et al, 2020) as an example of the development of UK specific SSPs. We stress the descriptions given below are taken from the study itself.

UK SSP1-Sustainability. A shift towards sustainability is triggered by natural disasters, the vulnerability of many job sectors, and worsening standards of living that are perceived to be connected to environmental degradation. Local green political networks and initiatives for change emerge, leading to strong support for regionalisation. New legislation integrates green development in lifestyle changes and in the technology, economic and energy sectors. Sustainable agricultural intensification, facilitated by effective "polluter pays" legislation, and international cooperation enable the UK to reduce its impacts from the externalities of agro-food systems. A UK-wide "green race" delivers the policies and technologies that maximise sustainability and is established across countries. Collaboration domestically and internationally plays a key role in the green race, ensuring technologies, ideas and projects are shared to gain mutual benefits. By 2100, the UK becomes a fully functional circular economy.

SSP2-Middle of the Road. Key public services, such as the health and pension sectors, reach a critical point prompting reform through public-private partnerships. Public-private partnerships also push forward technological development and investments in other sectors, such as transport, energy, IT and infrastructure. While the UK continues to enjoy overall economic growth, social inequalities increase and are countered by the introduction of a basic income and new working rights. A series of shocks, such as crop epidemics and severe water shortages, leads to strong policy responses that introduce Payment for Ecosystem Services schemes to address unsustainable food systems, pollution and biodiversity loss. Both urban and rural planning becomes highly regulated.

UK-SSP3-Regional Rivalry. With job losses and barriers to trade, the government lifts EU and UK environmental regulations to allow access to a wider supply of domestic natural resources. The UK increasingly closes its borders and invests in defence. Immigration from European and non-European countries decreases, but internal migration increases because people move around the UK in search of job opportunities which become concentrated in the major cities. The high competition for jobs leads to an exploited workforce with low salaries. With a reduction in personal income and the redistribution of public spending towards the defence sector, health prevention and treatments decrease and death rates from ill health increase. Around 2040, Scotland becomes independent from the UK, with the other nations following quickly afterwards. With increasing socio-economic barriers, conflicts arise, markets shrink and informal economies increase. With high levels of corruption, criminality is widespread across society and criminal bands substitute themselves for former institutions. Across the (former) UK, a return to self-subsistence lifestyles is widespread.

UK- SSP4-Inequality. In order to boost economic growth public support for radical action towards novel development strategies increases. A National Strategy Development Plan is created to foster business and economic opportunities in green energy and technological development through opening up access to land resources. As businesses and technology flourish, peer-to-peer networks for storing and distributing digital information become popular means for businesses to bypass centralised financial regulations and accumulate wealth. Society becomes increasingly polarised and the North South divide widens. The divide is accentuated by the lack of government intervention: the welfare state has been slowly eroded until its end in the 2060s. Lack of a stable income and poor living conditions means that the vast majority live through committing minor crimes, while a small proportion of rich elite control economic and natural resources.

UK-SSP5-Fossil-fuelled Development. Reduced public support for carbon taxation and taxes to finance green transformation of infrastructure, lead to continued demand for cheaper and more readily available fossil fuels. Strong development in domestic manufacturing is supported by the discovery of shale gas, which leads to reduced energy costs. Increasing public investments in shale gas production in northern England heavily contributes to the removal of the North-South divide. The economy increases exponentially and welfare increases. Large increases in population lead to rapidly expanding "city states" and massive urban sprawl. Large-scale environmental degradation is initially masked using technological solutions. However, environmental tipping points are reached by the end of the century ultimately leading to food shortages.

The scenarios present trends for a number of key socio-economic drivers, for various categories (e.g. demography and society) and elements (e.g. population, urbanisation) for each SSP above. These scenarios are being further developed under the UKRI-funded UK Climate Resilience Research Programme, also being led by Cambridge Econometrics.

2.6.2.3 Net Zero

During the period that the CCRA3 was undertaken, the UK Government adopted a Net Zero greenhouse gas emissions target for 2050. The 2008 Climate Change Act was amended from '*it is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline*' (net emission of CO_2 and net emissions of other targeted GHG), to '*at least 100% lower'.* The Scottish Government also set a net-zero target date of 2045 through the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (SP, 2019). The Welsh Government has announced a 95% reduction in greenhouse gas emissions by 2050 with an ambition to reach Net Zero (WG, 2019). At the time of writing, Northern Ireland had not yet adopted a target but this was under consideration.

This had important implications for the future baseline socio-economic scenarios in England and all DAs as well as mitigation-adaptation linkages. However, at the time of the CCRA3 analysis, there was no published Government studies or policy announcements on how this Net Zero target will be achieved. To consider this change, an additional step was included in the second round of the CCRA3 risk and opportunity scoring. This added two questions at the end of Step 1, for consideration at the level of each individual risk and opportunity. These were: 1) Is the Net Zero target likely to increase or decrease the magnitude of the CCRA3 risk/opportunity, e.g. due to the implementation of measures to achieve the target, and associated changes in the receptor the hazard is acting on? 2) Could the climate change risk or opportunity make the net zero target easier or harder to achieve? Given the current state of evidence (on Net Zero), these questions were addressed qualitatively. To inform these answers, CCRA authors were asked to draw on the techno-economic scenarios of the Net Zero report published by the CCC (CCC, 2019b). These scenarios illustrate ways in which extensive decarbonisation of the UK economy could occur by 2050 (to demonstrate that a Net Zero emissions target by 2050 is plausible). However, these scenarios are not prescriptive on which scenario is favoured, or which policies would need to be developed to achieve the goal.

It is stressed that the CCC scenarios are technical in nature and the Net Zero target does not mean that the UK is on a SSP1 sustainability trajectory (see Box 2.7), not least because the SSPs relate to both mitigation and adaptation challenges and need to be seen in the context of global scenarios.

2.6.2.4 Low likelihood, high impact scenarios

Although 4°C global warming in the 2080s is currently assessed as the fastest rate of warming consistent with current worldwide policies and a reasonably likely range of responses of the climate system, application of the Precautionary Principle motives consideration of more extreme scenarios. The possibility of emissions growing at higher rates cannot be ruled out, and neither can the possibility of strong feedbacks in the climate system, even if these are considered unlikely.

Moreover, there may be critical thresholds at which large-scale components of the Earth's climate system, at least sub-continental in scale, switch to a qualitatively different state due to a small perturbation, and which may be irreversible (Lenton et al., 2008; Lenton et al., 2019). A number of these are particular important for Europe (Levermann et al., 2012). Examples include Greenland and Antarctic ice sheet deglaciation, which could become irreversible even if warming is stabilised, accelerated loss of ice from the Antarctic ice sheet, collapse of the Atlantic Meridional Overturning Circulation (AMOC), and accelerated carbon release from forest dieback or thawing permafrost. The latter would affect the rate of global warming. Several of these are discussed in Chapter 1, and Good et al. (2018) provides a review of recent literature since the IPCC 5th assessment report.

In previous CCRAs, there was some consideration of extreme or high-end risks associated with a High++ scenario, and this was included again in CCRA3. However, in CCRA3, there is also more attention placed on additional low-likelihood, high impact scenarios and events. These include more extreme national to local high-end risks (sometimes called tail-end), higher warming scenarios (that lead to more than 4°C global warming by the 2080s), and global Earth System tipping points or tipping elements. These have not been included in the urgency scores analysis, due to the different nature of these outcomes, but they have been considered separately.

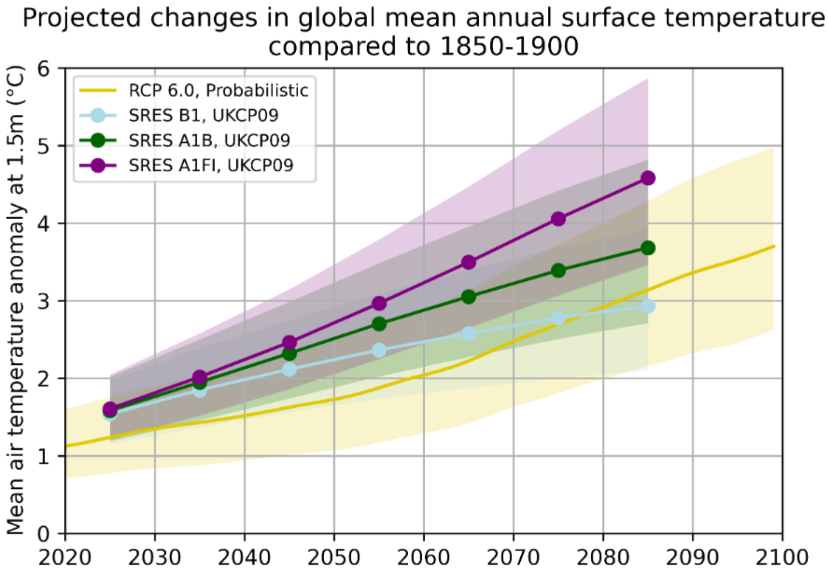
For individual risks and opportunities, authors were asked to capture and report any information on impacts of low likelihood, high impact risks in the evidence base. This could be new assessments of High++ scenarios, or evidence of impacts from projections that warm so rapidly that they reach 4°C earlier than the 2080s. The latter includes a large proportion of the UKCP18 projections with RCP8.5 emissions, and approximately the fastest-warming half of CMIP5 projections using RCP8.5 concentrations. The categorisation of different projections into the main analysis for the urgency scores versus Low Likelihood High Impacts scenarios is shown in Box 2.8. To help this, the question from the US 4th National Climate Assessment (USGCRP, 2018) was considered, i.e. 'how bad could things plausibly get?' This information was not used in the magnitude score and was reported separately.

Box 2.8. Categorising climate projections as "Main Analysis" or "Low Likelihood High Impact".

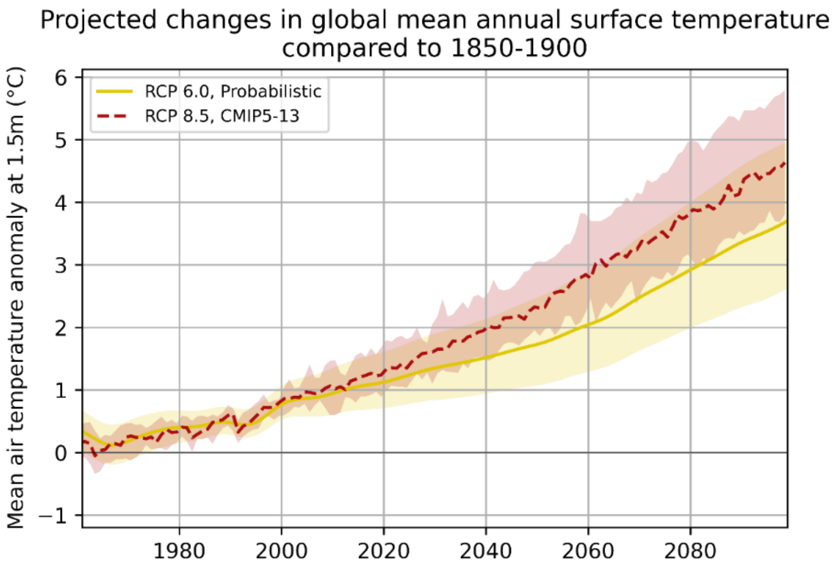
The upper boundary of the "main" projections for CCRA3 is defined by the earliest time of reaching 4°C global warming with emissions consistent with current policies (see Box 2.5). Impacts and risks studies that use projections that reach 4°C global warming between 2080 and 2100 are therefore within the "main" analysis as part of the higher warming pathway and are used for the magnitude scoring. Impacts and risks studies that use projections that reach 4°C global warming before 2080 are in the "low probability high impact" category**.** However, in some cases, information from the latter can still be used to inform assessments in the main analysis, e.g. by comparing results at a particular Global Warming Level (e.g. 4°C) to assess whether climate hazards or dynamical processes at a particular warming level are different in new projections such as UKCP18 compared to older projections such as UKCP09. This method works for some hazards (e.g. extreme precipitation) but not others (e.g. sea level rise).

The following projections were considered eligible for direct inclusion in the main analysis:

-UKCP18 projections driven by RCP6.0 emissions;
-CMIP5-based impacts studies using the RCP6.0 concentration pathway;
-Many of the UKCP09 "medium" (A1B) scenario – up to approximately the 75th percentile of the probabilistic projections (see Box 2.8 Figure 1) and the majority of the 11-member RCM Perturbed Parameter Ensemble;
Results from the lower percentiles of probabilistic projections with the UKCP09 "high" (A1FI) scenario (see Box 2.8 Figure 1 below)
-Some CMIP5-based impacts studies using the RCP8.5 concentration pathway, including those using central estimates of the ensemble, and individual models which reach 4°C in 2080 or later (see Box 2.8 Figure 2);
-Subsets of the UKCP18 probabilistic projections driven by RCP4.5, RCP6.0 or RCP8.5 emissions that reach 4°C close to 2100 (see Sayers et al., 2020; Arnell et al., 2021);
- Subsets of the UKCP18 projections driven by RCP6.0 or RCP8.5 emissions that reach 4°C between 2080 and 2100, i.e in the upper percentiles of the RCP6.0 probabilistic projections or lower percentiles of the RCP8.5 probabilistic projections.



Box 2.8 Figure 1 Comparison of global mean temperature projections (5th to 95th percentile ranges) from the UKCP18 probabilistic projections driven by RCP6.0 emissions with the UKCP09 probabilistic projections driven by SRES B1 ("low"), A1B ("medium") and A1FI ("high") emissions**.** Source for projections: Met Office



Box 2.8 Figure 2 Comparison of projected global mean temperature changes (5th to 95th percentile ranges) from the UKCP18 global probabilistic projections driven by RCP6.0 emissions with the CMIP5 multi-model ensemble driven by RCP8.5 concentrations. Sources for projections: Met Office, KNMI Climate Explorer https://climexp.knmi.nl/start.cgi

The following were considered part of the low likelihood, high impact (LLHI) analysis:

-CMIP5-based impacts studies using the RCP8.5 concentration pathway with *some* of the CMIP5 global models (those that reach 4°C before 2080 – roughly half of the models);
-A subset of the UKCP18 projections driven by RCP8.5 emissions that reach 4°C before 2080, i.e. in the middle and upper lower percentiles of the RCP8.5 probabilistic projections.

Use of projections that reach 4°C before 2080

In some cases, information from projections that reach 4°C global warming earlier than 2080 were used to inform the main analysis by applying the results to a later time (e.g. HRW, 2020). A change in climate hazard at, say, 4°C global warming in 2070 could still be representative of a change in climate hazard at 4°C global warming in 2090, if the associated regional changes in climate quantities are known to depend primarily on the instantaneous magnitude of global warming and are not strongly dependent on the rate at which this magnitude is reached (Wartenberger et al., 2017; Bärring and Strandberg, 2018). This allows a wider range of evidence to be included, but needs to be used with care, as it is not always scientifically appropriate – for example, this approach would not be appropriate for impacts of sea level rise, which responds to rising global temperatures over very long timescales.

Alongside this, a cross-chapter approach was taken to characterise low likelihood, high impact risks. These were discussed in Chapter 1 (Slingo, 2021). This included new information from the UK Met Office.

This information was included in an overall narrative for each chapter. It was also translated into a separate watching brief for Government for low-likelihood, high impact events and scenarios.

Finally, it is noted that the low-likelihood, high impact scenarios above relate to the earth system. There is a new emerging literature on socio-economic tipping points (van Ginkel et al., 2020), i.e. where the tipping point arises in the socio-economic system. The evidence on these extremes is more limited, which limits a more formal analysis, but some consideration of other large-scale, potentially catastrophic risks was considered in the watching brief for Government.

2.6.2.5 Distributional effects and inequalities

As identified in CCRA2 (Street et al., 2016), there is strong evidence that climate risks and adaptation measures will affect people differently, depending on their social, economic and cultural environment. People and communities facing both social vulnerability and exposure to climate hazards are likely to be the worst affected, and low-income households will be particularly affected through negative effects on the cost of living, and because they have fewer resources with which to respond (JRF, 2016).

There are many different approaches for considering these issues, with elements that consider hazard, exposure and vulnerability (including adaptive capacity). In CCRA3, they are considered in terms of environmental health inequalities, recognising that socioeconomic and demographic inequalities can be expressed in relation to factors such as income, education, employment, age, sex, race/ethnicity and specific locations or settings. The report is primarily focused on how these factors affect the risk of being exposed, but also that inequalities are also caused by social or demographic differences in vulnerability/susceptibility towards certain risks.

Many environmental health inequalities, particularly where they are linked to socioeconomic variables or gender, also represent "inequities" because they are unfair and unjust. The root causes of these inequalities are complex, but involve issues of distributive justice and procedural justice (see also the definition of environmental justice, USEPA, 2020), i.e. risks are not evenly distributed within societies and populations, and different population groups may have different opportunities to influence decisions affecting their environment.

In CCRA3, chapters were asked to discuss risks or opportunities across affected populations, by type of individual, and regional dimension, and assess inequalities in relation to the impact of climate change (climate risks) (Step 1) and those generated by any relevant adaptation responses (Steps 2 and 3).

2.6.2.6 Monetary valuation

The requirement statement for CCRA3 from Defra and the DAs included a request for an analysis of current and future risks and opportunities in monetary terms. This type of valuation (monetisation) is a standard part of government economic appraisal, as set out in the HM Treasury Green Book (HMT, 2018). It is based on the principles of welfare economics – that is, how the government can improve social welfare or wellbeing.

The aim of this sub-task was therefore to monetise current and future risks and opportunities (the results of Step 1a and also Step 1b below) as far as possible, expressing these in terms of the effects on social welfare or wellbeing (HMT, 2018), i.e. for society overall, as measured by individuals' preferences using a monetary metric. This values market and non-market impacts, and includes consideration of environmental, economic and social costs and benefits, not just financial costs. It is recognised, however, that it is much more challenging to value some risks, such as those in the natural environment theme. The valuation was undertaken for individual risks and opportunities.

In CCRA1, an indicative monetary valuation was undertaken. This used a consistent approach, drawing on the underlying quantitative and semi-quantitative assessment of individual risks and opportunities from the study (HRW, 2012a). It used a standardised approach for valuation, based on the guidance from HMT Green Book and from individual Government Department appraisal, and estimated the annual average damage for future time periods for the alternative UKCP09 projections for each individual risk and opportunity. Values were presented without discounting[8], in order to facilitate direct comparison over time and between sectors. The monetary valuation of risks and opportunities was not undertaken in CCRA2.

For CCRA3, the method used for monetary valuation mirrors the approach used in CCRA1, and aligns to existing Government appraisal. The valuation was undertaken by a cross cutting team, working with the chapter authors, looking at risks and opportunities individually in terms of annual average effects. These estimates are presented in a separate report, but were fed back into the current and future magnitude scores for each risk or opportunity.

As CCRA3 is a synthesis of existing research, quantification of monetary values is much more challenging than in CCRA1, due to a lack of quantified future impacts for different scenarios in many cases. In CCRA1, a consistent (semi-) quantitative analysis was undertaken for each individual risk as part of a detailed impact assessment, using harmonised climate model projections and socio-economic scenarios. In contrast, CCRA3 relies on existing studies (evidence) for each risk and opportunity, but this means there is little consistency due to differences in primary studies in the choice of climate and socio-economic scenarios, methods used, granularity (national/local), etc. This makes it much more difficult to produce directly comparable results. As a result, in CCRA3 the monetary valuation was primarily indicative, providing information on the order of magnitude of potential impacts or benefits, in line with the magnitude scoring set out in Table 2.2. Where possible, the valuation analysis imposed consistent practice through use of a common base year for prices, without discounting (as for CCRA1, see above) in order to facilitate direct comparison over time and between sectors. For some risks, direct economic cost estimates were already available (primarily floods). For some quantified risks, unit monetary values from existing Governmental appraisal guidance were applied. Where no quantitative information was available, estimates of the order of magnitude of the economic costs was made based on available information and expert judgement. As well as the estimated values, a consideration was made of any important distributional costs or benefits, in line with HMT Green book guidance (HMT, 2018). It is stressed

8 It is noted that the economic costs of climate change, and the use of these estimates in subsequent policy analysis, such as the social cost of carbon or adaptation policy cost-benefit, should discount. While the choice of discount rates has been a source of considerable disagreement in the literature, there is guidance set out in the Treasury Green Book (HMT, 2018), and supplementary guidance on intergenerational discount rates (HMT, 2008).

that due to the use of a synthesis approach and evidence gaps for many of the risks, it was not possible to provide an aggregate impact (of climate change) in the UK (i.e. the total costs of climate change, from all risks and opportunities, expressed as an equivalent % of GDP).

The potential to consider the economic costs on natural capital from climate change in CCRA3 was considered, but was not possible to undertake comprehensively as it was limited by the availability of evidence on the quantitative impact (or benefit) of climate change on natural capital – as well as the valuation of changes in natural capital.

2.6.3 Task 1c Assessing Possible Thresholds and Lock-in

As highlighted earlier (see section 2.3), CCRA3 has made more attempt to introduce adaptive management thinking**.** This included consideration of thresholds and lock-in risks.

Authors were asked to identify potential major thresholds and if changes might arise under different climate futures, notably with respect to the pathways to 2°C and 4°C global warming by the end of the century, including consideration of uncertainties in regional changes. This analysis was supported by a CCC commissioned CCRA3 research project on quantifying known threshold effects in the natural environment (Jones et al, 2020). The identification of thresholds was used to consider a possible change in the magnitude score, for example when it involved a major step-change in the risk (or opportunity), although the primary use was to consider whether current adaptation plans are sufficient and whether there would be benefits from additional adaptation (i.e. Steps 2 and 3).

For lock-in, CCRA authors were asked to identify any potential for lock-in (see section 2.3) over the next five years when considering risks and opportunities. This was focused on identifying actions or decisions that could potentially increase future risk or vulnerability that are also difficult or costly to reverse later (quasi-irreversibility / path dependency). This can be from an i) action or decision taken that is 'business-as-usual', ii) from a lack of an action or decision, or iii) from a maladaptive action or decision. This introduces the concept of path dependency. Ideally, the identification of lock-in risks would involve a quantified analysis of the impacts (and costs) of inaction, though is difficult to do in a synthesis exercise such as CCRA3. Similarly, authors were asked to identify decisions or actions in the next five years that needed to be taken to enable opportunities to be realised. The temporal focus of lock-in is on the short-term, particularly the next five years (consistent with the adaptation programme period), while noting these risks or opportunities from the lock-in emerge in the longer-term. While the analysis of lock-in was identified and reported in Step 1, it was used when considering the urgency scoring in Step 3.

2.6.4 Task 1d Investigate Cross-Cutting and Interdependencies

CCRA2 included a dedicated chapter on cross-cutting issues (Street et al., 2016). This considered two types of cross-cutting issues: first, cross-cutting issues related to risks which include interacting risks (hazards with multiple impacts), the consequences of interacting risks (knock-on effects) and distributional risks (how risk affects people differently); and second, cross-cutting issues related to adaptation.

For CCRA3, interdependencies, cascading risks and cross-cutting risks were considered and documented for each risk and opportunity. This analysis was supported by a CCC commissioned CCRA3 research project on Interacting risks in infrastructure, the built and natural environments (WSP, 2020). The project created 12 interlinked systems maps showing principal interactions within and between the three sectors. The analysis of interacting and cascading risks, as well as the possibility of combinations of hazards (Hillier et al., 2020) was subsequently considered in the magnitude score for each individual risk and opportunity, with authors given the option to increase the magnitude score based on evidence (using the magnitude in Tables 2.2 and 2.3).

2.7. Step 2 Assess Current and Planned Government and non-Governmental Adaptation

The second step in the CCRA3 Technical Report method (Figure 2.8) assesses the influence of current or planned adaptation in reducing current and future climate change risks, or responding to potential opportunities. This provides an analysis of whether the medium, high or unknown risks and opportunities identified in Step 1 are already being managed. The objective is to identify the benefit of current and announced adaptation policy in reducing risks or enabling opportunities. It also considers what might happen in the absence of further Government action, and thus whether there is a justification for additional action.

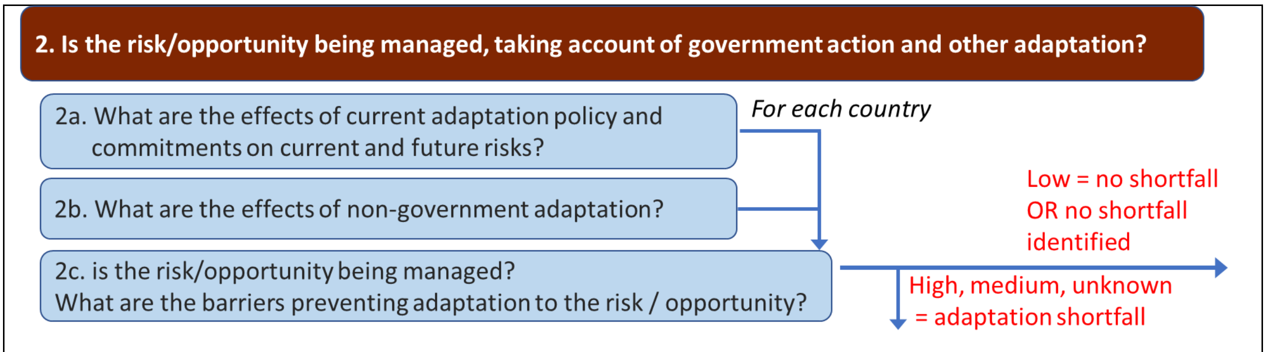


Figure 2.8. Step 2 in the overall method and urgency analysis.

These steps are described in more detailed below.

2.7.1 Task 2a Analysis of Current, Planned Government Adaptation

The first task is focused on assessing how current and planned adaptation might manage the risks identified (in Step 1). The tasks involved a mix of qualitative and/or quantitative assessment methods. Authors were asked:

- To assess the policy landscape for adaptation and identify existing policies and commitments (including current as well as announced policies).
- To review and assess how far current planned adaptation action is reducing current risks or fully realising current opportunities. For risks, this included consideration of how adaptation is reducing exposure, decreasing sensitivity or enhancing adaptive capacity.

- Authors were also asked to consider and document what effect adaptation actions have had since the last CCRA, i.e. between 2012 and 2019.
- To review and assess how planned adaptation, and announced plans, could reduce future risks or realise opportunities, as well as the potential for maladaptation from these plans.

This analysis was undertaken for each country. Additional information is given below.

The starting point was to understand the organisational responsibility and governance arrangements for climate risks and adaptation (noting the two may differ), as well as to identify the current and announced organisational objectives and policies/strategies of relevance for climate risk and opportunities (non-climate and climate). This considered Government strategies and policies (overall, and in the relevant sub-programmatic areas) both in relation to specific existing and announced climate or resilience policy (National Adaptation Programme (NAP1 and NAP2) and the adaptation programmes of the DAs) but also broader policy interventions that could reduce climate risk or vulnerability. It also considered existing standards and guidance (mandatory and voluntary).

This task then considered how far existing policies and interventions are managing current risks, or fully realising opportunities. CCRA3 authors were asked to consider what effect adaptation actions have had on the level of current risks since the CCRA2 assessment (and indeed since CCRA1). Following from Step 1, it was also important to consider if current government action is addressing lock-in risks.

The analysis then looked forward, and considered how far existing policies and interventions, including announced planned adaptation policies and strategies, are managing future risks or opportunities. This effectively considered a current 'adaptation policy scenario', which included a consideration of adaptation policy objectives (and targets), the planned activities and outcomes, and the possible effect on reducing risks (or realising opportunities). This is a key part of the analysis, but it is challenging because Government targets on adaptation are often quite generic (i.e. they may not be quantitative, or defined in SMART terms [Specific, Measurable, Achievable, Realistic and Timebound, see National Audit Office, 2019]). Furthermore, there is often no quantified analysis (in published adaptation policies and strategies) on the anticipated level of risk reduction and thus the benefits of adaptation policies and strategies (Watkiss et al., 2019). In short, there is often not the quantitative evidence presented in adaptation polices to know the extent to which future risks are being reduced or opportunities realised. Further, there are important differences in how adaptation objectives can be set, as well as the framing used in policy, that have a major influence, involving the absolute or relative level of risk reduction, as well as the trade-off between adaptation costs and benefits, as well as residual risks. Further information is presented in Box 2.9.

For adaptation to future risks, the analysis considered the degree to which existing and announced policies would help adapt across all scenarios (2°C and 4°C future warming scenarios by 2100 globally) including uncertainty. Initially, authors were asked to consider whether adaptation was sufficient to manage risks across the probability range, specifically the 10th to 90th percentiles in the UKCP09 or UKCP18 projections. However, there was rarely the evidence to undertake such an analysis in practice, and authors were asked to consider the ranges of uncertainty, as far as possible.

In the case of water availability and flood risk, a current adaptation policy scenario was calculated in the accompanying CCRA3 research projects and was used directly in the relevant chapters in the Technical Report to help to consider the level of risk reduction.

Authors were also asked to discuss whether the proposed adaptation (in policies and strategies) involves potential trade-offs or maladaptation. They were also asked to consider the distributional consequences or inequalities inherent in existing or planned adaptation.

Box 2.9 Adaptation Objectives.

There are many existing adaptation policies in place, as reported in the NAP2 (Defra, 2018) and the 25 Year Environment Plan (25 YEP; HMG, 2018) and the Adaptation Plans of the DAs. These form the basis for generating a current adaptation policy scenario, but it is often challenging in practice to assess the actual benefits of these policies because many of them are not specific in terms of objectives (Watkiss et al., 2019). Many of the targets in the 25 YEP and NAP2 are quite general, e.g. they set a general goal for reducing risks or enhancing resilience, but do not include a specific stated objective and outcome, which makes it is difficult to understand what level of adaptation benefit the policy is meant to achieve. This is important because there are different policy approaches and objectives for managing climate risks, and there is not a consistent approach used across Government for managing current risks, let alone for the future. To illustrate this by way of an example. In a hypothetical scenario of coastal protection, there are a number of potential choices for setting an adaptation objective:

- Maintain existing adaptation infrastructure. This involves additional maintenance costs in the future, but involves no additional enhancement of existing infrastructure or any additional adaptation infrastructure.
- Maintain current (policy) objectives. This aims to maintain a constant relative risk. For example, where a clear standard is set, e.g. an acceptable level of risk protection such as a 1 in 100 year level, this can be maintained over time. However, this involves cost implications, because additional infrastructure (increased costs) are projected to be needed in the future, to maintain the same (1 in 100) level of protection under a changing climate with higher risks. Importantly, maintaining the status quo will require additional action. Related to this, it cannot be assumed that Government will maintain existing objectives, unless there is an explicit policy commitment to also increase expenditure (on flood infrastructure).
- Maintain current levels of protection based on damage levels. This aims to maintain a constant absolute risk. While this looks similar to above, it involves much higher levels of protection, because of rising socio-economic change and increased value at risk, as well as increasing climate change. It therefore involves higher costs (though it also provides higher benefits).
- Maintain the (economic) optimal level of adaptation, where the costs and benefits of further protection are considered and the optimal response introduced. This usually involves lower levels of adaptation, because it avoids high-cost adaptation investments with lower benefits, but has higher residual damages when compared to risk-based approaches above (although these higher risks could, for example, be addressed through insurance). In practice, it is almost impossible to know the optimal level of adaptation because of uncertainty (though it is possible to consider dynamic optimality (Eijgenraam et al., 2013) or optimal-like responses under uncertainty.

Critically, each of these choices involve very large differences in the way that risks are managed, as well as the benefits of further action (and thus adaptation costs and benefits). These objectives would normally be compared to a counter-factual option to do nothing (to live with the risk), and would lead to the subsequent consideration of different types of interventions, e.g. whether to protect or retreat. It is highlighted that further consideration of objectives would be useful, including consideration of public risk preferences on these issues.

In theory, the analysis of planned adaptation should also take account of alternative socioeconomic futures, because these will affect exposure, residual impacts, etc. and thus the effectiveness of adaptation. They might also bound the national and regional availability of resources for adaptation. In practice it is very difficult to assess this except where there is very detailed quantified information available. Adaptation can also – itself – lead to lock-in, linking back to the lock-in issues identified in Step 1.

A similar approach is used to assess opportunities, although there are some important differences. For opportunities, there is a need to consider spontaneous and non-government planned adaptation first (Task 2b, below) and assess how far these realise the potential benefits or whether there is a potential shortfall. In the case of the latter, the analysis has to then consider if Government action is in place to help realise opportunities, e.g. to create the enabling environment to enhance potential benefits (of climate change). If not, then the opportunity is considered not to be fully managed. In theory, this could mean that the magnitude score of a potential opportunity could be high, but current actions are only likely to deliver a low or medium score. This is different to the scoring of risks (where a low magnitude assumes no additional action is needed). The analysis of whether opportunities are being managed was primarily qualitative, based on the evidence, expert judgement and discussion with Government and stakeholders.

The analysis of planned adaptation also considered the potential synergies and trade-offs with mitigation. This has an important linkage to the Net Zero target. As highlighted above, it was not possible to use Net Zero as a new business as usual scenario, because at the time the evidence review was undertaken there were no announced plans or policies on how this would be achieved. For this reason, CCRA authors were asked to consider the synergies and trade-offs between adaptation and mitigation in Step 3, as part of Net Zero considerations (see later discussion).

2.7.1.1 Adaptive capacity

Previous studies, including CCRA1, have highlighted the importance of adaptive capacity in adaptation. However, there are different definitions of adaptive capacity. From one perspective, it is a part of the IPCC Core Concepts and linked with vulnerability (see Step 1). However, there is a separate aspect of adaptive capacity that relates to the goal of CCRA3 and the capacity of planned Government action to respond to the risks identified. This emphasises socio-institutional and organisational aspects, i.e. associated with the 'process of adaptation' at organisational and/or structural (sector) level (see Box 2.10). This element sits within Step 2 of the method.

In CCRA1, Ballard, Black, and Lonsdale (2013) defined this form of adaptive capacity as *the ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.* In this definition, 'adaptive capacity' is the capacity to take effective adaptation actions, i.e. the extent to which organisations and individuals are able to identify climate risks and make well-informed, long-term decisions that could make them more resilient to the impacts of climate change. A survey was undertaken of the level of organisational and structural capacity in different sectors. This survey was not repeated in CCRA2, and was not included in CCRA3: this represents a missed opportunity to capture progress over time. It is noted that there would be benefits from a more explicit consideration of adaptive capacity in CCRA4.

Box 2.10 Adaptive Capacity.

Previous work on adaptive capacity (Ballard, Black, and Lonsdale, 2013) in CCRA1 differentiated adaptive capacity into two distinct components:

- Organisational adaptive capacity (OAC): a measure of the current ability of organisations within the sector to undertake effective adaptation actions in response to climate change. This considers the level of capacity of the organisation, i.e. does it have a climate risk management or adaptation plan through to whether it is planning strategically and has implemented adaptation.
- Structural adaptive capacity (SAC): a measure of the systemic factors currently at work within the sector that affect its ability to adapt to climate change. These consider the sector's complexity, typical decision lifetimes (short or long), and the extent of activity providing potential opportunities for undertaking adaptation actions.

In sectors where SAC is low (e.g. because the sector is highly complex or decision lifetimes are typically very long), a correspondingly higher level of OAC will be needed to compensate and so enable the sector to adapt successfully to the impacts of climate change. Underlying this is the assumption that capacity develops progressively, i.e. that organisations start off less effective, but grow capacity through learning, thus barriers that apply at early stages are different to those that apply when organisations improve. There are also some studies that have reported on success factors for building capacity for adaptation (Ballard, Black, and Lonsdale, 2013; Ballard, Bond, et al., 2013; Frontier Economics, 2013).

There is also a much wider literature on adaptive capacity that includes many more components and aspects. These are contingent on the wider enabling environment, such as access to data, scientific and technical knowledge, institutions, as well as learning. A good discussion of these was included in the CCRA2 Cross Cutting Chapter (Street et al., 2016).

2.7.2 Task 2b Assess Non-Governmental Adaptation

The next task was to consider additional forms of adaptation that might reduce current and future risks in the absence of further planned Government or other organisational action. It assessed what additional adaptation could happen, including spontaneous and non-Governmental planned adaptation, to help manage risks (or take advantage of opportunities), but also if these non-Governmental responses had the potential for maladaptation.

For some risks or opportunities, there is a strong rationale for non-government action to lead on adaptation, i.e. where an increase in government expenditure would result in a matching decrease in private expenditure, (known as 'crowding out') (HMT, 2018).

In the previous CCRAs, the consideration of this type of non-governmental adaptation (e.g. by the private sector or households) was called autonomous adaptation[9]. However, the focus of CCRA3 in step 2 of the method is to establish what could happen in addition to Government planned adaptation. This could include some spontaneous adaptation (i.e. reactive adaptation in response to

[9] The IPCC AR5 glossary (2014b) defined autonomous adaptation as a response to experienced climate and its effects, without planning explicitly or consciously focused on addressing climate change. This is also sometimes called spontaneous adaptation.

the changing climate), which might be termed autonomous. However, it could also include planned non-governmental action, such as planned adaptation by the private sector (including in privatised sectors). By definition, planned pro-active responses cannot be autonomous, irrespective of the actor, because they involve conscious plans and strategies for future climate change. For this reason, the term autonomous adaptation was not used in CCRA3.

Authors were asked instead to assess the potential for reactive, spontaneous adaptation which could arise from direct experience of a changing climate and whether these might manage risks in the absence of, or in addition to government policies and plans. This considered reactive or spontaneous adaptation as for example:

- A natural response, for example, natural species shifts to changing agroclimatic zones, or acclimatisation, for example, the physiological and behavioural acclimatisation of people to experienced higher temperatures.
- An autonomic (unplanned) response in a system, e.g. reduced winter temperatures, leading to reduced winter heating demand in households due to automatic temperature systems, reducing energy demand for heating (noting these can be defined as impact or an adaptation).
- The reactive response of households or the private sector to experienced climate change, including behavioural change (focused on the response to changes experienced, not planned, such as changing behaviour to reduce heat related risks, or fitting household level protection measures), without any Government intervention.
- The reactive market response e.g. changes in demand, etc. as a result of changing prices from experienced climate change.

It also considered planned, proactive adaptation by non-government actors, e.g. planned adaptation to future climate risks by the private sector. There is some information on private sector activities reported under the Climate Change Adaptation Reporting Power (ARP, currently going into its third round, although to note this also includes some governmental organisations as well), though this was not available at the time of CCRA3. The Climate Change Act 2008 allows the Government to ask certain organisations to produce reports on the current and future projected effects of climate change on their organisation and their proposals for adapting to climate change (though the reporting powers were changed from mandatory reporting in the first round to voluntary reporting for the second and current round). At the time of CCRA3, such reports were being prepared by a number of government agencies, authorities and regulators, as well as companies in key privatised sectors (water, energy). As highlighted earlier, this task is also important for opportunities, and the key issue in these cases is to assess whether benefits will be realised without Government action.

The consideration of additional non-Government adaptation (reactive and planned) was used to establish whether risks might be managed - and opportunities realised - even without government intervention. However, there is generally a low evidence base on non-governmental adaptation, and thus this task was primarily qualitative.

When non-Governmental adaptation is present, it is important to consider if it is beneficial, defined through the lens of social welfare, as if not this could be a form of maladaptation. Action by individual actors could, for example, shift vulnerability to others, or could lead to other impacts or disbenefits. As an example, the increase of air conditioning as a response to building overheating is a non-Governmental adaptation response, but it would increase energy use and carbon emissions, and possibly exacerbate social inequalities (as some can afford to pay for this and some cannot), thus could be a form of maladaptation. Likewise, some farm-level responses (e.g. increased irrigation and fertiliser use) may involve wider cross-sectoral trade-offs that necessitate a role for planned intervention. This assessment also considered cases in which adaptation could have unintended consequences, e.g. creating lock-in, or increasing risks in other sectors or associated with other development or social objectives.

2.7.3 Task 2c Analysis of Need for Further Adaptation and Barriers to Adaptation

The final task in Step 2 was:

- To re-assess the magnitude of future risks (or opportunities), with the current and planned adaptation in place, i.e. to identify future residual risk. In general, the output of this task was to identify if risks or opportunities are being managed down to a low magnitude level, though with some exceptions listed below.
- When residual risks remained (magnitude is high, medium or unknown), to assess why action to address these risks (or take advantage of opportunities) was not being taken, i.e. to identify the barriers (constraints) to adaptation.

At the end of this task, there was a re-analysis of the magnitude of future risks or opportunities (from Step 1), taking into account planned adaptation (from 2a) and non-governmental adaptation (from 2b) identified above. This analysis was evidence based and drew on a range of independent sources, including but not limited to the CCC's progress reports, as well as emerging information on the CCC's forthcoming independent assessment of the second Scottish Climate Change Adaptation Programme.

However, in many cases, the assessment of whether current and announced policies or strategies are managing risks often involved a level of expert judgement, especially as there is little academic literature or independent analysis that evaluates the potential effectiveness of Government adaptation policy. To address this, a set of criteria were used to assess whether the risk or opportunity was being managed sufficiently. These are set out in Table 2.7 below.

A risk was only considered to be ‘fully managed’ if clear plans and objectives were in place, and one of the following is true:

- The planned interventions reduce the magnitude to ‘low’ across both scenarios of 2°C and 4°C global warming at the end of the century, as defined in Box 2.5, and across the range of uncertainty. The latter was defined in the method as sufficient to manage risks across the probability range, specifically the 10^{th} to 90^{th} percentiles in the UKCP09 or UKCP18 projections. However, there was rarely the evidence to undertake such an analysis in practice, and authors were asked to consider management of risk across the range of uncertainty as far as possible.
- When a current risk is medium or high magnitude now, and increases further in the future due to climate change, but planned adaptation action will manage this risk (across scenarios of both 2°C and 4°C warming at the end of the century, as defined in Box 2.5, and across the range of

uncertainty) back down to the same absolute levels of risk as today[10]. In this case the risk is considered to be managed provided the future strategies include clear goals and objectives for adaptation, and that the drivers of vulnerability and exposure are being well managed (today and for the future), and there is evidence that this will be delivered with appropriate implementation plans. Furthermore, to be considered fully managed, current risks (and thus residual risks in the future) also needed to demonstrate they had considered recent climate trends including potential unobserved risks today, such as captured through the UNSEEN analysis.

- When a current and future risk is dominated significantly by other factors over and above climate, e.g. as is the case for air pollution, authors were only asked to score the incremental risk from climate change in Step 1. They were then only asked to consider if the risks of additional future climate-related risks were being managed in Step 2.

For opportunities, the analysis considered whether the enabling environment (to take advantage of benefits) was in place, noting at this stage, a low score for an opportunity is a trigger for the consideration of additional action.

In all cases, the justification for this scoring was set out. This assessment (of this adaptation gap) was undertaken for each of the four countries (England, Northern Ireland, Scotland and Wales).

In cases where there was insufficient evidence, but there was widespread agreement between the CCRA authors, CCC and peer reviewers that the risk might not be managed in the future (i.e. an adaptation shortfall), then this triggered further investigation in Step 3. Conversely, if these groups considered that the lack of evidence was not an issue, e.g. because the market was considered to incentivise appropriate action or because Government has commitments in place (with reasons why), then these were not recommended for further consideration and given a “sustain current action” or “watching brief” urgency score.

[10] The literature (Burton et al., 2004) identifies that adaptation to future climate will be less effective if adaptation deficits are not first addressed. If there is a medium or high current risk, this could mean there is an adaptation deficit, which could make future adaptation harder. Managing future risks only back down to this current medium or high level will also mean the adaptation deficit continues. However, it is also possible that a trade-off has been made over managing medium or high current risks based on the costs and benefits of further action versus the levels of residual risk, or based on societal risk preferences (see Box 2.7). It is difficult to judge if there is an adaptation deficit today without making a judgement on the risk appetite for addressing risks. The customer requirement from Government excluded the consideration of risk appetite in CCRA3, and thus possible issues around current adaptation deficits have not been considered.

Table 2.6 Criteria to assess whether risks or opportunities are being managed (in the future).

	Yes (fully)	**Partially**	**No**
Risks	Policy, strategy or plan in place, with clear objective (SMART) AND Actions will reduce risk to a low magnitude, across the range of future warming scenarios (2°C and 4°C at end of the century, as defined in Box 2.5, and across the uncertainty range [see text]), OR For risks that already have a medium or high magnitude today, actions are reducing the future risk (in the scenarios of 2°C and 4°C warming at end of the century, and across the uncertainty range) to maintain it at today's level, the drivers of vulnerability and exposure are being well managed (today and in the future), and recent climate trends are well accounted for in the policy, OR For risks that are dominated now and in the future by other factors over and above climate (e.g. air pollution) the incremental risk is being managed down to a low magnitude.	Policy, strategy or plan in place, but no clear objective. Or in place, but only commits to managing risk for 2°C warming pathway, or no uncertainty consideration.	No policy, strategy or plan in place to reduce risk, OR Government action or non-Governmental adaptation is managing risks as set out, but there is a risk of maladaptation, OR Lack of evidence of adaptation, but widespread agreement between the CCRA authors, CCC and peer reviewers that the risk might not be managed in the future.
Opport-unities	Opportunity will be fully realised in absence of government intervention OR The enabling environment is in place to fully realise the opportunity.	Opportunity will NOT be fully realised in absence of government intervention and only some elements of the enabling environment are in place.	Opportunity will NOT be fully realised in absence of government intervention and no elements of the enabling environment are in place.
Confidence in the assessment of adaptation (also shown in table2.4)	High: High quality evidence of the effects of future adaptation in managing the risk and high agreement between experts.	Medium: Some evidence on the effects of future adaptation in managing the risk and/or high agreement between experts.	Low: Little/no/ contrasting evidence of the effects of future adaptation in managing the risk and little agreement between experts.

2.7.3.1 Barriers

In cases where an adaptation shortfall was identified, the final task was to understand why adaptation is not taking place, i.e. what are the reasons for the adaptation gap. This builds on existing literature that identifies that there are often barriers (constraints) that make it difficult for individuals, businesses and Governments to plan and implement adaptation actions (Cimato and Mullan, 2010; Frontier et al, 2013; Klein et al., 2014). There were two considerations in this barrier analysis:

- To identify the barriers that might be stopping or hindering adaptation, e.g. market, information, policy and governance failures, behavioural barriers, etc.
- To assess how these barriers might be overcome, and thus help identify the appropriate type of planned adaptation (linked to Step 3).

These barriers and constraints are also important when considering opportunities. In many cases, the opportunities of climate change may not happen without Government providing the enabling environment, addressing the barriers that allow others to take advantage of the possible benefits.

2.8. Step 3 Assess the Benefits of Additional Adaptation Action

In the case where an adaptation shortfall is still identified after Step 2, i.e. the risk is not being fully managed or opportunities are not being fully realised, the final step considers the potential benefits of <u>additional</u> adaptation (see Figure 2.9). The aim is to identify if additional action would be beneficial, over the next five-year period, to manage the residual risks. As outlined above, CCRA3 aims to identify whether future action might be beneficial, but also what type of adaptation might be beneficial, categorised using the three building blocks set out earlier (see Figure 2.3). CCRA3 also has a new focus on understanding the scale, at least at an indicative level, of the potential costs and benefits of further action.

The findings of this analysis – along with other findings from Steps 1 and 2 – are then used to inform the overall urgency score for each risk or opportunity. CCRA3 also included a stronger linkage through to the next CCRA cycle – to CCRA4 – to identify research or information gaps that would help future adaptation (as part of adaptive management).

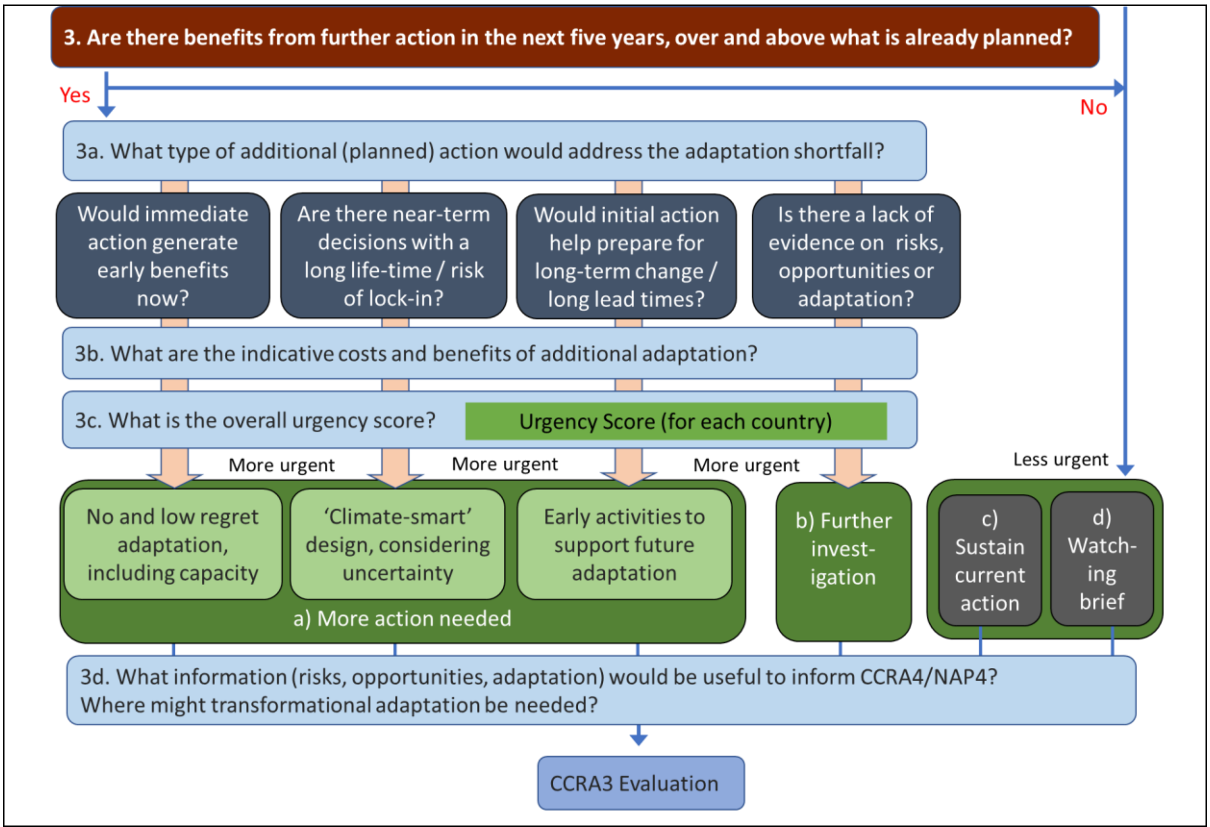


Figure 2.9 Step 3 in the overall method and urgency analysis.

Chapter authors were asked to undertake the following activities for risks:

- Identify possible areas of additional adaptation - noting this could be building capacity or creating the enabling environment for adaptation, as well as delivering adaptation.
- Where possible, to suggest the type of additional adaptation that might be relevant, i.e. aligned to the three building blocks (noting that at the national level, it is likely to involve a mix of all three types of intervention). This involves linkages to lock-in risks and thresholds, and also to how adaptation might need to evolve over time considering 2°C and 4°C warming pathways.
- Assess the indicative costs and benefits of further action, as well as possible co-benefits, including synergies (or trade-offs) with mitigation (and Net Zero).
- From the steps above, to identify if further adaptation action would be beneficial.
- For all risks and opportunities (including those identified as low magnitude or being managed): Assign an overall urgency score.
- Identify additional information that would be useful to inform CCRA4/NAP4, both with respect to risks and adaptation.
- For Government/CCC, to start the process for the formal evaluation of CCRA3.

These steps are described in more detail below.

2.8.1 Task 3a Analysis of Possible Early Adaptation Options

The first task of Step 3 was to identify potential additional adaptation that could be undertaken to reduce risks or enhance opportunities. This was framed as the additional adaptation scenario. It considered the broad type of adaptation that could be taken, focusing on the early adaptation priorities set out in Figure 2.3 (i.e. no and low regret options, climate-smart decisions to address lock-in, and early action to inform long-term risks or opportunities), noting that for many risks and opportunities, this may involve a portfolio across all three. In line with the mandate of the CCRA, and the advice from the Government and the DAs (in the Customer Requirement), this did not aim to define the risk appetite, or specifically on how to adapt, since those are policy or operational decisions (and thus fall to the NAP and Adaptation Programmes of the DAs). Instead, the aim was to identify potential additional adaptation interventions that were identified in the evidence and literature, as well as from inputs from chapter experts, stakeholder consultation and the peer review process. This might include direct Government intervention or by creating an enabling environment or building capacity to help others to act.

The focus was to identify additional possible action in the next adaptation reporting period (i.e. the next five years), to address risks in the current, medium or even long-term. A similar approach was taken for opportunities, except for these, it is the potential to seize an opportunity rather than avoid a negative impact that was considered. Authors were asked to consider if there were particular adaptation priorities associated with the risks of lock-in (see section 2.6.3), which would necessitate more urgent action in the next adaptation programme period. Authors were also asked where possible to consider the potential differences in adaptation that would be needed under pathways to 2°C and 4°C global warming, including uncertainty in regional impacts. These can be indicatively identified as part of a pathways approach, especially if there are potential thresholds involved (see section 2.6.3). In some cases, the difference between 2°C and 4°C warming scenarios could be a case of doing more (i.e. with higher sea level rise, there is an incremental increase in coastal protection) but in other cases, it could also mean doing something different (i.e. with higher heat thresholds, a heat alert system may not deliver the necessary adaptation to address health risks and building design may also be needed). Related to this, an important issue here was the rate of change, i.e. as well as how much adaptation action, how quickly this might it be needed. These various elements were introduced to try and encourage a more adaptive management approach, but it is stressed such considerations could only be indicative, given CCRA3 is a synthesis: much greater resources and new analysis are needed to implement adaptive management for each risk and opportunity (as found in the Economics of Climate Resilience study, HMG, 2013; Frontier et al., 2013).

Authors were also asked to consider alternative socioeconomic futures, as these will affect adaptation needs and opportunities, and also allows consideration of different adaptation options, e.g. that tackle vulnerability or adaptive capacity, rather than climate hazards directly.

This task also included a linkage to the Net Zero target, which has important implications for adaptation. CCRA3 authors were asked to consider the synergies and trade-offs between adaptation and mitigation in this task, as part of Net Zero considerations. This followed on from the questions asked in Step 1 (see earlier section) on Net Zero alignment. Authors were asked to consider if additional adaptation action might increase emissions, and thus act to make the Net Zero targets more challenging. This involves a consideration of the changes that will happen along the pathway to Net Zero, i.e. low-carbon electricity generation could reach 75-85% by 2030 (CCC, 2019b) and will be zero carbon by 2050. Conversely, additional adaptation action that had neutral or positive synergies with mitigation – and especially Net Zero – were considered more relevant (while noting synergistic emissions reductions were not a pre-requisite for further adaptation action).

2.8.2 Task 3b Costs and benefits of further action (Indicative)

A new task included in CCRA3, at the request of the Customer Group, was to consider the possible costs and benefits of the further action identified in Task 3a above. As set out earlier, valuation (monetisation) is a standard part of UK government policy development and economic appraisal, as set out in the HM Treasury Green Book (HMT, 2018). It is based on the principles of welfare economics – that is, how the government can improve social welfare or wellbeing. These same concepts are applicable to the identification of possible further adaptation interventions, and the analysis of the benefits of further action. This task involved two economic elements from the Government appraisal process (HMT, 2018).

The first task in the appraisal process is to provide the rationale for intervention. HMT (2018) sets out that a clear rationale for intervention should be identified and then used to develop the objectives or outcomes the government wishes to meet through intervention. The same issues apply when considering further Government action on adaptation (Cimato and Mullan, 2010; HMG, 2013). In CCRA3, the justification for intervention was linked to the barriers identified in Step 2, i.e. the economic, policy and governance barriers that arise from market failures, or information, policy and governance failures. The rationale for intervention considered the relevant barrier or constraints involved with each risk or opportunity, and why adaptation was not already happening. This was then used to provide the economic rationale for early adaptation and some early information on what types of interventions might be appropriate.

The second task in the appraisal process is the consideration of options, starting with a long-list and then undertaking filtering this down to a short-list for detailed economic analysis. (HMT, 2018). The latter involves analysis of the costs or benefits of policies or projects (and options), where possible valued and monetised, in order to provide a common metric. In CCRA3, following from the monetary valuation of risks outlined in Step 1, this task investigated the indicative costs and benefits of the further adaptation action. This information was used to help identify the possible priority areas for action (from Figure 2.3), to assess the possible benefits of further action as compared to costs, and to help inform the urgency score. Given the synthesis nature of CCRA3, this was primarily based on a review of existing evidence and qualitative analysis.

It is stressed that the analysis of the costs and benefits of adaptation is challenging, much more so than for mitigation, and this makes it difficult to gather comparable information on further action across risks and opportunities. For mitigation, benefits are measured using a common burden (tonnes of GHG reduced), irrespective of location and sector, and many studies prioritise options using a cost-effectiveness analysis (£/tCO_2), which is a relative measure and provides direct comparability across interventions. This also makes it easier to use a synthesis exercise to gather information on benefits of further action. In contrast adaptation benefits require quantification of the reductions in climate impacts (not burdens), and these are time-, sector-, location- and context-specific. Adaptation is also generally introduced as part of a mainstreaming approach in the UK, which requires consideration of multiple metrics, not a single metric, and this means that a cost-effectiveness approach is insufficient. The economic prioritisation of adaptation is therefore better suited to cost-benefit analysis (CBA). However, because of uncertainty, as well as valuation in non-market sectors and of non-technical options, this normally requires extended cost-benefit analysis or multi-metric appraisal (see Chambwera et al., 2014).

There is also a very low evidence base on the costs and benefits of adaptation and many estimates in the literature are based on technical (engineering) adaptation options for long-term climate change (OECD, 2015). For CCRA3, however, the focus is on the costs and benefits of short-term adaptation priorities (implemented over the next five years), which might have short, medium or long-term benefits. Given the synthesis approach of CCRA3, it was not possible to undertake new analysis, and thus the task drew on previous evidence reviews (ECONADAPT, 2017) and available literature.

It is noted that the consideration of the costs and benefits of adaptation, as part of economic appraisal, does require the use of discount rates, in order to estimate the net present value or benefit to cost ratio. As highlighted earlier, the use of discount rates when calculating the social cost of carbon, or the costs and benefits of mitigation policy, has been very contentious. However, CCRA3 is not looking at mitigation policy: it is focused on domestic adaptation, particularly near-term actions that align within the existing policy decision landscape and thus existing Government recommended discounting approaches. For longer-term adaptation investments, it is stressed that the UK guidance (HMT, 2018) already uses declining discount rates. It is also noted that CCRA3 still prioritises long-term adaptation considerations, see Figure 2.3, with early action to plan for longer-term risks. However, it is highlighted that in future CCRAs, if transformational adaptation is identified, this may necessitate consideration of intergenerational issues when considering the costs and benefits of further action (and accordingly, the HMT intergenerational discount rate scheme, HMT, 2008).

Towards the end of the CCRA3 process, in late 2020, new HMT supplementary Green Book guidance was published on accounting for the effects of climate change (adaptation) (Defra, 2020). While this was too late to inform this task (3b) in CCRA3, the approach the guidance recommends broadly aligns with the description above.

The consideration of further adaptation also considered if there were additional co-benefits. This included potential synergies (or trade-offs) with mitigation and Net Zero. Previous studies (e.g. Watkiss et al., 2015) have identified that adaptation and mitigation options can lead to synergies and potentially increase the attractiveness of adaptation, though in other cases there is also the potential for conflicts. Finally, as with Task 1a, the potential distribution of costs and benefits associated with adaptation measures was considered, i.e. to consider in broad terms who bears the costs or gains the benefits.

This information was used to assess if further action would be beneficial in managing risks or opportunities. If not, then it was categorised as a ‘sustain further action’ or ‘watching brief’.

2.8.3 Task 3c overall urgency score

This task brings together the information above. It addresses the primary goal of the CCRA, which is to provide an assessment of risks and opportunities to inform the priorities for adaptation at the national level, and thus primarily seeks to provide information for the UK Government and devolved administrations.

To do this, an overall urgency score is given to each risk or opportunity. This is undertaken separately for each country. It is stressed that the urgency score provides different information to the magnitude score. For example, even if the future magnitude of a risk is classed as medium in the 2050s, the urgency might be high if plans do not exist to manage this as yet, and might be compounded if there are the risks of lock-in in the short-term. Indeed, for many future risks, there is often a window for intervention (Ballard, Black, and Lonsdale, 2013) today to change the course of action for the future.

In the CCRA context, urgency is defined as a measure of 'the degree to which action is needed to reduce a risk or realise an opportunity from climate change'. It identifies where the need for adaptation is likely to be most 'urgent' between 2023 and 2027 (the next adaptation programme period) and similar periods for the devolved administrations (e.g. for Scotland, the next adaptation programme is due in 2024).

The CCRA3 urgency score follows from the previous three steps, i.e. from the assessment of 1) the current and future level of risk or opportunity, 2) the effects of current and planned adaptation, and 3) the benefits for further beneficial action in the next five years. It assigns a single urgency score for each risk and opportunity for each UK country, along with a summary of what additional adaptation could be beneficial (where relevant) and what this might look like. This simple urgency scoring approach is used because it is transparent and can be understood and considered with ease and speed by policy-makers with responsibility for large and diverse policy areas.

This urgency scoring was used in CCRA2, but some minor changes were made to the approach in CCRA3. It assigns each risk and opportunity one of four urgency scores (see Table 2.8). It is important to note that no risk or opportunity 'falls out' of the framework. Risks and opportunities identified as more urgent ('more action needed') have a specific and immediate action, but even those identified as less urgent ('watching brief' and 'sustain current action') require ongoing action and/or monitoring to see if the actions that should be happening, are happening.

Based on the urgency score, the UK Government and devolved administrations then need to decide what specific action to take to address each risk and opportunity. The effectiveness of the National Adaptation Programme for England in reducing these risks and realising opportunities is subsequently evaluated within the CCC's statutory evaluation role. The CCC has also evaluated the effectiveness of the Scottish Climate Change Adaptation Programme in response to requests from Scottish Government.

Table 2.7 CCRA3 Urgency Score descriptions.	
Urgency score	**Description**
'More action needed'*	New, stronger or different Government action, whether policies, implementation activities, capacity building or enabling environment for adaptation – over and above those already planned – are beneficial in the next five years to reduce climate risks or take advantage of opportunities. This will include different responses according to the nature of the risks and the type of adaptation: • Addressing current and near-term risks or opportunities with low and no-regret options (implementing activities or building capacity). • Integrating climate change in near-term decisions with a long life-time or lock-in. • Early adaptation for decisions with long lead-times or where early planning is needed as part of adaptive management.
'Further investigation'*	On the basis of available information, it is not known if more action is needed or not. More evidence is urgently needed to fill significant gaps or reduce the uncertainty in the current level of understanding in order to assess the need for additional action.
'Sustain current action'*	Current or planned levels of activity are appropriate, but continued implementation of these policies or plans is needed to ensure that the risk or opportunity continues to be managed in the future.
'Watching brief'*	The evidence in these areas should be kept under review, with continuous monitoring of risk levels and adaptation activity (or the potential for opportunities and adaptation) so that further action can be taken if necessary.

* Note that all risks and opportunities require further research and evidence - not just those listed under further investigation - and all the risks and opportunities in this CCRA require ongoing monitoring (some form of watching brief) on risk / opportunity levels and adaptation activity. The urgency categories assigned are thus the most important priorities.

The four urgency scores have been slightly revised from those used in CCRA2. The category of 'Research Priority' in CCRA2 has been replaced with 'Further investigation' in CCRA3. This is because of some confusion following CCRA2 that 'Research Priority' only denoted that more research was needed, when in fact the urgency is to establish the extent to which further adaptation is required. All risks and opportunities require further research, and given the state of current knowledge, continued research is essential across all the priority risks and opportunities in this CCRA. Similarly, the greater focus on adaptive management recommended in CCRA3 means that all of the priority risks and opportunities should be monitored and measured: it is not just risks or opportunities identified as a watching brief where periodic review and updates are needed. The four urgency scores should therefore be seen as the most important element, but all should be seen as being within a package of ongoing research, monitoring, piloting, evaluation and learning.

It is highlighted that for some risks and opportunities, the lack of quantitative evidence means that expert judgement is needed to assign different risks and opportunities to the urgency categories. To make this process robust, this was based on the consensus (through consultation and discussion) of Technical Report authors, the CCC, and the CCRA peer reviewers. The information on each risk and opportunity is set out in detail, which accompanies the urgency scores and rationale for those scores, so the reader can see transparently how these were made and can judge the urgency scores for themselves.

CCRA3 does include one additional extension on the urgency score, compared to CCRA2. When the category ‘more action needed’ is identified, then further information is presented on what form that action might take, using the three early adaptation building blocks set out in Figure 2.3, i.e. drawing on information from Task 3a and 3b above. In summary, urgent action is likely to be greater when:

- There is a high short-term adaptation shortfall (i.e. a large current adaptation gap) that provides opportunities for no and low-regret adaptation, and/or
- There is a risk of lock-in from action/inaction in the next five years, and/or
- There are benefits from early action to address major future risks.

2.8.4 Task 3d Learning and Evaluation – linking to CCRA4

The final task in CCRA3 is an addition to the CCRA2 method. It seeks to link the successive five-year cycles and encourage adaptive management thinking. Authors were asked where additional information or analysis would be useful to inform CCRA4 and subsequent adaptation programmes. This could be in the form of clearer research priorities, for both risks and adaptation, noting authors were encouraged to prioritise practice orientated research. It could also be in terms of other adaptive management activities, whether monitoring, piloting, learning, building capacity, etc.

Authors were also asked to summarise in a ‘looking forward’ section for each risk or opportunity some key reflections. They were also asked to address the question ‘where might transformational adaptation be needed?’. The rationale for this section was to try and encourage authors to look beyond CCRA3 – to CCRA4 and even later cycles – and identify if adaptation might need to move beyond current incremental activities. In such cases, this may involve a shift from the present-day situation where the aim of adaptation is to maintain the essence and integrity of a current system - to changing the fundamental attributes of a system itself (IPCC, 2014). It is often characterised as moving from ‘doing things differently’ to ‘doing different things’ (see Lonsdale et al., 2015; CRC, 2020). The early consideration of transformational adaptation is important, because by the time of the CCRA4, the UK will be considering actions for the period 2028-2032. If insufficient progress is made globally towards the Paris Agreement during the 2020s, it is likely that the next round of adaptation programmes (NAP4 and the AP of the DAs) will have to significantly scale-up.

Finally, following the publication of the CCRA Evidence and Government Report and the next set of national adaptation programmes, a formal evaluation of CCRA3 should be undertaken prior to CCRA4. This would provide an opportunity to review CCRA3 and introduce a stronger learning element. The results of this evaluation, along with other consultation and stakeholder feedback, should be used in the design of CCRA4. This evaluation would need to be undertaken in 2023, after the CCRA3 Technical Report, Government Report and the National Adaptation Programme.

2.9. References

Arnell, N.W., Kay, A.L., Freeman, A., Rudd, A.C., and Lowe, J.A. 2020 Changing climate risk in the UK: a multi-sectoral analysis using policy-relevant indicators. *Climate Risk Management,* **100265** https://doi.org/10.1016/j.crm.2020.100265

Asian Development Bank (2020). Principles of Climate Risk Management for Climate-Proofing Projects. Manila, Philippines. Available at https://www.adb.org/publications/climate-risk-management-climate-proofing-projects. Accessed April 2021.

Ballard, D., Black, D., and Lonsdale, K. (2013). Initial Assessment of the UK's Adaptive Capacity for Responding to the Impacts of Climate Change. Report for Department for Environment, Food and Rural Affairs as part of the UK Climate Change Risk Assessment. Available at http://randd.defra.gov.uk/Document.aspx?Document=11254_AdaptiveCapacity-CA0506-FinalReport.pdf

Ballard, D, Bond, C, Pyatt, N, Lonsdale, K, Whitman, G.P., Dessai, S., Evans, M., Tweed, J.H. (2013) PREPARE - Barriers and enablers to organisational and sectoral adaptive capacity - qualitative study, Part of the PREPARE Programme of research on preparedness, adaptation and risk, Final Report for project ERG1211 by Ricardo-AEA for Defra. Report reference Ricardo-AEA/R/ED58163/PREPARE R1a/Issue 1.0.

Belcher, C., Brown, I., Clay, G., Doerr, S., Elliott, A., Gazzard, R., Kettridge, N., Morison, J., Perry, M., Santin, C., and Smith, T. (2021) UK Wildfires and their Climate Challenges. Report for the Third UK Climate Change Risk Assessment. https://www.ukclimaterisk.org/independent-assessment-ccra3/research-supporting-analysis/

Betts, R.A. and Brown, K. (2021) Introduction. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/independent-assessment-ccra3/technical-report/

Beier, P., Hansen, L. J., Helbrecht, L., & Behar, D. (2016). A How-to Guide for Coproduction of Actionable Science. Conservation Letters. http://doi.org/10.1111/conl.12300 .

BoE (2018). Climate change: what are the risks to financial stability? Bank of England. Available at https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability. Accessed April 2021.

Boulton, C.A, Booth, B.B.B, Good, P.(2017) Exploring uncertainty of Amazon dieback in a perturbed parameter Earth system ensemble. Global Change Biology 23, 5032-5044. https://doi.org/10.1111/gcb.13733

Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011). The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

Burton, I. (2004) Climate Change and the Adaptation Deficit. Occasional paper 1, Adaptation and Impacts Research Group, Meteorological Service of Canada, Environment Canada, Toronto, 6 pp.

Cambridge Econometrics (2019). A consistent set of socioeconomic dimensions for the CCRA3 Evidence Report research projects. Available at https://www.ukclimaterisk.org/ccra-research/ . Accessed April 2021.

CCC (2015). Progress in preparing for climate change: 2015 Report to Parliament. Committee on Climate Change 2015. Published by the Adaptation Sub-Committee, London.

CCC (2016). UK Climate Change Risk Assessment 2017. Synthesis report: priorities for the next fi e years. Published by the Committee on Climate Change, London, July 2016. Available at https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf . Accessed April 2021.

CCC (2017). Progress in preparing for climate change. 2017 Report to Parliament. Committee on Climate Change, Published by the CCC, London, June 2017. Available at https://www.theccc.org.uk/publication/2017-report-to-parliament-progress-in-preparing-for-climate-change/. Accessed April 2021.

CCC (2019a). Adaptation Progress in preparing for climate change – 2019 Progress Report to Parliament. July 2019. Published by the CCC. Available at https://www.theccc.org.uk/wp-content/uploads/2019/07/CCC-2019-Progress-in-preparing-for-climate-change.pdf. Accessed April 2021.

CCC (2019b). Net Zero: The UK's contribution to stopping global warming. Climate Change Committee May 2019. Available at https://www.theccc.org.uk/wp-content/uploads/2019/05/Net Zero-The-UKs-contribution-to-stopping-global-warming.pdf. Accessed April 2021.

Cimato, F. and Mullan, M. (2010) 'Adapting to climate change: Analysing the role of Government'. DEFRA Evidence and Analysis Series Paper 1. London, UK. Available at https://www.gov.uk/government/publications/adapting-to-climate-change-analysing-the-role-of-government. Accessed April, 2021.

Challinor, A. and Benton, T. (2021) International dimensions. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/independent-assessment-ccra3/technical-report/

Chambwera, M., G. Heal, C. Dubeux, S. Hallegatte, L. Leclerc, A. Markandya, B.A. McCarl, R. Mechler, and J.E. Neumann (2014) Economics of adaptation. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., et al., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 945-977. Available at https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap17_FINAL.pdf. Accessed April 2021.

CRC (2019). climate risk and opportunity assessment for Glasgow City Region. Climate Ready Clyde. Available at http://climatereadyclyde.org.uk/publications/. Accessed April 2021.

CRC (2020). What does transformational adaptation look like? Report of the Clyde Rebuilt project, Published by Climate Ready Clyde. Available at http://climatereadyclyde.org.uk/wp-content/uploads/2020/12/What-does-transformational-adaptations-look-like-FINAL2.pdf. Accessed April, 2021.

CPI (2019). Global landscape of climate finance 2019. Published by the Climate Policy Initiative, London, UK. Available at https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2019/. Accessed April 2021.

COACCH (2018). D1.4 Co-design and co-delivery protocol. Deliverable of COACCH: CO-designing the Assessment of Climate CHange costs. Available at https://www.coacch.eu/deliverables/. Accessed April 2021.

Defra (2018). The National Adaptation Programme and the third strategy for climate adaptation reporting: Making the country resilient to a changing climate. July 2018. Department for Environment Food, and Rural Affairs. Available at https://www.gov.uk/government/publications/climate-change-second-national-adaptation-programme-2018-to-2023. Accessed April, 2021.

Defra (2020) Accounting for the Effects of Climate Change: Supplementary Green Book Guidance, November 2020. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/934339/Accounting_for_the_Effects_Of_Climate_Change_-_Supplementary_Green_Book_.._.pdf . Accessed April 2021.

DfT (2019). Transport analysis guidance (WEBTAG). Published by the Department for Transport, 2019. Available at https://www.gov.uk/guidance/transport-analysis-guidance-tag. Accessed April 2021.

Dittrich, R., Wreford, A., and Moran, D. (2016). A survey of decision-making approaches for climate change adaptation: Are robust methods the way forward?. Ecological Economics. 122. 79-89. https://doi.org/10.1016/j.ecolecon.2015.12.006.

ECONADAPT (2017). Review of the Costs and benefits of adaptation. Report of the EC RTD Economics of Adaptation Project. Available https://econadapt.eu/sites/default/files/docs/Econadapt-policy-report-on-costs-and-benefits-of-adaptaiton-july-draft-2015.pdf.

Eijgenraam, C., Kind, J., Bak, C., Brekelmans, R., den Hertog, D., Duits, M., Roos, K., Vermeer, P, and Kuijken, W. (2013). Economically Efficient Standards to Protect the Netherlands Against Flooding. Interfaces. Volume 44, Issue 1. http://doi.org/10.1287/inte.2013.0721.

Fankhauser, S., Smith, J.B., and Tol, R., (1999). Weathering Climate Change. Some Simple Rules to Guide Adaptation Investments. Ecological Economics, 30(1), pp.67-78. https://doi.org/10.1016/S0921-8009(98)00117-7.

Fankhauser, S., Ranger, N., Colmer, J., Fisher, S., Surminski, S., Stainforth, D., and Williamson, A. (2013) An independent national adaptation programme for England. Published by The Grantham Research Institute on Climate Change and the Environment and The Centre for Climate Change Economics and Policy, March 2013. Available at https://www.lse.ac.uk/granthaminstitute/publication/an-independent-national-adaptation-programme-for-england/. Accessed April 2021.

Field, C.B., et al., 2014 Technical summary. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 35-94. Available at https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-TS_FINAL.pdf . Accessed April 2021.

Frontier Economics, Irbaris LLP and Ecofys UK (2013). The Economics of Climate. Synthesis Report March 2013. Report to Defra and the Devolved administrations. March 2013. Available at http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016. Accessed April 2021.

Gohar, L., Bernie, D., Good, P. and Lowe, J.A. (2018) UKCP18 Derived Projections of Future Climate over the UK. Available at https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Derived-Projections-of-Future-Climate-over-the-UK.pdf.

Hanlon, H., Palmer, M. and Betts, R.A. (2021) Effect of Potential Climate Tipping Points on UK Impacts. Report for the Third UK Climate Change Risk Assessment. https://www.ukclimaterisk.org/independent-assessment-ccra3/research-supporting-analysis/

Haasnoot, M., Kwakkel, J.H., Walker, W.E., ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change. Volume 23, Issue 2, April 2013, Pages 485-498. https://doi.org/10.1016/j.gloenvcha.2012.12.006 .

Hallegatte, S., Shah, A., Lempert, R., Brown, C., Gill S (2012). Investment Decision Making under Deep Uncertainty - Application to Climate Change. World Bank Policy Research Working Paper 6193. Published by the World Bank, https://doi.org/10.1596/1813-9450-6193.

Hausfather and Peters (2020) Emissions – the 'business as usual' story is misleading. *Nature* 577, 618-620. https:/doi.org/10.1038/d41586-020-00177-3.

Hegger, D., Lamers, M., Van Zeijl-Rozema, A., & Dieperink, C. (2012). Conceptualising joint knowledge production in regional climate change adaptation projects: success conditions and levers for action. Environmental Science and Policy, 18, 52–65. http://doi.org/10.1016/j.envsci.2012.01.002.

Hillier, J. K. , Matthews, T., Wilby, R., Murphy, C. (2020) Multi-hazard dependencies can increase or decrease risk. Nat. Clim. Chang. 10, 595–598 (2020). https://doi.org/10.1038/s41558-020-0832-y.

Hinkel, J., D. Lincke, A. T. Vafeidis, M. Perrette, R. J. Nicholls, R. S. J. Tol, B. Marzeion, X. Fettweis, C. Ionescu, and A. Levermann (2014). Coastal flood damage and adaptation cost under 21st century sea-level rise. Proceedings of the National Academy of Sciences Mar 2014, 111 (9) 3292-3297; DOI: https://doi.org/10.1073/pnas.1222469111

HMT (2008). Intergenerational wealth transfers and social discounting: Supplementary Green Book guidance. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/193938/Green_Book_supplementary_guidance_intergenerational_wealth_transfers_and_social_discounting.pdf. Accessed April 2021.

HMG (2013). The National Adaptation Programme Report: Analytical Annex: Economics of the National Adaptation Programme. Publication. Published by HM Government, 1 July 2013. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727453/pb13942a-nap-annex-economics.pdf. Accessed April 2021.

HMG (2018). A Green Future: Our 25 Year Plan to Improve the Environment. Published by Defra. Available at https://www.gov.uk/government/publications/25-year-environment-plan. Accessed April 2021.

HMG (2019). Green Finance Strategy. Transforming Finance for a Greener Future. Published by HM Government, July 2019. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/820284/190716_BEIS_Green_Finance_Strategy_Accessible_Final.pdf. Accessed April 2021.

HMG (2020). National Risk Register, 2020 edition. Published by HM Government. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/952959/6.6920_CO_CCS_s_National_Risk_Register_2020_11-1-21-FINAL.pdf. Accessed April 2021.

HMT (2018). The Green Book: Central Government Guidance on Appraisal and Evaluation. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf.

Howarth, C. Morse-Jones, S. Brooks, K. Kythreotis, A.P. (2018). Co-producing UK climate change adaptation policy: An analysis of the 2012 and 2017 UK Climate Change Risk Assessments, Environmental Science & Policy, Volume 89, 2018, Pages 412-420. https://doi.org/10.1016/j.envsci.2018.09.010.

HRW (2012a). The UK Climate Change Risk Assessment 2012. Evidence Report. Project deliverable number D.4.2.1 Release 8. January 2012. HR Wallingford. Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15747#RelatedDocuments . Accessed April 2021.

HRW (2012b) Climate Change Risk Assessment Recommendations Report. HR Wallingford. Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15747#RelatedDocuments. Accessed April 2011.

HR Wallingford. (2020). Updated projections of future water availability for the third UK Climate Change Risk Assessment. Available at https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Updated-projections-of-future-water-availability_HRW.pdf

IPCC (2014a). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth

Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32. Available at https://www.ipcc.ch/report/ar5/wg2/.

IPCC (2014b). Glossary. Annex II. Impacts, Adaptation, and Vulnerability, Working Group 2 of the IPCC 5th Assessment Report. Available at https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf.

IPCC (2018a). Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, Y. Chen, S. Connors, M. Gomis, E. Lonnoy, J. B. R. Matthews, W. Moufouma-Okia, C. Péan, R. Pidcock, N. Reay, M. Tignor, T. Waterfield, X. Zhou (eds.)]. In Press. Available at https://www.ipcc.ch/sr15/ .

IPCC (2018b). Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press https://www.ipcc.ch/sr15/chapter/glossary/

IPCC (2019). Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. In press. https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/

Jackson, L.C., Kahana, R., Graham, T. *et al.* (2015) Global and European climate impacts of a slowdown of the AMOC in a high resolution GCM. *Clim Dyn* **45,** 3299–3316. https://doi.org/10.1007/s00382-015-2540-2

Johns, T.M. (2021) Comparison of climate change and climate impact metrics over the UK for the UKCP09 and UKCP18 RCM-PPE ensembles, within a broader context of climate modelling uncertainty. Report for the Third UK Climate Change Risk Assessment. https://www.ukclimaterisk.org/independent-assessment-ccra3/research-supporting-analysis/

Jones, R. N., et al. (2014). Foundations for decision making. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. C. B. Field, V. R. Barros, D. J. Dokken et al. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press: 195-228. https://www.ipcc.ch/report/ar5/wg2/

Jones, L., Gorst, A., Elliott, J., Fitch, A., Illman, H., Evans, C., Thackeray, S., Spears, B., Gunn, I., Carvalho, L., May, L., Schonrogge, K., Clilverd, H., Mitchell, Z., Garbutt, A., Taylor, P., Fletcher, D., Giam, G., Aron, J., Ray, D., Berenice-Wilmes, S., King, N., Malham, S., Fung, F., Tinker, J., Wright, P., Smale, R. (2020). Climate driven threshold effects in the natural environment. Report to the Climate Change Committee. May 2020. Available at: https://www.ukclimaterisk.org/ccra-research/

JRF (2016). Climate Change Impacts on the Future Cost of Living (SSC/CCC004). Research published by the Joseph Rowntree Foundation, March, 2016. Available at http://paulwatkiss.co.uk/documents/FINAL%20Watkiss%20report%2030032016.pdf. Accessed April 2021.

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Legg, T. (2018). State of the UK climate 2017. INTERNATIONAL JOURNAL OF CLIMATOLOGY. Volume: 38 Supplement: 2. https://doi.org/10.1002/joc.5798.

Klein, R.J.T., G.F. Midgley, B.L. Preston, M. Alam, F.G.H. Berkhout, K. Dow, and M.R. Shaw (2014). Adaptation opportunities, constraints, and limits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 899-943. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap16_FINAL.pdf

Kok, K. and Pedde, S. (2016). IMPRESSIONS socio-economic scenarios. EU FP7 IMPRESSIONS Project Deliverable D2.2. Available at http://impressions-project.eu/documents/1/

Lenton, T.M., Held, H. Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf S. and Schellnhuber H.J. Tipping elements in the Earth's climate system, Proceedings of the National Academy of Sciences USA, 2008, 105(6):1786–1793. https://doi.org/10.1073/pnas.0705414105.

Lenton, T.M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Schellnhuber, H. J., (2019). . Climate tipping points—too risky to bet against. Nature, 575, 592-595. https://doi.org/10.1038/d41586-019-03595-0.

Levermann A, Bamber J L, Drijfhout S, Ganopolski A, Haeberli W, Harris N R P, Huss M, Krüger K, Lenton T M, Lindsay R W, Notz D, Wadhams P and Weber S (2012). Potential climatic transitions with profound impact on Europe. Clim. Change 110 845–78. https://doi.org/10.1007/s10584-011-0126-5.

Lonsdale, K., Pringle, P. and Turner, B. (2015). Transformative adaptation: what it is, why it matters & what is needed. UK Climate Impacts Programme, University of Oxford, Oxford, UK. ISBN: 978-1-906360-11-5. Published by UKCIP 2015. Available at https://ora.ox.ac.uk/objects/uuid:40000abd-74a0-4a3e-8e73-34374852474c . Accessed April, 20201.

Lowe, J.A., Bernie, D, Bett, P., Bricheno, L., Brown, S. et al. (2018). UKCP18 Science Overview report. Published by the Met Office, November 2018. Available at https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf. Accessed April 2021.

Mach, K., Mastrandrea, M.D., Freeman, P.T., and Field, C.B. (2017). Unleashing expert judgment in assessment. Global Environmental Change 44: 1-14.https://doi.org/10.1016/j.gloenvcha.2017.02.005 .

Marcel J. F. Stive, Louise O. Fresco, Pavel Kabat, Bart W. A. H. Parmet, and Cees P. Veerman (2011). How the Dutch plan to stay dry over the next century. Proceedings of the Institution of Civil Engineers - Civil Engineering 2011 164:3, 114-121

McGlade, C. and Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2°C. Nature. https://doi.org/10.1038/nature14016.

MDBs (2017). Joint report on Multilateral Development Banks Climate Finance. Multilateral Development Banks. Accessed from: www.ebrd.com/2017-joint-report-on-mdbs-climate-finance.

Murphy, J., Sexton, D., Jenkins, G., Boorman, P., Booth, B., Brown, K., Clark, R., Collins, M., Harris, G. and Kendon, L. (2009) UK Climate Projections science report: Climate change projections, Met Office Hadley Centre. Available at http://cedadocs.ceda.ac.uk/1320/1/climate_projections_full_report.pdf

Murphy J.M., Harris, G.R., Sexton, D.M.H., Kendon, E.J., Bett, P.E. et al., (2018). UKCP18 Land Projections: Science Report. Published by the Met Office, November 2018. Available from https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Land-report.pdf. Accessed April 2021.

NAO (2019). Successful Commissioning Toolkit. National Audit Office (NAO). Available at https://www.nao.org.uk/successful-commissioning/. Accessed April 2021.

NAS (2016). Adapting with Ambition: National Climate Adaptation Strategy 2016 (NAS). Published by the Ministry of Infrastructure and the Environment, the Hague. Available at ruimtelijkeadaptatie.nl/publish/pages/125102/nas_implementation_programme.pdf. Accessed April 2021.

NCC (2017). How to do it: a natural capital workbook. Natural Capital Committee. Available at https://www.gov.uk/government/publications/natural-capital-committee-natural-capital-workbook. Accessed April 2021.

NGFS (2019). Network for Greening the Financial System. A call for action Climate change as a source of financial risk. First comprehensive report. Published by the Network for Greening the Financial System, April 2019. Available https://www.banque-france.fr/sites/default/files/media/2019/04/17/ngfs_first_comprehensive_report_-_17042019_0.pdf . Accessed April 2021

Palmer, M., Howard, T., Tinker, J., Lowe, J.A., Bricheno, L. et al (2018). UKCP18 Marine report November 2018. Published by the Met Office. November, 2018. Available at https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-marine-report-updated.pdf. Accessed April 2021.

Pedde, S., Harrison, P. A., and Bullock, J.M (2020). Development of Shared Socio-economic Pathways for the UK. Part of the UK SCAPE project on Spatially explicit Projections of EnvironmEntal Drivers SPEED. https://doi.org/10.1016/j.scitotenv.2020.143172 .

OECD (2015), Climate Change Risks and Adaptation: Linking Policy and Economics, OECD Publishing, Paris. https://doi.org/10.1787/9789264234611-en.

OECD (2017), Investing in Climate, Investing in Growth, OECD Publishing, Paris, https://doi.org/10.1787/9789264273528-en .

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Clim Change 122, 387-400. https://doi.org/10.1007/s10584-013-0905-2.

Power, K., Lang, A., Wood, J., Gubbels, F., McCullough, J., Carr, A., England, K., Guida, K. (2020) Understanding how behaviour can influence climate change risks, AECOM and Sniffer. Available at https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Understanding-how-behaviours-can-influence-climate-change-risks-Main-Report_AECOM.pdf

Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A. and. Ruta, G. (2010) Adaptation in the UK: a decision-making process. Policy Brief. Published by The Grantham Research Institute on Climate Change and the Environment and The Centre for Climate Change Economics and Policy, September 2010. Available at https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2014/03/PB-Ranger-adaptation-UK.pdf . Accessed April 2021.

Ranger N., Reeder T. and Lowe J. (2013) Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project. EURO J Decis Process. https://doi.org/10.1007/s40070-013-0014-5 .

Reeder, T. and Ranger, N. (2011). "How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project." World Resources Report, Washington. http://www.wri.org/node/40317.

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob Environ Change 42, 153-168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Ritchie, P.D.L., Smith, G.S., Davis, K.J. *et al.* Shifts in national land use and food production in Great Britain after a climate tipping point. *Nat Food* **1,** 76–83 (2020). https://doi.org/10.1038/s43016-019-0011-3

Rojas, R, Feyen, L and Watkiss, P. (2013). Climate Change and River Floods in the European Union: Socio-Economic Consequences and the Costs and Benefits of Adaptation. Global Environmental Change. GEC-D-13-00086R2. Global Environmental Change, Volume 23, Issue 6, December 2013, Pages 1737-1751. doi.org/10.3354/cr01200. https://doi.org/10.1016/j.gloenvcha.2013.08.006

Sayers, P.B., Kay, A., Mauz, J., Horritt, M., Carr, S., Lamb, R., Renning-Rowsell, E. (2020). Climate Change Risk Assessment 2022: Projections of future flood risk in the UK. Research undertaken by Sayers and Partners for the Committee on Climate Change. Published by Committee on Climate Change, London. Available at https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Future-Flooding-Main-Report-Sayers-1.pdf .

Seto, K. C., Davis, S. J., Mitchell, R. B., Stokes, E. C., Unruh, G and Ürge-Vorsatz, D. (2016). Carbon Lock-In: Types, Causes, and Policy Implications. Annual Review of Environment and Resources 2016 41:1, 425-452 https://doi.org/10.1146/annurev-environ-110615-085934

Slingo, J. (2021) Latest scientific evidence for observed and projected climate change. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V.

(eds.)]. Prepared for the Climate Change Committee, London https://www.ukclimaterisk.org/independent-assessment-ccra3/technical-report/

Smith, D.M., Eade, R., Scaife, A.A. et al. (2019). Robust skill of decadal climate predictions. Climate and Atmospheric Science volume 2, Article number: 13 (2019). https://doi.org/10.1038/s41612-019-0071-y.

SP (2019). Climate Change (Emissions Reduction Targets) (Scotland) Act 2019. Bill for Act of the Scottish Parliament. Published at www.legislation.gov.uk/asp/2019/15/enacted. Accessed April 2021.

Stammer, D., van de Wal, R. S. W., Nicholls, R. J., Church, J. A., Le Cozannet, G., Lowe, J. A., et al. (2019). Framework for high-end estimates of sea-level rise for stakeholder applications. Earth's Future., 7, 923–938. https://doi.org/10.1029/2019EF001163.

Street, R., Di Mauro, M., Humphrey, K., Johns, D., Boyd, E., Crawford-Brown, D., Evans, J., Kitchen, J., Hunt, A., Knox, K., Low, R., McCall, R., Watkiss, P., and Wilby, R. (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 8, Cross-cutting Issues. Report prepared for the Adaptation Sub-Committee of the Climate Change Committee, London. https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-8-Cross-cutting-issues.pdf

Tangney, P. and M. Howes (2016). The politics of evidence-based policy: A comparative analysis of climate adaptation in Australia and the UK. Environment and Planning C: Government and Policy 34(6): 1115-1134. https://doi.org/10.1177/0263774X15602023.

Tangney, P. (2017). The UK's 2012 Climate Change Risk Assessment: How the rational assessment of science develops policy-based evidence. Science and Public Policy 44(2): 225-234. https://doi.org/10.1093/scipol/scw055 .

TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Published by the Task Force on Climate Related Financial Disclosures, June 2017. Available https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-2017-TCFD-Report-11052018.pdf . Accessed April 2021

Thompson, Vikki; Dunstone, Nick J.; Scaife, Adam A.; et al. (2017). High risk of unprecedented UK rainfall in the current climate. Nature Communications, 8, Article Number: 107 https://doi.org/10.1038/s41467-017-00275-3 .

UNEP (2018). The Adaptation Gap Report 2018. United Nations Environment Programme (UNEP), Nairobi, Kenya. Available at https://www.unep.org/resources/adaptation-gap-report-2018 . Accessed April 2021 .

UNEP (2019). Emissions Gap Report 2019. United Nations Environment Programme, Nairobi. Available at https://www.unep.org/resources/emissions-gap-report-2019. Accessed April 2021.

UNEP (2020). Emissions Gap Report 2020. United Nations Environment Programme, Nairobi. Available at https://www.unep.org/resources/emissions-gap-report-2020. Accessed May 2021.

USEPA (2020). Environmental Justice. Available at https://www.epa.gov/environmentaljustice.

USGCRP (2018): Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. https://doi.org/10.7930/NCA4.2018.

van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. (2011). The representative concentration pathways: an overview. Climatic Change (2011) 109:5–31. DOI https://doi.org/10.1007/s10584-011-0148-z

van Ginkel, K., W. Botzen, M. Haasnoot, G. Bachner, K. Steininger, J. Hinkel, P. Watkiss, E. Boere, A. Jeuken, Elisa Sainz de Murieta and F. Bosello. (2020). Climate change induced socio-economic tipping points: review and stakeholder consultation for policy relevant research" Environ. Res.Lett.15(2020)023001. https://doi.org/10.1088/1748-9326/ab6395.

Warren, R., Watkiss, P., Wilby, RL., Humphrey, K., Ranger, N., Betts, R., Lowe, J., and Watts, G. (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 2, Approach and Context. Report prepared for the Adaptation Sub-Committee of the Climate Change Committee, London. Available at https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-2-Approach-and-context.pdf . Accessed April 2021.

Warren, R., Wilby, R., Brown, K., Watkiss, P., Betts, R., Murphy, J., and Lowe, J. (2018). Advancing national climate change risk assessment to deliver national adaptation plans. Philosophical Transactions A. https://doi.org/10.1098/rsta.2017.0295.

Watkiss, P. and Hunt, A. (2011). Method for the Adaptation Economic Assessment to accompany the UK Climate Change Risk Assessment (CCRA). Final Report to Department for Environment, Food and Rural Affairs. Submitted by HR Wallingford Ltd, Contract CEOSA 0901. May 2011. http://www.paulwatkiss.co.uk/newimagesanddocs/AEA%20Method%20Tier%201%20steps%20vs%206.pdf

Watkiss, P. and Hunt, A. (2012) Filling the Gaps around the CCRA: Assessing the Economic Impacts of Indirect, International and Major Risks. Paul Watkiss Associates.

Watkiss, P., Hunt, A., Blyth, W. and Dyszynski, J (2014). The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. Climatic Change. https://doi.org/10.1007/s10584-014-1250-9.

Watkiss, P., Benzie, M, and Klein, R. J. T (2015). The complementarity and comparability of climate change adaptation and mitigation. WIREs Clim Change 2015, 6:541–557. https://doi.org/10.1002/wcc.368.

Watkiss, P., Cimato, F., Hunt, A. and Moxey, A. (2019). The Impacts of Climate Change on Meeting Government Outcomes in England. Support research for the 2019 Progress Report. Report to the UK Climate Change Committee (CCC). Available at https://www.theccc.org.uk/publication/impacts-of-climate-change-on-meeting-government-outcomes-in-england-paul-watkiss-associates/. Accessed April 2021.

Werners et al. (2013). Adaptation Turning Points: Decision Support Methods for Adaptation, MEDIATION Project, Briefing Note 9. Available at https://www.weadapt.org/sites/weadapt.org/files/legacy-new/knowledge-base/files/742/526e89aa80569briefing-note-9-lr.pdf

Wilby, R. L. and Dessai, S. (2010). Robust adaptation to climate change. Weather – July 2010, Vol. 65, No. 7. https://doi.org/10.1002/wea.543 .

Wilby, R. L. (2012) Review of the First UK Climate Change Risk Assessment: A framework for delivering regular assessments of climate risks and opportunities. Report on behalf of the UK Climate Change Committee (Adaptation Sub-Committee), London, UK.

Wise, RM. Et al. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. Global Environmental Change. Volume 28, September 2014, Pages 325-336 https://doi.org/10.1016/j.gloenvcha.2013.12.002.

WG (2019). Wales accepts Climate Change Committee 95% emissions reduction target. Welsh Government. Available at https://gov.wales/wales-accepts-committee-climate-change-95-emissions-reduction-target. Accessed April 2021.

WSP (2020). Interacting risks in infrastructure, the built and natural environments: Research in support of the UK's Third Climate Change Risk Assessment Evidence Report. Available at https://www.ukclimaterisk.org/ccra-research/. Accessed April 2021.

Annex 1: Risk/Opportunity template (Round 1)

Templates were used for the first round of the CCRA3 methodology by authors. They were completed for each individual risk and opportunity. For the second round of the methodology, these templates were updated (and are shown below), but rather than using these, authors converted into report sections, as set out in the following chapters.

Step 1: What is the current and future level of risk/opportunity?
<u>**Current risks or opportunities**</u> Describe current risks or opportunities. In addition, identify and document additional changes in the current risk or opportunity observed since CCRA1 or CCRA2. Discuss any observed inequality of the current risks in relation to individual, place and regional dimensions (see note on inequalities description). <u>**Future risks or opportunities**</u> Describe future risks or opportunities. Please report evidence that captures <u>low and high scenarios</u> for the <u>mid-century and late century</u>. Ideally this would be for time slices of the 2050s (2040–2070) and 2080s (2070–2100) for scenarios that project global warming to stabilise at 2°C ± 0.5°C by 2100, or project global warming to reach 4°C ± 0.5°C in 2081 – 2100. If information is not available for these time slices in projections of those rates of global warming, it may be appropriate to examine projected climate changes at global warming levels of 2°C and 4°C reached at other times, and apply these to the required dates. The validity of this will depend on whether the specific climate variables being assessed have a strong dependency on the rate of warming rather than its instantaneous magnitude, and needs to be judged on a case-by-case basis. In addition: • Report the scenario and the time period for the evidence cited. When evidence relates to standard time slices, please document scenario and time period (e.g. RCP2.6, 2071-2100, relative to baseline period 1971-2000). When evidence is for global warming levels please document the GWL and time period (e.g. 2°C GWL, relative to preindustrial, exceeded in time period centred on 2070). • Document the uncertainty. This should report the scenario uncertainty associated with the evidence (e.g. RCP2.6, SRES A1B, etc) and the climate model uncertainty for each scenario (e.g. 10^{th} to 90^{th} percentile range from UKCP09). • Document the relative importance (where evidence exists) of the climate change versus the socio-economic drivers in the evidence reported. Please capture and report on any tail-end risks, including low-probability high-consequence extremes (events). This could be High++ studies, or projected changes with rates of warming above the 50^{th} percentile of probabilistic projections with the RCP8.5 emissions scenario. It may help to consider the question '*how bad could things plausibly get*?' Discuss projected changes in risks or opportunities across affected populations, across the individual, place and regional dimensions (see note on inequalities description). Use this information to score the magnitude (see final section).

<table>
<tr><td>Lock-in</td><td>Identification of potential lock-in risks, or loss of opportunities, focused on next reporting period (current, 2022 – 2027).
Could these affect the urgency score (link to Step 3)?</td></tr>
<tr><td>Thresholds</td><td>Document thresholds, whether biophysical thresholds, engineering, performance or policy thresholds. Does exceedance of these vary over scenarios or across projections (uncertainty)?
Please consider results of the CCRA3 Thresholds research project.
Could these alter the magnitude score (expert judgement and agreement across authors)?</td></tr>
<tr><td>Interacting risks</td><td>Document interacting risks and potential size.
Please consider results of the CCRA3 Interacting Risks research project.
Could these potentially increase the magnitude score?</td></tr>
<tr><td>Net Zero</td><td>1) Is the net zero target likely to increase or decrease the magnitude of the risk/opportunity?
2) Could the climate change risk or opportunity make the net zero target easier or harder to achieve?
(See net zero supplementary note)</td></tr>
<tr><td>Overall magnitude and evidence</td><td>Score the magnitude using the magnitude tables, with the differentiated scoring matrix for each country.
Report on the quality of evidence (see magnitude tables and quality of evidence table supplementary note).

Score Current Magnitude

<table>
<tr><td></td><td>England</td><td>NI</td><td>Scotland</td><td>Wales</td></tr>
<tr><td>**Magnitude**</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td></tr>
<tr><td>Quality of evidence</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td><td>H /M /L /Unknown</td></tr>
</table>

Score Future Magnitude
Note that the future magnitude score is based on the highest risk or opportunity score across all scenarios and time periods, including consideration of available information on uncertainty ranges (but not including tail end risks).

<table>
<tr><td></td><td>England</td><td>NI</td><td>Scotland</td><td>Wales</td></tr>
<tr><td>**Magnitude**</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td></tr>
<tr><td>Quality of evidence</td><td>H /M /L</td><td>H /M /L</td><td>H /M /L</td><td>H /M /L</td></tr>
</table>

If the risk or opportunity scores as a medium, high or unknown for current or future, progress to Step 2.
If it scores low in both current and future, go to Step 3.</td></tr>
</table>

<table>
<tr><th colspan="2">Step 2: Is the risk/opportunity going to be being managed, taking into account government commitments and other adaptation?</th></tr>
<tr><td colspan="2">Describe current and announced planned adaptation (including adaptive capacity).
Who is responsible for adaptation (institutional landscape)?
What plans are in place or published?

Document the changes in adaptation, and potential benefits from current adaptation, that have occurred since CCRA1/CCRA2.
What effect adaptation actions have had on the level of current risks between 2012 and now?

Document the potential reduction in future risks / realisation of future opportunity from the planned adaptation in place. This should also consider if government action involves potential maladaptation, or involves lock-in.

For opportunities, the steps are slightly different. There is a need to consider spontaneous and non-government planned adaptation first, and then to assess whether these actions are likely to be sufficient to fully realise potential benefits or whether there is an additional need for Government action, and if so, whether this is in place.</td></tr>
<tr><td>Is there an adaptation shortfall in planned adaptation?</td><td>Based on the analysis above, assess if there is a shortfall. Yes/No/Unknown
To score yes, risks should be managed across the uncertainty range (but not including tail end risks).</td></tr>
<tr><td>Evidence</td><td>Document the evidence.</td></tr>
<tr><td>Quality of evidence</td><td>Rate the quality of Evidence – high, medium, low.
(see magnitude tables and quality of evidence table supplementary note – quality of evidence row 2).</td></tr>
<tr><td>Will this shortfall be addressed by non-governmental adaptation?</td><td>Will other forms of adaptation, including action by the private sector or households, reduce the risks / realise opportunities, in the absence of planned government action? Yes/No</td></tr>
<tr><td>Evidence</td><td>Document the evidence on non-governmental adaptation.</td></tr>
<tr><td>What are the barriers to adaptation?</td><td>If there is an adaptation shortfall, discuss the barriers or constraints that stop adaptation being managed .</td></tr>
<tr><td>Is the risk being managed or is there an adaptation shortfall?</td><td>Re-score the magnitude from Step 1 with information above.
<u>Future Magnitude with existing adaptation action</u>
<table><tr><th></th><th>England</th><th>NI</th><th>Scotland</th><th>Wales</th></tr><tr><td>Magnitude</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td><td>H /M /L/ Unknown</td></tr></table>If there is still a medium or high or unknown magnitude, progress to Step 3. If there is a low risk (no adaptation shortfall) with planned and other action, then go to urgency score (Sustain current action / Watching brief).</td></tr>
</table>

<table>
<tr><td colspan="2">Step 3: Are there benefits to further action in the next five years, over and above what is already planned?</td></tr>
<tr><td colspan="2">Describe potential additional adaptation that could be taken.
Document the evidence on possible additional actions.

This can describe possible additional adaptation, but should not be prescriptive on new policy. Ideally, please try and capture the type of early adaptation (that could be introduced in the next five-year period) and how it aligns to the 3 building blocks and linkages, i.e.:
i) Low or no-regret adaptation (including capacity building).
ii) Climate-smart' design or mainstreaming in early decisions.
iii) Early adaptation activities to support future decisions and action or a combination (portfolio) of all of these.

For opportunities, this should consider additional adaptation to fully realise potential benefits (including creating the enabling environment).

What might be the additional costs and benefits of further adaptation?

Describe any observed and projected implications for distribution of adaptation (i.e. will the strategy benefit some groups/areas more than others, and/or leave others at a disadvantage?)

Are there synergies or trade-offs with mitigation and the net zero target? Does this affect the attractiveness of different types of further action?</td></tr>
<tr><td>Are there benefits of action in next 5 years?</td><td>Based on the analysis above, are there benefits of further action?
Yes/No</td></tr>
<tr><td>Urgency ranking</td><td>Score urgency (into one of four scores):
• More action needed.
• Further investigation.
• Sustain current action.
• Watching brief.

<table><tr><th></th><th>England</th><th>NI</th><th>Scotland</th><th>Wales</th></tr><tr><td>Urgency score</td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td></td><td>Document the rationale for urgency ranking.</td></tr>
<tr><td>Confidence</td><td>Rate the quality of Evidence – high, medium, low.
(see magnitude tables and quality of evidence table supplementary note – quality of evidence row 3).</td></tr>
<tr><td>CCRA4 and transformational adaptation</td><td>What information (risks, opportunities, adaptation) would be useful to inform CCRA4/NAP4?
Where might transformational adaptation be needed?</td></tr>
</table>