The Impacts of Climate Change on Meeting Government Outcomes in England

Final Report

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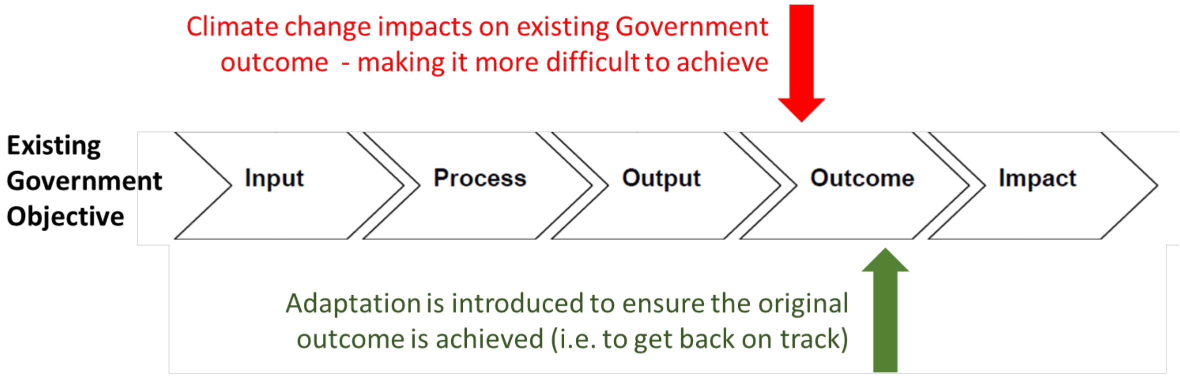
Summary

This report presents the results for the study on 'The Impacts of Climate Change on Meeting Government Outcomes in England', undertaken by Paul Watkiss Associates for the Adaptation Committee of the Committee on Climate Change (CCC). The aim of the study is to help inform the CCC's first progress report on the Government's second National Adaptation Programme (NAP). The objective is to assess how climate change might affect the ability of Government to achieve existing policy outcomes (of relevance to the NAP). Where this is the case, it then considers how existing or future adaptation could address these climate change risks, and ensure that the original outcomes are achieved (against the background of climate change). To investigate this, the analysis undertook a high-level assessment of the impacts (and costs) of not achieving the goals and outcomes due to climate change, then the potential costs and benefits of additional adaptation. The aim was to provide insights on the benefits of taking account of climate change in policy. The CCC is interested in this research to ascertain and communicate to Government the added benefits of including adaptation in policies where it is either currently absent, or where there is a potential gap between the level of risk and the adaptation response as currently set out in the NAP. The focus is on current Government objectives and goals, not specifically derived adaptation objectives and goals. The study is focused on England only, to align with CCC reporting on the NAP.

Method.
The study built on existing approaches used for policy development in UK Government, and the use of a theory of change and logic models (logical frameworks). These allow a structured and quantitative approach for appraisal and evaluation. They identify how to deliver policy objectives through a series of steps, which progress from initial inputs and activities (or processes), through to the outputs and outcomes, and finally, to the overall impact, as shown in the figure below. The project considered a series of case studies on existing Government outcomes. In each case, it assessed how climate change might affect the ability to achieve each existing outcome, using a logical framework, and then assessed if adaptation could get the delivery of the outcome back on track. It is stressed that the project did not develop separate adaptation outcomes, as it focused on the impacts of climate change on core departmental objectives and outcomes, consistent with a climate mainstreaming approach.



The method developed involved five steps, framed around a series of questions:

- Step 1. What is the existing objective and outcome of interest?
- Step 2. How does climate change (in a 2 vs 4°C pathway) affect the outcome, including the effect of existing adaptation?
- Step 3. What are the economic costs of climate change, i.e. the effect on the outcome?
- Step 4. What additional adaptation options could offset these impacts, and help ensure the original outcome is achieved?
- Step 5. What are the potential costs and benefits of additional adaptation, including trade-offs?

This method was applied to ten existing Government objectives and outcomes.

Climate change involves long time-periods, as compared to short-term departmental objectives, and its impacts are uncertain, depending for example on whether the world is on a 2 or 4°C pathway. This meant that there was a need to focus adaptation on early actions. To address this, the project applied the adaptation framework from the 2nd and 3rd UK Climate Change Risk Assessment (CCRA). This framework identifies priorities for early adaptation, i.e. actions that could be undertaken in the next five years or so, centred on three early priority areas. These are:

- Early low and no regret options that address current risks and build resilience;
- Adaptation for early decisions with a long life-time and/or the risk of lock-in;
- Early planning as part of iterative adaptive management, to start preparing for longer-term major impacts and/or where adaptation involves long-lead times.

Analysis of the impacts of climate change on existing outcomes.
An initial set of possible outcomes and indicators for the study were developed by the CCC secretariat. These focused on existing departmental outcomes, although many of them were published in the 25 Year Environment Plan (25YEP) and/or the 2nd National Adaptation Programme (NAP2). An initial list of around 50 outcomes was identified. Following discussion with the CCC secretariat and the Adaptation Committee, this was shortened to a list of 10 outcomes for more detailed case study analysis. The method above was then applied to each of these. The key findings by outcome are summarised in the Table below. These present each Government outcome, and assesses how well these are defined. It then summarises if climate change is already considered in the policy supporting the outcome, and the potential effects of climate change on the outcome. This includes a separate analysis of the risk of lock-in (i.e. where early action, or lack of action, could lead to future climate risks). The table then summarises the potential economic costs (the impact of climate change on the outcome) and assesses if there is a potential adaptation gap, defined as the presence of large residual climate risks even when taking account of current planned adaptation. Finally, it considers the potential for future adaptation action to reduce the impacts of climate change on the outcome, and the costs and benefits of further action.

Key Findings.
The first and most important finding of the study is that in nearly all cases, **climate change will make existing Government outcomes more challenging to achieve**. In most of the cases analysed (but not all), there is insufficient consideration of climate change risks in current policies and activities, i.e. climate change is not being adequately mainstreamed. There were, however, two exceptions to this finding. The first was for English wine production, which was chosen specifically to consider a potential benefit from climate change on an outcome. The second was for green infrastructure, where climate change might influence the demand for the outcome (more GI), because of its potential role as an adaptation option.

The study did find that the analysis of climate change on Government outcomes is challenging for a number of reasons:

- Most of the existing Government outcomes considered did not have a published logical framework, and most did not have well defined and measurable outcomes. This made it difficult to assess the impact of climate change or adaptation.
- There was often a mismatch in timing between the long time-periods involved in climate change, versus the short-term focus of departmental objectives and outcomes. When Government targets were long-term (e.g. in the 25 Year Environment Plan), they were often aspirational and not defined quantitatively.

ES1. Study findings by Outcome

Outcome	Defined outcomes	Consideration of climate change (CC)	Lock-in	Cost of inaction/ adaptation gap	Benefits of further action
Heat – preventable deaths Heatwave plan goal 'reducing summer and spring deaths' from heatwaves	Defined goal, but not quantitative target (e.g. how much should deaths be reduced by)	Plan focuses on current heatwaves (not future CC). CC will increase heat-related deaths making outcome more challenging	Medium-high. Lock-in risks for new care homes and hospitals / social care policy	High residual deaths and high economic costs (£Billions/year by mid-century) even with existing measures. Large adaptation gap	High economic benefits from further health and social care adaptation (high benefit to cost ratios), and climate-smart health infrastructure.
Green infrastructure 25 YEP goal to 'green our towns and cities by creating green infrastructure (GI)'	Broad target, with no quantification, (e.g. no target for the level of GI).	CC not considered in GI policy. CC could reduce benefits of GI. But CC could increase demand for GI (as adaptation option)	Medium to Long life time for some GI (e.g. tree species) and involves land-use change.	Some risks for GI (damage, but also benefits) and modest adaptation gap Enhanced need for urban adaptation (large gap)	Opportunity for climate smart design of GI. Benefits from addressing barriers to enable scale-up of GI as an adaptation option
Fisheries 25YEP 'fish stocks recovered to and maintained at levels that can produce maximum sustainable yield, while continuing to protect and improve marine environment'	Defined target (maximum sustainable yield), repeated in Fisheries White Paper Assumed time period of 25YEP (i.e. 2043)	CC not considered in 25YEP goal, or supporting legislation (Fisheries White Paper or Bill) CC will make target more difficult to achieve, potentially significantly in 25YEP timeframe	Medium Some potential lock-in for new marine protected areas (under a changing climate).	Lack of current mainstreaming indicates large adaptation gap (£hundreds of millions/yr by mid-century). Potential need for more Marine Protected Areas to address increasing impacts	High economic benefits from adaptive management approach to fishery management (and increase value) High economic benefits from enhanced Marine Protected Areas (if no take areas)
Peatlands 25YEP target to restore 75% of terrestrial protected sites to favourable condition / to restore vulnerable peatlands by 2030	Target for protected sites defined with quantified target and date. Awaiting target for peatland restoration	CC will make targets more difficult to achieve, with potential non-linear effects	High Once degraded, high cost to restore and risk of irreversible damage	GHG increases £Billions/yr by mid-century, plus biodiversity losses. Current voluntary enrolment limited by funding availability	Further adaptation beneficial, but questions on what to prioritise, plus how to address opportunity cost for lowlands
Plant pathogens 25 YEP goal for 'managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species'	Not clearly defined (i.e. reduce the impact to what level?)	Some existing CC actions in policy, but partial. CC will affect outcome, increasing some diseases, but reducing others	High Once established, often high costs and difficult to control	Potential impact of CC (£hundreds of millions/yr by mid-century). Some actions in place, but gap remains, and further intervention likely to be needed	Economic benefits from enhanced intervention in research, monitoring, awareness raising and for proactive co-ordination (with high benefit to cost ratio)

Outcome	Defined outcomes	Consideration of climate change (CC)	Lock-in	Cost of inaction/ adaptation gap	Benefits of further action
Soil health 25YEP goal for all of England's soils to be managed sustainably by 2030, and 25YEP/NAP2 action to develop better information on soil health	Very broad goal, e.g. does not define what is 'sustainably managed'	CC could increase future impacts and affect outcome, but not currently most important driver (i.e. land use and management practice)	Low-medium	High existing climate impacts (>£Billions/yr) and CC potential to increase, e.g. by 20% by mid - century. Actions underway, thus difficult to assess gap	High economic benefits from use of information in soil policy (adaptive management). Likely to be a need to incentivise and scale-up sustainable management with adaptation benefits
Water supply 25YEP 'Ensuring interruptions to water supplies are minimised during prolonged drought'	Not clearly defined (e.g. what level of minimisation?)	Included in current water planning regime, but increasing risk of CC by mid-century/ under more extreme outcomes	High Infrastructure investment, long life-times	Existing actions, but still considered to be adaptation gap – though are additional National Infrastructure Commission recommend-actions	High benefits (although also high potential costs) Need for further action to address barriers.
New infrastructure 25YEP 'Ensuring all policies, programmes and investment decisions take account of climate change'. Focus on case study on new infrastructure	Extremely broad (i.e. not well defined) and very ambitious	Comprehensive action in some areas, but very focussed on flood hazard. CC will have increasing risks to infrastructure thus effect likely on outcome	High New infrastructure (and major upgrades) have lock-in risk due to long life time	Large economic costs. Some activities, but current actions (25YEP and NAP2) insufficient to deliver goal. Adaptation gap (with cost of up to £5Billion/yr).	High benefits from enhanced climate risk management and adaptation appraisal, for public and private sectors, but needs to consider economics. Benefits from addressing barriers to adaptation.
Wine Pledges for increasing production and exports of English wine	Not formal target, but short-term quantitative goal to increase production (extended in this study)	CC will improve chance of achieving outcome (as more suitable climate), but with some downside risk (increased climate variability).	High Investment in new land-use change and high capital investment	Potential benefit of ~£50Million/yr by 2050s but only if variability addressed. Some ongoing activities, but adaptation gap to deliver benefits and manage risks	High potential economic benefits from creating enabling environment and enhancing uptake of low regret adaptation, with high benefit to cost ratio.
Food supply chains NAP2 'Ensure a food supply chain which is resilient to the effects of a changing climate'	Very broad (i.e. not well defined)	Some existing planning in place. CC could potentially affect prices and producers (less so supply constraints)	Low	Some activities in place, but potential adaptation gap	Potential benefits, particular for removing barriers and incentivising adaptation

- The impacts of climate change are uncertain, and vary strongly with the climate projections, which makes it harder to assess the potential impacts on the outcome.
- There was often not good (quantitative) information on the risks of climate change, and the benefits of existing and future adaptation. This made it difficult to quantitatively assess the case for additional adaptation, i.e. in addition to what is set out in NAP2, although there was strong qualitative evidence for additional action.
- Assessing the costs and benefits of adaptation was particularly difficult, due to the lack of existing quantitative information.

Nonetheless, a number of other key findings emerged from the case studies:

Existing Government outcomes are not well defined, and many climate related outcomes are aspirational. To understand outcomes, and assess the potential impact of climate change on them, there is a need for clear policy objectives, including a solid theory of change and logical framework, with defined and measurable outcomes (i.e. SMART outcomes). In nearly every case, the existing Government outcomes did not meet these criteria. This was particularly true for many of the targets in the 25 Year Environment Plan, but it was also the case for NAP2. As an example, both these documents outline a goal of 'resilience' in many areas, but do not define what resilience is (or how it will be measured). For most outcomes, they do not define target levels or how these could be set (i.e. to maintain current levels of risk, to reduce to the optimal level based on costs and benefits, or to prevent all future risk). In the absence of concrete outcomes, the study team and CCC secretariat had to build up a logic model and to more accurately define each outcome, to allow a more quantitative analysis. Following from this, a first recommendation is that <u>Government targets, especially in the climate and resilience domain (and notably in the 25YEP and NAP2), need to move away from aspirational goals towards more defined and measurable outcomes</u>. This would also help stimulate the necessary policy discussion and stakeholder dialogue on what target levels are appropriate.

In the medium-term, i.e. to 2050, model uncertainty is more important that scenario trajectory in climate projections. A finding widely acknowledged in the scientific literature, but less so in policy making, is that there is little difference in climate projections between 2 and 4°C scenarios before 2050. This is because of the time lag in the climate system. This applies even to the longer targets in the 25YEP target (i.e. to 2043). The main differences (between 2 and 4C° futures) arise in the period after the mid-century. However, there is a very large difference in short-term and medium-term impacts across the range of climate model projections, driven by model uncertainty and natural variability (i.e. between the 10^{th} and 90^{th} percentile values in the UKCP18 climate projections). This uncertainty can make a dramatic difference to the impact on outcomes, and it influences the level of additional adaptation needed significantly, even in the near-term. This highlights <u>there is a need for policy to consider uncertainty (not just central values (e.g. 50^{th} percentile) when mainstreaming</u>. The case studies show that some existing adaptation policy responses have mainstreamed using central projections, and thus may be missing important risks of climate change on outcomes. It is stressed, however, that the consideration of more extreme outcomes (high emission pathways, 90^{th} percentile values) should not be taken as a signal to over-design to all possible futures, because this could be a very costly and a highly inefficient response. Instead it requires the consideration of these outcomes and consideration of risk tolerance and decision making under uncertainty.

In nearly every case, the activities associated with Government outcomes– even over the next five years - involve a risk of lock-in. This means that decisions or action associated with the policy in the current policy cycle (but also necessary decisions or action not taken) will lead to increased climate risks in the future, i.e. that could be difficult or expensive to address later. This finding has important implications. As an example, there is a large portfolio of new infrastructure planned under the National Infrastructure Delivery Plan (£483 billion to 20/21 and beyond), that is long-lived and will be exposed to future climate change. The opportunity for climate smart design of this infrastructure is now. Similarly, there are a large number of new houses planned (Budget 2017 set out an ambition to deliver 300,000 new homes a year in England) and these should be designed to address overheating risks, to avoid the lock-in of future climate risks. Even when there are potential opportunities from climate change, there is a need to plan for the future and not just the current climate. For example, land-use change for new wine production needs to consider the changing climate when considering varietal choice for new planting. The risk of lock-in emphasises the urgent need to increase adaptation action now, even in the short-term. The study has explored the potential costs of this lock-in risk, and finds that in many cases, the lack of early action could be very significant in economic terms, but also that it could be avoided by making sure current investment and policy decisions are climate smart.

There are cost-effective early adaptation options that can address climate risks, and ensure existing Government outcomes can be moved back on track. However, for nearly all the case studies, the study identified that currently, there is insufficient adaptation happening to ensure this. Importantly, little of the adaptation that is needed (to reduce impacts on outcomes) will happen autonomously, i.e. the market and individuals will not deliver this adaptation on their own. In all cases, the case studies found there is a clear rationale for further Government intervention, even though this often only requires Government to create the enabling environment, i.e. it does not necessarily require a large increase in public adaptation budgets.

For many outcomes, there is a critical opportunity (now) to introduce iterative climate risk management. This is often called adaptive management and is an iterative process that ensures a cycle of learning and revision to inform future policy cycle and responses. This is key for climate change, because of the uncertainty, but also the opportunity to learn over time, in the face of increasing risks. The analysis found opportunities for such an approach in most case, but it was identified as being particularly important for a number of areas where there are long-term risk or opportunity pathways, notably for fisheries policy, for major heat extremes and the effects on health and social care, for the emerging risks of climate induced animal and plant disease, for climate and soil health, and for new wine production.

Finally, as highlighted in the table above, an adaptation gap was identified for all of the outcomes considered: this leads to the question on why this adaptation gap remains, especially as the UK is now into its third Climate Change Risk Assessment (CCRA) cycle. Based on the analysis in the case studies, the **mainstreaming approach used by the UK Government does not appear to be delivering an effective and efficient level of adaptation**, and as a consequence, this looks likely to affect the delivery of existing Government objectives. The study has reviewed the existing literature on mainstreaming and the success factors that are associated with high uptake. An initial analysis (as part of this study) has identified that at the time the 1st CCRA was being developed in around 2008, almost all of the success factors for climate mainstreaming were in place. At the current time (2019), the picture is more mixed. The underlying legal and policy frameworks for climate adaptation in the UK remain strong (with the Climate Change Act and CCRA cycle) and there is information on risks from UKCP18 and CCRA Evidence reports. However, this information does not appear to be translating into effective domestic adaptation action. To illustrate, not even the 25YEP has adequately integrated climate change, and this has subsequently led to insufficient discussion, analysis and uptake in subsequent policy, for example, with the omission of climate change in the new fisheries policy, or the potential for a missed opportunity to use Green Infrastructure as an urban adaptation option. This indicates that further action is needed to integrate climate change (to mainstream) in Government policy, programmes and investment decisions. Based on the initial analysis here, we recommend that this mainstreaming might be advanced through a greater focus on climate risk assessment in Government policy appraisal and evaluation, including regulatory impact assessment.

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This report was produced by Paul Watkiss Associates. The authors were Paul Watkiss, Federica Cimato, Alistair Hunt and Andrew Moxey.

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1. Introduction

Background

In the summer of 2019, the Adaptation Committee of the Committee on Climate Change (CCC) will publish its first progress report on the second National Adaptation Programme (NAP), which was published in July 2018 (Defra, 2018).

To inform this report, the CCC is interested in building a further layer into its assessment framework to determine what outcomes the NAP is - or could be - seeking to deliver progress against, and following from this, to identify indicators to allow the CCC to measure progress against these outcomes. For this, the CCC is interested in current Government objectives, goals and outcomes, rather than a specific set of 'adaptation outcomes'.

The aim of this study on 'The Impacts of Climate Change on Meeting Government Outcomes in England' was therefore to assess whether existing Government outcomes are more difficult to meet in the face of climate change, and to scope out the costs that missing these outcomes could entail. In cases where outcomes could be missed, the study aimed to assess the potential costs and benefits of adaptation to address climate risks and ensure that the anticipated Government outcomes are achieved.

Study aims

This report presents the results for the study

This study was undertaken in two parts.

The first part of the project was undertaken by the CCC, with the aim to:

a) Identify existing Government outcomes or targets that link with the ASC's adaptation priorities, indicators and CCRA risks. Some, but not all of these outcomes are already set out in the NAP, but it also included other published outcomes, where the ability to achieve these outcomes could be affected by climate change.

b) Map the outcomes identified against the ASC's adaptation priorities, indicators and the risks set out in the UK Climate Change Risk Assessment (CCRA).

c) Identify if there are gaps where no outcomes currently exist to measure progress against.

The second part of this project built on this work, and was undertaken by Paul Watkiss Associates for the Adaptation Committee of the Committee on Climate Change (CCC). The aims were:

1. For the outcomes identified, to review the current published literature to assess how feasible it is to achieve the outcome or goal in a 2°C world versus a 4°C world, and on whether the goal is reasonable given the risks from climate change.
2. Identify any outcomes listed where the effects of climate change or behavioural responses to climate change have not yet been factored into the Government's policy. In such cases, to undertake a high-level assessment of the costs of not achieving the goal (in the absence of adaptation), and then the costs and benefits of achieving the goal (with adaptation). The aim was to assess the benefits of taking account of climate change in policy.
3. Identify where conflicts exist between different outcomes, or baseline and adaptation actions, in the context of climate change.

It is stressed that this analysis is focused on England only, to align with CCC reporting.

Report Outline

This report is set out as follows

Chapter 2 sets out the background on outcomes and logical frameworks.

Chapter 3 sets out the methodology for the study, outlining the analytical steps.

Chapter 4 summarises the results for each of the identified outcomes, drawing on a set of case study documents that accompany this summary report.

Chapter 5 summarises the key findings from the study.

2. Outcomes

Logic Models

Existing guidance on decision making and policy development in UK Government recommends a framework based on a process cycle of 'rationale, objectives, appraisal, monitoring, evaluation, and feedback' (ROAMEF). To help support this, there is UK Government guidance on how to develop and apply transparent, objective, and evidence-based appraisal, as well as how to evaluate policy.

Appraisal occurs after the rationale and objectives of the policy have been formulated: the purpose is to identify the best way of delivering on the policy prior to implementation (HMT, 2015). The Treasury Green Book (HMT, 2018) presents the recommended framework and guidance for the development and appraisal of all policies, programmes and projects in Government. It sets out the key stages in the development of a proposal, from the articulation of the rationale for intervention and the setting of objectives, through to options appraisal and, eventually, implementation and evaluation. The process of appraisal takes place after the rationale and objectives of a policy have been formulated, and identifies the best way to deliver the policy prior to implementation. In theory, this process of development and appraisal should be undertaken for all policy development, though in reality, political priorities often drive policy, and may limit the degree of evidence-based policy development, as well as the choice of options in appraisal. The Green Book recommends that economic principles should be applied to the development of Government policy, appraisal and subsequently to evaluation. This includes the economic justification for public intervention, as well as the economic appraisal of alternative ways of delivering objectives, the latter including the identification of options (that could meet the objectives) and their costs and benefits (from a societal perspective). The previous Economics of Climate Resilience study (HMG, 2013: Frontier Economics et al., 2013) advanced the application of Green Book concepts for adaptation, notably for the development of policy and the justification and rationale for public intervention.

Evaluation is the assessment of the policy effectiveness and efficiency during and after implementation of a policy: it seeks to measure outcomes and impacts in order to assess whether the anticipated benefits have been realised (HMT, 2015). The Treasury Magenta Book (HMT, 2015) provides guidance on the evaluation stage of the policy process, and states that central Government departments and agencies should ensure that their manuals or guidelines are consistent with these principles contained, and thus ensure the guidance is implemented.

This process of policy and programme development often uses a theory of change (ToC) and logic models (also known as logical frameworks or logframes). These allow a structured approach. A Theory of Change (ToC) sets out the problem, and identifies the causal linkages and potential pathways that move through to achieving a desired impact (i.e. a clear hypothesis on how change is going to happen). These are used in policy and programme development. A logical framework focuses down at the programme level, showing how programme activities will lead to the desired outcome and impacts. They develop the framework into which an evaluation can be designed, the data analysed and results interpreted. As set out in the Magenta book, developing a logic model sets out the theory for the programme or policy, and enables the processes, impacts and outcomes of an intervention to be identified and articulated, in a way that ensures they link to the anticipated results (UK Government Guidance, 2019). They also set out the assumptions that are associated with this pathway (and the delivery of impacts), at each stage, along with the preconditions for it to happen.

There is a standardised set of steps (the causal pathways or results chains) in a logical framework, which follow from the inputs and activities (also known sometimes as processes), to the subsequent outputs and outcomes, and finally, to the overall impact.

Logic Model. Source: Magenta Book, 2015.

Term	Definition	Example
Inputs	Public sector resources required to achieve the policy objectives.	Resources used to deliver the policy.
Activities	What is delivered on behalf of the public sector to the recipient.	Provision of seminars, training events, consultations etc.
Outputs	What the recipient does with the resources, advice/ training received, or intervention relevant to them.	The number of completed training courses.
Intermediate outcomes	The intermediate outcomes of the policy produced by the recipient.	Jobs created, turnover, reduced costs or training opportunities provided.
Impacts	Wider economic and social outcomes.	The change in personal incomes and, ultimately, wellbeing.

Note that activities are sometimes called processes, and intermediate outcomes are often just called outcomes.

A key determinant of the success of a ToC and logframe is the outcome, i.e. the goal that should be achieved. The term 'outcome' in this case relates to real-life economic, social and/or environmental improvements. There is also supplementary guidance on setting outcomes, to ensure that they are SMART (Specific, Measurable, Achievable, Realistic and Timebound) (National Audit Office, 2019).

Consideration of Outcomes for the Study

The ToC and logic models set out in the previous section can (and should) be applied to adaptation as part of the process of policy development, appraisal and evaluation.

It is stressed that there are different programming modalities for adaptation. The UK has primarily used climate mainstreaming (or integration). Mainstreaming is the integration of climate change adaptation into current policy, programmes and plans, rather than implementing stand-alone adaptation policies or programmes. This recognises that, for example, adaptation in the agriculture sector needs to be integrated within agriculture policy and objectives, and is best taken forward through the existing institutional and governance landscape, e.g. with mandated Ministries and organisations that lead on agriculture policy. This approach requires a broader analysis of policy objectives and wider costs and benefits, not just climate change, and it means that adaptation becomes a cross-cutting activity. Mainstreaming has important advantages to move national and sector policies and plans along climate smart pathways, although it also involves important challenges (including how to incentivise many departments and agencies to consider climate change amongst other multiple, often shorter-term, priorities).

In line with this mainstreaming approach, the focus of this study is on how climate change affects existing Government outcomes, and when climate change is likely to make outcomes harder to achieve, to assess if adaptation can get the delivery of the outcome back on track. It is stressed that the project has not developed separate adaptation outcomes. The analysis is focused on the existing logical framework – and outcomes – associated with existing Departmental objectives and policy goals, targets and outcomes. This is shown in the figure below, noting the main analysis point has been on outcome delivery. It is noted that to measure (outcome based) progress towards adaptation targets, new adaptation-specific indicators would be required (linked to adaptation objectives).

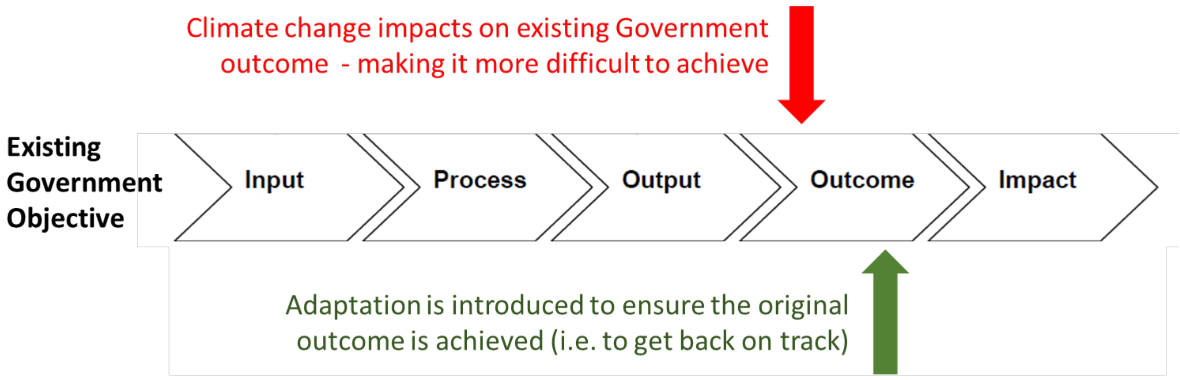


Figure 1 Framing of the current study on the logic model framework

Note that climate change might also have effects on the inputs, processes, and outputs, although in many cases, it will not directly affect these activities, but effect the effectiveness of them in delivering the anticipated outcomes.

The degree to which this analysis is possible also depends on the starting outcome, and the ability to assess the impact of climate change on this. One problem here is that many existing Government objectives are not clearly defined and do not include a specific goal, or cannot be easily translated into a quantitative outcome. Indeed, previous work on adaptation objectives and indicators in the UK (AEA, 2005) found this is often the case, i.e. that targets identified (across Government) were process-based or not formulated specifically enough to identify a relevant outcome indicator. This lack of specificity is an issue on many of the objectives, goals, targets, and outcomes for the two main documents that form the basis for the current Government adaptation policy landscape, the 2nd National Adaptation Programme (Defra, 2018) [NAP2] and the 25 Year Environment Plan (HMG, 2018) [25YEP].

Moreover, undertaking the two steps above – the analysis of impacts and adaptation – is very challenging (see box for details). Climate change involves complex temporal dimensions, which makes it difficult to assess the impact on a present-day logic model for current policy – and to assess how adaptation could address these risks. Adaptation has to address impacts that vary dynamically and non-linearly over time (see HMT supplementary guidance, 2009). It is also quite localised and site-specific. This means the effectiveness of the same adaptation action can vary with context and over time. In the context of the short-term five-year cycles of the National Adaptation Programme, assessing progress is therefore challenging, especially for proactive (future orientated) adaptation.

Furthermore, future climate change is very uncertain (see Wilby and Dessai, 2010). This uncertainty is a well-known issue in the adaptation community. This includes the issue of whether the world is on a 2 or 4°C pathway (i.e. that change in global average surface temperature by 2100), but also climate model uncertainty (for example the 10^{th} to 90^{th} percentile range presented in the UKCP18 projections, noting that the range for the latter is greater than the former up to mid-century). Indeed, this uncertainty may even involve a change in sign, for example UKCP18 projects a large decrease in summer rainfall (10^{th} percentile) to a small increase (90^{th} percentile) for the 2050s, and vice versa for winter rainfall (Lowe et al, 2018). The implication of this is that climate change might increase the achievability of an existing outcome in some projected futures, but decrease it in others.

Adaptation Outcomes

Adaptation is quite challenging for logical frameworks, especially for the identification of quantitative outcomes.

Reactive adaptation is a response to the impacts of experienced climate change[1] including variability, extreme weather events and shocks (Berrang-Ford et al, 2011). These events are probabilistic in nature i.e. they vary between years and even over decades. This makes it hard to measure outcomes, because any changes over a programme lifetime may be due to differences in the levels of climate variability or extremes. To illustrate, an adaptation measure may improve the resilience of agricultural productivity, and thus deliver enhanced yields or revenues, however, because of high rainfall variability and periodic droughts, it is difficult to know whether the benefits in a given period, relative to a baseline, are merely a function of the variability differences in these two periods It is possible to disaggregate out these climate effects, but this requires more detailed analysis and is rarely undertaken. Over the longer-term, the ex post benefits of adaptation actions may be more apparent (e.g. reductions in damages from extreme events), but these out-turns are also influenced strongly by socio-economic change, as evidenced by the rising losses from extremes over time (see IPCC SREX, 2012).

Proactive (planned) adaptation is the preparation for anticipated future climate change and is even more difficult to measure outcomes for, because it invests in actions that will (primarily) deliver benefits in the future, beyond a typical programme lifetime. This makes it extremely difficult to measure progress within a NAP programme period for example – and as a result - progress towards proactive adaptation is usually measured with process-based outcomes and indicators. These are associated with outcomes related to the earlier process (or activity) step in the logical framework. The use of process based indicators has been adopted alongside vulnerability and exposure indicators by the Adaptation Committee (CCC, 2017), as it tracks progress on adaptation plans to address key risks (i.e. it assesses if there is a plan). However, while process-based indicators demonstrate that some action is being taken, they provide no information on whether the plan is effective, if the plan will actually lead to the anticipated benefits, or whether the plan represents value for money, etc. The CCC follows its assessment of process with an, arguably more important, assessment of what difference is being made to climate vulnerability and exposure (and therefore risk).

It is noted that much of the climate change literature on indicators has focused on a scientific-led approach, looking to identify / measure vulnerability or risks, rather than focusing on a theory of change that is related to policy and delivered impact (e.g. Nicholls, 2006: Lamari et al, 2016). These analyses have little explicit linkage with a logical framework, or with the practicalities of implementation. Instead, they tend to focus on i) biophysical metrics, e.g. sea level rise (cm) (measurement), ii) exposure metrics, e.g. people in the hazard zone, people at risk, or iii) impact metrics, e.g. land area lost, people displaced, which in a few cases, are then extended to iv) adaptation metrics, e.g. km of shoreline protected, capital and maintenance cost of adaptation.

The setting of adaptation objectives (or targets) involves complex issues (see UNEP, 2014) and choices. The economically optimal level of adaptation generally involves a trade-off between the reduction in impacts (the benefits), the costs of adaptation, and the residual impacts (damage) after adaptation. As adaptation costs generally rise disproportionately at higher risk reduction levels, the optimal economic level often involves residual impacts. However, these residual impacts involve impacts that those affected may consider unacceptable, e.g. such as the higher risk of loss of life or more abandonment of communities due to sea level rise. This complicates target setting. To illustrate, there will be differences in the level of flood protection (and thus current adaptation) depending on whether a cost-benefit framework is used to set policy, as compared to a level of acceptable risk (i.e. protection to a 1 in 100 year return period). Furthermore, the approach used for target setting can vary across Government, e.g. transport appraisal typically has a strong cost-benefit focus (as in the webtag transport appraisal guidance (DfT, 2019), but health policy often uses cost-effectiveness (as in the cost per QALY of interventions used for new health treatments, NICE, 2013).

[1] Weather is the condition of the atmosphere are over a short period of time. Climate is how the atmosphere "behaves" over long periods of time (i.e. long enough to provide an average, i.e. 20 or 30 years). It is the average pattern of weather for a particular region. Climate variability reflects periodic or intermittent changes from this average, such as caused by El Niño or La Niña events.

It is also challenging to identify efficient and effective adaptation interventions to implement now (i.e. in a NAP) in economic present value terms, because of discounting. Discounting is a technique used (in economic appraisal) to compare the costs and benefits occurring over different time periods on a consistent basis (HMT, 2018). Discounting is applied to all future costs and benefits, and is based on the concept of time preference, i.e. that generally people (and society) prefer to receive goods and services now rather than later. Discounting is important for adaptation, because the largest benefits of adapting to future climate impacts arise in the long-term, and therefore because of discounting, these future benefits can be low in present value terms when compared to up-front and early adaptation costs.

None of these challenges are insurmountable, but it does require a different approach than when looking at the impact of current risk on a current outcome.

Recognising these types of issues exist – also in other areas and not just for climate change - there has been development of the 'Iterative' Theory of Change. Indeed, the idea of adopting an 'iterative approach' is referred to in most of the existing Theory of change/logical framework literature produced by the UK Government (and particularly the UK Department for International Development, DfID, Vogel, 2012).

These derive from the literature on the management and resolution of complex problems (Snowden and Boone, 2007; Andrews et al. 2012) and organisational learning (Argyris and Schon, 1978.

The main feature of an iterative ToC is 'feed-back loops'. These allow for research or monitoring to be conducted, or information to be gathered, to inform subsequent decisions, so that as the programme is reviewed, things can be changed or done differently. The UK Government has published a 'Guidance Note: Developing a Theory of Change (DFID, 2015)', which states that changes are not usually linear, [and] feedback loops can be added where possible. These approaches can also include more complex feedback loops (so called double loop learning[2]), which involves questioning and reviewing the objectives as well, over time).

These iterative theory of change approaches align well with the adaptive management literature, which uses a monitoring, research, evaluation and learning process (an iterative cycle) to improve future management strategies (Tompkins and Adger, 2004).

A final aspect that is relevant for adaptation is that traditional policy approaches are often not good at delivering <u>institutional change</u>. This is key for adaptation, because of the need to build adaptive capacity across multiple organisations. This has led to a move away from traditional "solution-driven" approaches to problem-driven approaches (Andrews et al, 2012). These are sometimes known as Problem Driven Iterative Adaptation (PDIA). This tries to achieve change through a process which is motivated by a problem, not a solution, whereby the reform emerges through a process of experimentation, trial and error and learning. It also tends to use an iterative approach. This has high relevance for climate adaptation, especially for more transformational adaptation, although it requires a different way of thinking that would be difficult to deliver across Government (not least because it has to accept, tolerate and then learn from failure).

[2] Double-loop learning is (obviously) different than single-loop learning (Argyris and Schon, 1978). SLL involves changing methods and improving efficiency to obtain established objectives (i.e. "doing things right"). Double-loop learning concerns changing the objectives themselves (i.e., "doing the right things"), and even questioning the assumptions about the objectives, the ways of discovering and inventing new alternatives, objectives, and perceptions, as well as ways of approaching problems. In essence, 'double loop learning' can lead to an alteration in the governing variables and, thus, a shift in the way in which strategies and consequences are framed.

3. Study Method

A methodology for this study was developed, centred on five steps (table 1):

- Step 1. Identification and definition of the objective and outcome;
- Step 2. Analysis of the effects of climate change (in a 2 vs 4°C pathway) on the outcome, on the basis of current levels of adaptation;
- Step 3. The costs of policy inaction (with climate change but without additional adaptation);
- Step 4. The identification of additional adaptation measures, including the type of action;
- Step 5. The costs and benefits of further adaptation, including trade-offs.

Table 1 – Study method	
Step	**Tasks**
Step 1. Identification and definition of the objective and outcome.	Identify the policy objective – and ideally the Theory of Change / logical framework- that the outcome is associated with. Define the outcome, including the desired outcome level. Map the institutional arrangements associated with the outcome (risks and adaptation) to identify the relevant departments and organisations.
Step 2. Analysis of the effects of climate change (in a 2 vs 4°C world) on the outcome.	Understand the current influence of current climate variability and extremes on the objective and outcome (today). Consider how climate change (in 2°C versus 4°C pathway, including socio-economic change and uncertainty) could impact on the objective and outcome. Identify any threshold risks and lock-in risks
Step 3. The costs of policy inaction (without adaptation case).	Estimate the cost of the effect of climate change on the outcome, including not achieving outcome, (£million) due to climate change (in 2°C versus 4°C scenario).
Step 4. The identification of adaptation, including the type	Assess the current policy and interventions – both adaptation and other– that are currently in place and manage or reduce risks (both current and announced). Consider the potential impact of reactive adaptation in future years. Identify potential additional adaptation interventions Identify promising early adaptation options (type I, II, III) and build up an adaptation pathway.
Step 5. The costs and benefits of adaptation, including trade-offs.	High-level assessment of the costs and benefits of adaptation, i.e. the benefits of (re) achieving the goal or outcome with adaptation, as compared to the costs of adaptation.

1. Identification and definition of the objective and outcome

Early work by the Adaptation Committee identified a list of possible outcomes to address for the study, based on the 25YEP, NAP2 and other policy analysis. These are presented in the next chapter. In order to assess the impact of climate change on these, a number of activities were undertaken:

- To identify the policy objective and outcome–ideally with a Theory of Change and logical framework;
- To define the outcome in quantitative terms, including the desired outcome level;
- To map the institutional arrangements associated with the outcome (risks and adaptation) to identify the relevant departments and organisations;

As highlighted earlier, all Government policy should – in theory - have been set through the process and guidance set out in the Green Book and Magenta Book. This will include the justification (rationale) for public intervention, as well as an appraisal. For all UK Government interventions of a regulatory nature that affect the private sector, the third sector and public services, a Regulatory Impact Assessment (RIA) is also required (see UK RIA guidance, BEIS, 2016). This requires an analysis of the costs and benefits of the policy. The development of most policy and programmes should therefore include economic analysis, as well as relevant outcomes and indicators, which could then be used for this first task.

It is noted, however, that there was no RIA of the 2nd National Adaptation Programme, because a formal impact assessment was not required as the NAP is not of a regulatory nature (there was an economic annex to the first NAP (HMG, 2013b), but no such analysis for the 2nd NAP). Furthermore, many of the targets in NAP2 are taken directly from the 25 year environment plan (HMG, 2018) which also does not have a RIA. As the goals in the 25YEP are medium-term, they are often aspirational. As an example, one of the goals in the 25YEP/NAP2 is to *reduce the risk of harm to people, the environment and the economy from natural hazards including flooding and coastal erosion by taking appropriate action*. This general nature of the goal makes it difficult to provide a measurable outcome, because it does not specify the definition of harm, how much to reduce it by (to zero? to an economically optimum level?), and what is appropriate action (acceptable? economically efficient?).

This meant that in practice, a part of this first task was to interpret the existing policy objectives, and to try and express these as a defined outcome, upon which climate change could act. In some cases, this meant developing an indicative theory of change/logical framework, and proposing a potential outcome. It should be stressed that the interpretation of the goals was that of the authors of this study, not Government.

Following this, this first task also looked at the responsibility and roles involved in the outcome and for adaptation. This recognised that there are key socio-institutional issues involved with adaptation. Outcomes that are part of underlying Government objectives and policies will have a clear organisational owner (a Department). However, when it comes to climate change, many climate risks and adaptation decisions are not owned by a single organisation (or Department) or are cross-sectoral. An example is for heat-related mortality, where heat alert systems fall under the mandate of public health, while changes in the built environment (buildings) or spatial planning sit with other Government departments with responsibilities for policy in these areas. The study therefore sought to understand the organisational responsibility and governance arrangements for risk and adaptation (noting the two may differ), as well as the current and announced organisational objectives (non-climate and climate), the current strategies and policies (overall, and in the relevant sub programmatic areas), and the existing standards and guidance (mandatory and voluntary).

2. Analysis of the effects of climate change (in a 2 vs 4°C world) on the outcome

The next step was to analyse the effects of climate change on the outcome and to:

- Understand how climate could affect the outcome;
- Assess the current influence of climate variability and extremes on the objective and outcome;
- Assess how climate change (in 2°C or 4°C future, including socio-economic change and uncertainty) could impact on the objective and outcome;
- Identify any threshold risks and lock-in risks.

Understanding the outcome, assess current risks and identify current adaptation policy

In line with the CCRA2 method (Warren et al, 2016), the priority was to start with the current and assess how current climate variability and extremes affect the outcome today, before moving to consider future climate change. It was also useful to understand the drivers for the success of the Government policy and outcome (without climate change), and then to understand how climate variables could affect these. This focus on understanding what matters first, before considering climate change, is also used in the decision making under uncertainty literature, notably in the decision scaling method (Ray and Brown, 2015). This encourages the identification and analysis of key performance indicators that are critical for the success of the policy or project, then assesses how important current climate risks are for these KPIs, before moving to analyse the potential importance of future climate change. This task was particularly important for outcomes that were less well covered in the literature.

Assess future risks including uncertainty and other factors (socio-economic)

Once the impact of the current climate was understood, the next task was to assess the future climate risks on the outcome (and its achievability) under different futures. In some cases, this was similar to a classic climate risk assessment and drew on existing CCRA1, CCRA2, CCC and other studies. In such cases, the analysis investigated how future climate change could lead to differing impacts on the outcome, under a 2°C and 4°C future pathway or different emissions pathways (RCPs) where possible, see box 2. In the study, we use '2°C and 4°C pathways' as shorthand for the global temperature increase that would be experienced by 2100 above pre-industrial levels.

Box 2. The Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs)

The four RCPs span a range of possible future emission trajectories over the next century, with each corresponding to a total radiative forcing (W/m^2) in the year 2100. The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6 W/m^2 (RCP2.6), only marginally higher compared to today (2.29 W/m^2, IPCC, 2013). It is a "peak-and-decline" scenario and is representative of scenarios that lead to very low GHG concentration levels. This scenario is considered to have a fair chance of achieving the 2°C goal. There are also two stabilization scenarios (RCP4.5 and RCP6). RCP4.5 is a medium-low emission scenario in which forcing is stabilised by 2100. It is similar to the A1B scenario from the SRES. Even in this scenario, annual emissions (of CO_2) will need to sharply reduce in the second half of the century, which will require significant climate policy (mitigation). Finally, there is one rising (non-stabilisation) scenario (RCP8.5), representative of a non-climate policy scenario, in which GHGs carry on increasing over the century. Leading to very high concentrations by 2100. Note that achieving RCP4.5 or below always requires mitigation, but more is required under SSP3 and SSP5.

The Shared Socio-economic Pathways (SSPs) provides a new set of socio-economic data for alternative future pathways. They include differing estimates of future population and human resources, economic development, human development, technology, lifestyles, environmental and natural resources and policies and institutions. Note that the SSPs include a quantitative and qualitative component. Five alternative future SSPs are provided, each with a unique set of socio-economic data and assumptions. SSP2 is the central, Business As Usual (BAU) scenario, as it relies on the extrapolation of current trends. The SSPs are presented along the dimensions of challenges to mitigation and adaptation. For example, in a world in which economic growth is high, there are sufficient resources to adapt, but the challenges in mitigation are high. Note that combining SSPs and RCPs gives a matrix of possible combinations of socio-economic and climate assumptions.

In these cases, there was also a need to consider the influence of future socio-economic change as well as the climate signal, recognising that future socio-economic change can be as important as the future climate in determining future impacts. For this study, where the focus is on influencing policy, the main priority was to understand potential impacts in the short- and medium-term (2020s and 2050s), although some consideration of long-term risks (2080s) was included where relevant. However, as well as uncertainty around any temperature pathway (2 or 4°C), the analysis considered the climate model uncertainty range (i.e. the 10th to 90th percentile range from UKCP18), as this is likely to lead to as great a range of uncertainty as the future trajectory in the shorter-term especially.

In cases where there was less direct information on how climate affects outcomes, the study assessed the influence of the current climate, then extrapolated forward and undertook qualitative or 'what-if' analysis. It is highlighted that within the resources of this study, it was not possible to undertaken new primary quantitative impact assessment analysis.

The main output of this task was an assessment of how much climate change could affect the delivery of the outcome and goal, and whether climate change makes the goal easier or harder to meet.

Risk and adaptation thresholds, lock-in

The analysis in this step also introduced a stronger adaptation pathways narrative, to consider the potential timing and sequencing of adaptation. This identifies if there are any particular threshold levels associated with the outcome (or the objective), which if exceeded, would necessitate a different adaptation policy or intervention. This is particularly important with respect to the different risk levels between the 2 and 4°C pathways. The case studies considered potential thresholds (such as biophysical, engineering or policy thresholds, and standards). The application of this approach can be used – in more detailed analysis – to consider adaptation turning points (or tipping points) (Werners et al, 2013), which identify threshold levels that necessitate different adaptation interventions, because an unacceptable level of climate impact or policy failure occurs.

Alongside this, the study included an analysis of lock-in. This was considered important, especially given the short-term policy focus of this study. From a review of the literature (e.g. Fankhauser et al., 1999; Ranger et al., 2014), a definition of lock-in was developed as: where a decision (or lack of a decision) today 'locks-in' the possibility of future climate vulnerability or risk, because it is difficult or costly to reverse or change later. This includes decisions or investments that involve a i) long life-time, ii) the potential for large future climate risks and iii) a degree of irreversibility (quasi-irreversibility). It typically includes long-lived infrastructure, land-use plans, and some major sectoral policy or structural shifts. It could also be where a lack of early action leads to irreversible changes, e.g. such as species loss.

3. The costs of policy inaction (without adaptation case)

Following on from above, the study assessed the potential economic costs of climate change. This provides evidence on the costs of inaction, and the cost of climate impacts on the delivery of non-climate Government objectives and outcomes in monetary terms.

Where possible, the analysis monetised risks and opportunities of climate change, expressing the risk in terms of the effects on social welfare, 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, not just financial impacts. The methodology for the monetary valuation was based on the approach used in the First UK Climate Change Risk Assessment and guidance from HM Treasury Green Book and Government Departments for appraisal. The feasibility of valuation depended on the level of quantification (from the previous step): in cases where there was more quantitative risk information, valuation was undertaken. In cases where there was only qualitative information, an indicative economic analysis was undertaken (similar to CCRA1). The main output was an analysis of the costs of not achieving the outcome, i.e. the marginal impact of climate change. However, for most outcomes, it was extremely difficult to get monetary estimates, and even more challenging to try and differentiate these costs across 2 and 4°C pathways.

4. The identification of additional adaptation, including the type

The next step was to consider the potential for additional adaptation to address the climate risk where there was a gap, i.e. to assess the additional interventions needed to get the desired outcome 'back on track'. This involved a number of tasks, including to.

- Assess the current policy and interventions – both adaptation and other– that are currently in place and manage or reduce risks (both current and announced);
- Assess the type of planned adaptation decision, and identify early adaptation priorities as part of a pathway.

Current policy

The first task was to assess the existing policy and interventions in place that are managing current risks. This included the activities set out in the NAP1 and NAP2, and progress measured by the CCC. It also included other policies or interventions to manage risk, noting these may not be designed to explicitly reduce climate risks. Importantly, this included both current and announced policy. The aim of this sub task was to confirm that the effects of climate change or behavioural responses to climate change have not yet been factored in to the Government's policy response (or if they have, to document their presence and likely effect on current and then future risks). In practice, it was often very challenging to identify the potential impact of current adaptation policy on current and future risks, reflecting a low evidence base (and a lack of current adaptation evaluation). The analysis was therefore primarily qualitative, assessing if there was a potential adaptation gap based on a review of current policies and the scale of the likely risks. The analysis also included what might happen in the absence of further adaptation action, i.e. whether reactive adaptation (from the private sector, or households, etc.) might address the problem in the absence of planned Government intervention.

Assess the adaptation options and identify early priorities

After assessing current adaptation, the next stage was to start identifying additional adaptation options that would address the outcome gap (between baseline and the future with climate change). The approach for this step was first to identify potential adaptation options, and then to assess the possible short-term adaptation priorities (in the next few years) using frameworks for prioritising adaptation. Several organisations have developed criteria to identify these types of early adaptation investments. These centre on early adaptation. This includes DfID's framework on early low regret adaptation (DfID, 2014), the method used in the Adaptation Committee's progress report (built around Ranger et al, 2010), and the method developed for the UK Economics of Climate Resilient method (Watkiss and Hunt, 2011). It is noted that it is easier to develop adaptation pathways for specific risks – or as here – for specific outcomes.

CCRA2 also developed a similar early adaptation priority framework (Warren et al, 2016: 2018), which identified three priorities for early adaptation implementation (i.e. for the next five or so years). These were:

- Address the existing adaptation deficit by implementing 'no-regret' or 'low-regret' actions (IPCC, 2014: DFID, 2014)[3] to reduce risks associated with current climate variability as well as building future climate resilience.

[3] 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, 2014). A variation of no-regret options are win-win options, which are

- Intervene early to ensure that adaptation is considered in decisions that have long lifetimes, such as major infrastructure developments, in order to avoid 'lock-in'. This includes the use of decision making under uncertainty concepts (i.e. flexibility, robustness).
- Fast-track early adaptation steps for decisions that have long lead times or involve major future change, e.g. monitoring and research now, to improve future decisions. This includes the concepts of the value of information, options values and learning.

This approach has been further developed in the ongoing CCRA3 method approach and this revised approach – shown below - was used in this study.

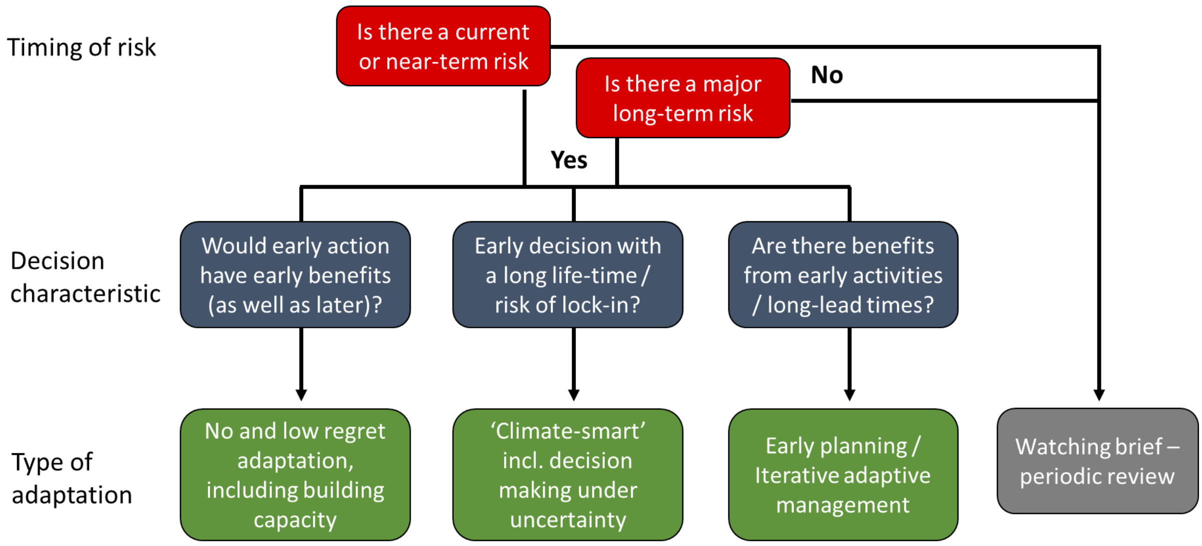


Figure 2 Early priorities for adaptation. Source CCRA3.

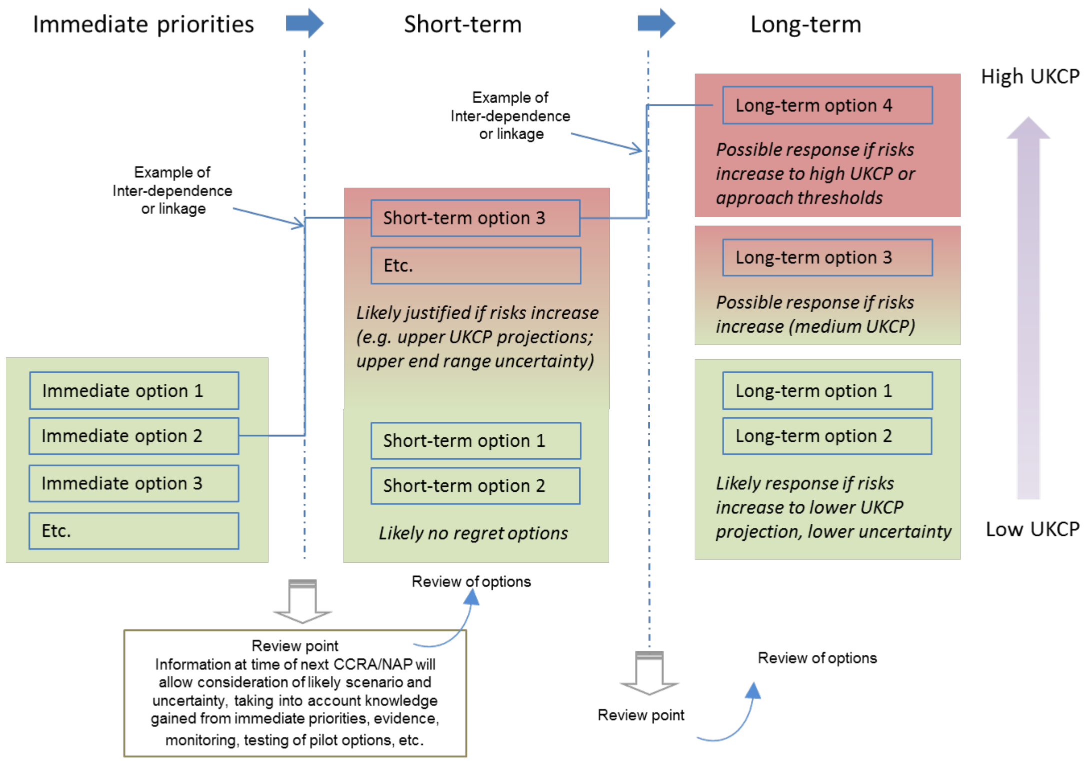
Note that for the national and programme level, i.e. for a Government outcome, all three of the adaptation responses are relevant (they are not mutually exclusive), and there is often a need for a portfolio, i.e. an overall adaptation pathway.

The use of this approach means that it is important to identify the type of risk and type of adaptation decision first, then to match it to the appropriate type of adaptation. To do this, it is useful to look at the outcomes (and the associated activities and outputs) and (Watkiss and Wilby, 2018) assess:

- The lifetime of the activities and outputs involved;
- Whether the activities or outputs involves irreversibility or lock-in.
- If there are additional reasons for a precautionary approach. E.g. does the programme involve critical infrastructure? Are there existing design standards where over-design is already required?

Where possible this analysis can also include the potential difference in adaptation options that would be needed under a 2 versus 4°C pathway. These are only likely to emerge in later years, but can be explored as part of a pathways approach, especially if there are potential thresholds involved. An illustration of this type of thinking is shown below.

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 (DFID, 2014).



Adaptation pathways and different options under different future scenarios.
Source Watkiss and Hunt, 2011.

In some cases, the difference between 2 and 4°C pathways could be a case of doing more (i.e. with higher sea level rise, there could be an incremental increase in coastal protection in some areas) but in other cases, it could mean doing something different (i.e. if some fish species disappear from UK waters, a switch to different species would be needed).

Where adaptation options were identified, the analysis also tried to understand the rationale for intervention, and especially the role for Government intervention. To address this, it looked at the potential barriers to adaptation. Adaptation is unlikely to happen on its own (without some form of intervention) because there are barriers that make it difficult for individuals, businesses and Governments to plan and implement adaptation actions. These include economic, political economy and governance barriers, arising from market, information, policy and governance failures (Cimato and Mullan, 2010: Frontier Economics et al., 2013; FCFA, 2017). These barriers are largest for proactive adaptation. Addressing these barriers is critical. The same barriers often limit synergistic green growth (mitigation and adaptation, e.g. see Neufeldt et al, 2010). The analysis therefore looked at the justification for intervention, and tried to identify the specific failure (market, policy or information failure), and how the adaptation response could be targeted to address this.

5. The costs and benefits of additional adaptation, including trade-offs

The final task aimed to undertake a high-level assessment of the costs and benefits of adaptation, i.e. to ensure the goal or outcome is achieved.

It is stressed that the analysis of the cost and benefits of adaptation is very challenging. For mitigation, benefits can be measured using a simple, common burden (tonnes of GHG reduced), irrespective of location and sector, and prioritised using a simple cost-effectiveness analysis ($/t$CO_2$). This provides direct comparability across interventions. In contrast, adaptation benefits require quantification of reductions in impacts (not burdens), which are sector-, location- and context- specific. Furthermore, adaptation seeks to reduce impacts on existing activities, so it must take into account these characteristics and not just focus on climate change: this requires analysis of multiple objectives and criteria at the same time. As a result, adaptation cannot easily be measured with cost-effectiveness and cost benefit analysis (CBA) is preferable. However, CBA is difficult to apply for adaptation, because of the complexity of analysis, as well as valuation challenges (in non-market sectors) and therefore there is a need for an extended multi-metric appraisal that includes risk and uncertainty (see IPCC, 2014: economics of adaptation).

Furthermore, there is a lack of existing studies and evidence based on the costs and benefits of adaptation, on which to base the analysis upon. A recent global review (ECONADAPT, 2017) found only 700 studies in total (academic and grey literature) on the costs and benefits of adaptation. Further, many of the older studies found use technical (engineering) costs (only) to assess options, and are generally presented for technical responses for a predict and optimise framework, rather than for short-term adaptation, which was the focus of this study.

Given the low evidence base, there was rarely information on the costs and benefits of adaptation to deliver this task in detail. Nonetheless, it was possible to draw on previous work, and what-if analysis, to provide some insights.

Finally, one further part of this final task was to check if there were any trade-offs.

4. Analysis of Outcomes

Identification of outcomes to assess

As part of this study, the Adaptation Committee Secretariat identified a set of possible outcomes and indicators. These were focused on existing departmental outcomes, although most of them are from the 25YEP or NAP2. An initial long list was put together, comprising around 50 outcomes (shown in Appendix 1). Following discussion, this was shortened to a short-list list of around 15 outcomes.

This short-list was presented at the Adaptation Committee meeting in December 2018. Comments from committee members identified additional areas of interest around business and supply chains, investment and finance, as well as possible opportunities (rather than just risks). These inputs were used to refine a list of 10 outcomes. The method in the previous chapter was then applied to each of the outcomes. In each case, a detailed case study was undertaken. These are presented in a separate set of supporting documents. In this chapter, the summary findings for each of the outcomes is presented.

The outcomes are:

- People and the built environment:
    - Preventing people from dying prematurely (i.e. preventable deaths);
    - Greening towns and cities by creating green infrastructure;
- Natural environment:
    - Ensuring marine fisheries produce maximum sustainable yield, while protecting the environment;
    - Restoring vulnerable peatlands;
    - Managing and reducing the impact of plant disease (pathogens);
    - Improving the approach to soil management / managing soils sustainably;
- Infrastructure:
    - Ensuring interruptions to water supplies are minimised during prolonged drought;
    - Ensuring all policies, programmes and investment decisions take account of climate change (with a focus on new infrastructure);
- Business:
    - Increasing production and exports of English wine;
    - Ensuring the food supply chain is resilient;

These are summarised below. A longer assessment for each risk is also available from the CCC website.

1. Preventing people from dying prematurely (from heat) in the health and social care system

What is the outcome?

The focus of the case study is on England only. The study initially identified the NHS outcome on preventing people from dying prematurely (reducing the number of preventable deaths), in this case from heat. This is focused on people dying while in NHS care (following hospitalisation), but the case study has considered all premature deaths from heat. The case study has also looked at a related climate-relevant outcome set out in the current Heatwave Plan for England (PHE, 2018), for 'protecting health and reducing harm from severe heat and heatwaves'. The Heatwave Plan includes a broad aim to reduce spring and summer deaths and illness by raising public awareness and triggering actions in the NHS, public health, social care and other community and voluntary organisations. The plan is underpinned by a heatwave alert early warning, the heat health watch system (HHWS) in England. This study has assessed if climate change could make both outcomes (NHS and the Heatwave Plan outcomes) more difficult to achieve. It has:

- Assessed the current and future risks of climate change and how these might affect the outcome of preventing premature deaths (with a focus on heat-related premature deaths);
- Assessed the benefits of current extreme weather and adaptation measures in the health and social care system (the Heatwave Plan and HHWS) in reducing current and future heat-related deaths, and benefits for the Government outcome (preventing premature deaths) and the adaptation-related outcome in the Heatwave Plan (reducing spring and summer deaths);
- Investigated if further adaptation would be justified, beyond current adaptation plans, focusing on health and social care organisations (and other public agencies and professionals who interact with those most at risk) and potential benefits and costs.

It is stressed that this case study is challenging because the policy landscape for managing heat-related health risks involves shared institutional responsibilities across Government. Public Health England (PHE) is the operational lead for the current Heatwave Plan. More generally, health-related responsibilities sit with the NHS and the overall healthcare system, while the management of relevant heat risks (risk reduction) for the built environment sits with MHCLG, and to a lesser extent, BEIS. These organisations have a shared responsibility for adaptation. For this case study, we have focused on adaptation measures in the health and social care system, rather than the built environment, but we do include consideration of built environment responsibilities within the health system (e.g. care homes and hospitals).

How does climate change affect the outcome, in a 2 vs 4°C pathway?
Current. Daily deaths increase with average outdoor temperature, above certain thresholds, and can lead to large number of additional fatalities during warm periods, including (but not limited to) heatwaves. There were major heatwaves in England in 2003 and 2006, which were both attributed with causing over excess 2000 fatalities, and there have also been heatwaves in recent years, in 2016 (908 excess deaths), 2017 (778 excess deaths), and 2018 (863 excess deaths overall) (PHE, 2018a: 2018b: 2018c). However, many heat-related excess deaths arise outside of heatwaves. It is difficult to estimate the total number of heat-related deaths each year as many of these occur outside of heatwave events and at relatively moderate temperatures but current estimates suggest that there are around 2000 heat-related deaths per year in the UK (Hajat et al., 2014: Kovats and Osborn., 2016).

Future. Future climate change is estimated (Hajat et al.,2014) to increase heat-related fatalities to potentially 3000 per year by the 2020s, and to 5000 per year by the 2050s (if the additional effects of climate only are considered). However, the total number of heat-related fatalities is projected to increase to 7000 per year by the 2050s when population and age distribution changes are also considered (i.e. the combined effect of climate and socio-economic change acting together). These central values (Hajat et al., 2014) are based on a medium emission scenario only. However, there is uncertainty around these estimates, reflecting different emission pathways (2°C vs 4°C pathways) and climate model uncertainty. The Hajat study does consider the latter and reports a range of 2000 to 5000 deaths in the 2020s (mid estimate of 3000 including climate and population change) and 3000 to 13000 in the 2050s (mid estimate of 7000). These estimates may not fully capture future extreme temperature impacts or urban heat island effects (which might increase impacts), but they do not include the effects of natural acclimatisation, or any effects of the Heatwave plan and HHWS, which could reduce these impacts, potentially significantly.

Thresholds. One of the additional issues in this case study is to consider the thresholds involved with heat-related mortality and morbidity. There are several different types of thresholds for heat-related mortality.

- The temperature threshold for heat-related mortality, i.e. the 17-20°C range (daily mean temperature) reported in Hajat et al. at which mortality starts to increase, and the threshold of approximately 25°C (daily maximum temperature) for excess summer deaths reported by PHE

(2018a). Some heat-mortality curves also show strong (non-linear) increases in the mortality rate at higher temperatures.

- The HHWS threshold temperatures (maximum day and night temperatures), and the triggering of HHWS responses, noting these vary by English region (PHE, 2018a).
- Threshold indoor temperatures for buildings, for overheating and comfort levels (daytime and night-time), as well as occupational standards, which are relevant for hospitals and care homes.
- The possibility of a policy threshold, i.e. a major event that could be considered an unacceptable policy risk (e.g. a Paris 2003 type event) – noting this does not exist at present.

It is noted that the recent update of the UK climate projections, UKCP18 (Lowe et al., 2018), reports that hot summers are expected to become more common, with the probability of seeing a summer as hot as 2018 of the order of 50% by mid-century, regardless of the future emissions trajectory. UKCP18 appears to project higher heat extremes than the previous UKCP09 projections. This has important implications for threshold exceedances.

<u>Lock-in.</u> There is also a potential lock-in issue. For the health system, these include the building of hospitals and care homes (CCC, 2014: CCC, 2017), noting there is a wider lock-in for new buildings and overheating risk more generally. There is therefore a need to ensure new hospitals are designed for the future climate. For care homes, there is a major issue because of the changing age distribution of England, and the high projected increase in the numbers of older people requiring care (>75 and especially >85 years, i.e. those most vulnerable to heat). In the UK, there are currently 410,000 residents in care homes (CMA, 2017). The number of additional people projected to become dependent is another 71,000 by 2025 and 190,000 by 2035 (Kingston et al., 2018): this implies a large increase in the number of vulnerable people in the care sector [care homes or care in the home]. If early action is not taken to consider heat risks for this emerging group, there is a risk of locking in future exposure and health risks. This also means that future care policy could have important lock-in risks, e.g. a policy towards greater independent care in the home might actually increase future risks.

What are the economic costs of climate change, i.e. the effect on the outcome?
This study has estimated the economic costs of the additional heat-related mortality cases. We use the Hajat et al. estimates and use the standard approach in UK Government appraisal for valuing changes in fatality risk (called the value of a prevented fatality, VPF) (DfT, 2019). This captures the total effect on society's welfare, assessing resource costs i.e. medical treatment costs; opportunity costs, e.g. lost productivity; and dis-utility i.e. pain or suffering. However, there is some debate on the applicability of these values to the heat mortality context, because a proportion of people affected are old or have existing health conditions and/or lower life expectancy, and thus the fatalities may reflect a death brought forward (displaced) by only a short period of time (Watkiss and Hunt, 2012). There is uncertainty in the evidence base about how strong an effect this is. For this reason, a sensitivity analysis with an adjusted value is also used (as commonly used in the air pollution context, where similar issues exist). With the use of the full Value of a Prevented Fatality, the estimated economic costs from the increase in heat-related mortality from climate change are very large, with costs of £2.5 billion/year (combined effect of climate and population change) in the 2020s, rising to £9.9 billion/year (climate and population change) in the 2050s. However, the sensitivity analysis that takes account of a short period of life lost (using a Quality Adjusted Life Year value, and 1 year of life lost on average) reduces these economic costs significantly, to £58 million to £83 million in the 2020s (climate / climate and population) and £213 million to £323 million in the 2050s. In practice, the economic cost may lie between these two values. It is stressed that these numbers do not include existing adaptation policy (including the HHWS) or physiological acclimatisation.

What are the benefits of existing adaptation on the achievability of the outcome?
The next step is to consider the potential benefits of current adaptation (the current Heatwave Plan, including the HHWS (PHE, 2018a), plus additional announced adaptation policy in NAP2 (Defra, 2018))

in reducing the current and future climate-related risks set out above. This aims to assess how much current policy in the health and social care system could help to achieve the Government outcome (of reducing preventable premature deaths) and adaptation outcome (of reducing spring and summer deaths). The Heatwave Plan (2018) sets out what should happen before and during periods of severe heat in England, focusing on how health and social care organisations can raise awareness of risks and what preparations to make to reduce them. The main focus is on short-term measures, centred on actions around the HHWS. This has been the focus of the analysis. The Heatwave Plan also includes a set of long-term measures that extend towards the built environment and extend outside the health and social care responsibility, which are not included in this analysis. However, the analysis here has considered built environment aspects that are relevant for health and social care organisations.

It is stressed that most of the evidence on effectiveness comes from heatwave events (rather than the total heat-related mortality burden), and this only captures a proportion of the burden in England. For this case study, the analysis applied the effectiveness of heatwave responses to the overall heat-related mortality burden.

The study has analysed the potential effectiveness, and estimated costs and benefits of the HHWS, now and in the future with climate change, noting that CCRA 1 and 2 did not assess the potential impact of the scheme in reducing risks (Kovats and Osborn., 2016). There is currently no published data on the effectiveness of the Heatwave Plan and HHWS in England, although an evaluation led by PHE is expected to be published soon. There is some evidence that suggests that the scheme has had some benefits in reducing mortality for temperatures above the HHWS thresholds (Green et al., 2016), but that heat-related mortality below the thresholds has not changed significantly. There is also evidence from other countries with heatwave plans (Tooloo et al., 2013: Chiabai et al., 2018), that report a wide range of estimated benefits, which indicate an average effectiveness of around 40%, though with some plans reporting a 90% effectiveness level (noting most, but not all of these benefits are associated with heatwave events).

To explore the potential benefits, we use a sensitivity range with a lower value of 0% and an upper value of 40% (i.e. we assume the Heatwave plan, including year-round actions, prevents up to 40% of potential premature fatalities). This estimate was based on information from heatwave plans from other countries, from Tooloo et al., 2013. We applied this effectiveness level to the total number of estimated heat-related fatalities above, as there is no data on the proportion of fatalities that occur during and outside heatwaves (although we acknowledge that the Heatwave plan is likely to primarily reduce excess deaths primarily during heatwaves). This analysis was based on the method used in Hunt et al., 2016. The analysis also assumes a similar level of effectiveness from the HHWS under future climate change (as a %). The analysis finds that the economic benefits of the Heatwave Plan and HHWS – at the upper level – could be very large (perhaps as much as £1 billion/year by the 2020s, based on the full VPF). However, climate change will increase the increase the resource costs of operating the HP and HHWS (Hunt et al., 2016), as it is triggered more frequently, reflecting a higher incidence of heatwaves (unless trigger levels are changed). The study has estimated the indicative increase in resource costs of the HP and HHWS under future climate change, using the estimated health staff resource costs associated with different trigger levels (again based on Hunt et al., 2016). This finds the indicative increases are modest (£million/year), but rise more strongly under higher warming scenarios. Overall, the analysis indicates a potentially high benefit to cost ratio for the current scheme (for the upper values) now and in the future. As an example (for London, Hunt et al., 2016), the marginal benefit to cost ratio would range from 10:1 to 30:1 for the 2040s (for low and high warming scenarios, respectively). Note that the BCR may be much lower, pending the results of the HHWS evaluation.

However, even with the Heatwave Plan and HHWS, there will be high residual impacts, and these are projected to increase (in absolute numbers) over time. There is therefore a large adaptation gap. Even under an optimistic scenario with the upper effectiveness value used, residual economic costs would be £1.3 billion/year in the 2020s, rising to £4.9 billion/year by the 2050s (central estimates). Furthermore, the likelihood of a major unprecedented heatwave event in the next decade is considered high. This could have large policy impacts. Therefore, we consider that current policy outcomes (to reduce premature deaths, and reduce heat-related fatalities) are likely to be missed. There are further opportunities for additional options that would provide additional adaptation to reduce current and future risks and help achieve the outcomes.

What are the potential additional adaptation options to address these impacts?
The next step is to consider the potential additional adaptation options that could reduce heat-related mortality risks, and help achieve the original outcomes (preventable premature deaths, and deaths during spring and summer). This is focused on actions in the health domain for reducing future climate change risks and fatalities, while noting that there is a wider set of adaptation actions for reducing heat exposure in buildings in general (residential) and the urban environment.

There are some additional adaptation actions to address heat-related health risks in the 2nd NAP for England (Defra, 2018). This list of actions is quite comprehensive, but they are primarily focused on monitoring and process-based outcomes (the production of adaptation plans). This makes it very difficult to know what adaptation is planned, and how effective it will be. Nevertheless, there is a need for additional adaptation (not least to specify what should be in these adaptation plans). A review of the literature has found that most of the current focus is on the built environment and urban environment. However, while this has many benefits, it is not explicitly targeted at heat-related mortality (rather it includes a set of outcomes, including overheating and comfort, building energy use and health), and there are also likely to be health system responses, including behavioural change among the public and for health and social care workers, that could achieve high cost-effectiveness in reducing specific health risks. To explore this, the analysis has looked at three types of options for early priorities in a high-level adaptation pathway.

<u>No- and low-regret measures.</u> A number of low-regret measures could enhance the effectiveness of the Heatwave Plan, HHWS and actions, notably drawing on lessons from current (hotter) countries that report much higher effectiveness levels (in reducing summer deaths) from similar heat warning systems. Indeed, some studies report effectiveness levels of 80 to 90% (Tooloo et al., 2013). A key priority is therefore to understand the success factors in these other countries, and identify additional cost-effective measures for the UK. Contingency planning for an unprecedented heatwave event (>40°C) is also highlighted.

<u>For lock-in risks</u>, there are important climate smart priorities on the design of new hospitals (Giridharan et al., 2013: Fifield et al., 2018) and care homes (JRF, 2016), the latter including the support from Government needed to create the awareness and enabling environment for the private sector.

<u>For early planning to address long-term risks</u>, there is a priority to develop iterative adaptation pathways for public health and social care options for heat and health (and not assume that these future problems will be addressed adequately by the built environment), especially given the projected change in heatwave frequency and severity with the new UCKP18 projections.

What are the benefits and potential costs of additional adaptation?
Research on the costs and benefits of adaptation to heat risks from climate change has overwhelmingly focussed on heat wave warning systems, or the built environment (ECONADAPT, 2017): little quantitative analysis has been undertaken on other measures, particularly those tailored to health and social care. In the absence of such data, the study has looked at a qualitative indication of the possible scale of costs (low, medium, high) and effectiveness (low, medium, high). These indicate potentially

promising additional options with high benefit to cost ratios, that are likely to be more cost-effective (than general built environment options) for targeting heat-related fatalities.

Key policy messages

This case study considers how climate change (specifically, the hazards to health from increased heat) could affect a current NHS outcome of preventing people from dying prematurely. It also considers the existing emergency response plan in England for severe heat and heatwaves - the Heatwave Plan – and its purpose of reducing summer and spring deaths for such events. The study notes that heat-related fatalities in England are projected to increase with climate change, especially under higher warming scenarios: this would have a major impact on these outcomes/goals, making them more difficult to achieve. These fatalities have high economic costs, estimated in this study as a range from £323 million to £9.9 billion per year by the 2050s. The Heatwave Plan, which includes the Heat-Health Watch System (HHWS), should have some impact in reducing these future risks, although its effectiveness is currently being evaluated. Based on similar international schemes, the plausible benefits of the heat alert system could be around an average 40% reduction in fatalities during heat extremes. This means there although the heatwave plan could reduce deaths, there will still be rising numbers of residual heat-related deaths because of climate change. Furthermore, climate change will increase the costs of delivering the HHWS, as the scheme will be triggered more frequently (unless the threshold triggers are changed). This study has also identified a risk of short-term lock-in, associated with the additional numbers of elderly people requiring care (estimated to be an additional 71,000 by 2025 and 190,000 by 2035, on top of current numbers of 410,000). A failure to plan heat management in new care homes / care in the home could lock-in large numbers of people to heat risks, and a similar issue arises with new build hospital design. The conclusion is that even with the current heatwave plans, there is a major adaptation gap in the health and social care system. This is a key concern because there is a risk of an unprecedented heatwave event in the future. Based on the latest science, an extreme heatwave with temperatures exceeding 40°C in England could well be experienced in the next few years, and there should be planning for this now. This study has undertaken an initial scoping of additional adaptation options for health and social care organisations. This identifies no and low-regret options from other countries (that experience extreme heat more routinely). We identify a targeted set of possible options for reducing heat-related mortality in vulnerable groups, which have high benefit to cost ratios - it is recommended that further analysis of health and social care options/lessons from other countries would be beneficial (especially if the forthcoming evaluation of the Heatwave Plan shows low evidence of benefits). This study also highlights the need for greater early action to address heat and health risks in care homes and hospitals (to avoid lock-in), and action to start iterative adaptation planning for major heat extremes.

2. Greening towns and cities by creating green infrastructure

What is the outcome?

The 25YEP (HMG, 2018) sets out a policy to green towns and cities by creating (urban) green infrastructure and making sure there are high quality, accessible, natural spaces close to where people live and work. We refer to green infrastructure as GI in this document. The 25YEP states that the introduction of green infrastructure (new, upgrading and retro-fitting) is aimed at improving health and mental well-being (as the primary objective and benefit). It is highlighted that the 25YEP outcome is not specific and there are no quantitative targets (e.g. area or number of schemes).

This case study is different to the others, because it involves two separate questions.

1. The first question is whether climate change will affect the delivery of the Government outcome, i.e. the goal to increase the amount of Green Infrastructure (GI) and deliver health and well-being benefits.

2. The second question relates to whether climate change will itself increase the demand for GI, because of the adaptation benefits it can provide, which could in turn make the Government outcome (to increase GI) easier to achieve.

The analysis has therefore considered both of these.

The first part of this case study assesses if climate change could make the delivery of the 25YEP outcome, to 'Green our towns and cities by creating green infrastructure', more difficult to achieve, i.e. in terms of hectares or numbers of schemes, and the anticipated benefits of the goal (health and well-being, as set out in 25YEP). It subsequently considers what additional action might be needed to make green infrastructure climate smart (to future climate change) to ensure the increase in GI delivers its anticipated benefits.

However, urban green infrastructure is also a form of ecosystem-based adaptation. The second part of the case study therefore assesses whether climate change could increase the demand for green infrastructure as an urban adaptation option, and thus make the 25YEP outcome easier to achieve. These demand effects might relate to the direct adaptation benefits of GI (e.g. cooling, flood risk management) but it also might arise from increased demand for other GI benefits (e.g. urban recreation).

While there are a large number of potential urban GI options, the study has focused on urban green spaces (e.g. parks), green roofs, and urban flood management including sustainable urban drainage systems.

How does climate change affect the outcome, in a 2 vs 4°C pathway?
The first finding is that the 25YEP goal for green infrastructure does not take climate change into account, i.e. it does not consider the potential impact of climate change on GI, nor the role for GI as an adaptation option. This is highlighted as an important gap. Turning to the first question above, it is unlikely that climate change would make the actual 25YEP outcome itself more difficult to achieve, i.e. in terms of hectares or numbers of schemes. However, climate change could affect the anticipated benefits of GI. To investigate this, the study has assessed the function of green infrastructure, then the potential effects of climate change on these.

Green infrastructure provides 'ecosystem services', i.e. provisioning, regulating, cultural and supporting services. For urban GI, these include amenity and recreational value; improved physical health and mental well-being; social cohesion; air quality improvements; and CO_2 sequestration, but they also include adaptation benefits, from reducing urban heat island (UHI) effects and reducing water runoff/managing flood risks (Demuzere et al., 2014; Matthews, 2015). Some schemes are primarily introduced for amenity benefit, but have adaptation co-benefits (e.g. green spaces), while others are targeted at climate risks but have ecosystem service co-benefits (e.g. sustainable urban drainage) (McVittie et al., 2017). There is relatively little literature on the potential effects of climate change on green infrastructure, with only a small number of specific assessments (e.g. de Sousa et al., 2016; Sarkar et al., 2018). However, there are already current impacts of climate extremes (notably storms) on urban green spaces (e.g. Prichard, 2012), and there is also the potential that changing extremes (windstorms, heat extremes, and droughts) could increase damages to GI (Defra, 2018) or exceed its functional range (Dadson et al, 2017). Furthermore, there is a wider literature on the impacts of climate change on the natural environment (forests, plant species) (e.g. Brown et al., 2016) and based on this, it is possible that climate change could affect the climatic suitability of particular species used for green infrastructure (in a particular location). However, climate change may also lead to benefits, e.g. the climate projections forecast extended growing seasons and there are potential CO_2 fertilisation effects, which might enhance some GI benefits, although this would increase maintenance costs for vegetative control (Hudson, 2003). This case study has mapped the potential impact of climate change on each of the ecosystem services provided by green infrastructure, based on literature review. We find that climate change has highest potential impacts on adaptation services, and CO_2 sequestration potential, with lower potential impact on amenity and physical / mental health. These effects are likely to be greater in a 4°C pathway, though in the short to medium-term a greater difference is likely to arise from uncertainty in the projections (i.e. the 10th to 90th range in UKCP18, Lowe et al., 2018). In the short-term, the review identifies the largest effects are likely to arise from changes in extremes. If these impacts are not considered, therefore, climate change could alter the effectiveness of GI.

Thresholds and lock-in. As natural systems, green infrastructure will have thresholds associated with bioclimatic suitability levels and extreme tolerances (heat, dry spell duration). Based on the literature on climate change and UK ecosystems (Brown et al., 2016), these thresholds are more likely to be exceeded in a 4°C world. New GI also involves land-use change and therefore lock-in. The design of GI, including plant species choice as well as engineering design, and therefore needs to consider the implications of future climate. This involves some challenges due to uncertainty (to a 2 and 4°C world or to the 10th to 90th percentile uncertainty range for each particular scenario), especially because of the long life-times involved (e.g. for tree species). However, the level of irreversibility is generally lower for GI than for grey infrastructure, as the latter has high capital costs and is often difficult and costly to change later (ECONADAPT, 2017), and thus GI may offer greater adaptation flexibility. With the 25YEP goal to increase GI, there is an opportunity to introduce climate risk screening for GI design, i.e. using similar methods to those being implemented for grey infrastructure (see later case study).

Does climate change affect the demand for green infrastructure and its level of uptake? The case study has assessed whether climate change could affect the demand for services that GI provides. First, the review has considered non-climate GI ecosystem services. Under a warmer climate, there is likely to be greater outdoor recreational demand, which could increase the demand for urban green areas and GI. Climate change does have potential effects on air pollution (Hames et al., 2012; Vautard et al., 2015). However, green infrastructure is not seen as a major option for reducing air pollution in current air quality policy (e.g. see Defra, 2019b): while some studies report that GI could have air quality benefits (Fairbrass et al., 2018) others highlight these are likely to be temporary due to resuspension (Defra, 2010). Climate change and mitigation policy, especially under new net zero targets (CCC, 2019) will increase the demand for CO_2 sequestration, however, urban green space is relatively ineffective at sequestration at scale compared to other options, and would also have low cost-effectiveness as a sequestration option due to land-use prices (though rural green areas will be key to delivering net zero emissions).

More obviously, climate change could also increase the demand for urban adaptation. This could in turn increase the demand for green infrastructure, and therefore make it easier to achieve the 25YEP goal (for more GI). The increased uptake of GI could possibly happen reactively (autonomous) due to the changing climate, but due to the barriers to uptake (see later), it is considered more likely that it would increase as a result of planned adaptation policy. However, for this to happen, GI would need to have net benefits over other adaptation alternatives, in keeping with standard Government options and policy appraisal (HMT, 2018). It is noted that the level of increased demand (and relative performance) could be different under a 2 vs 4°C pathway. To expand, rising urban heat is likely to incentivise the uptake of cooling options, but the uptake of GI as an adaptation option alone to address this will depend on the relative costs and benefits (compared to alternatives), and subsequently whether there are incentives to increase uptake (see next section). Increasing heavy precipitation could also increase the demand for urban flood management, but there are some studies that highlight the limits of natural flood management (Dadson et al, 2017), i.e. it is unclear if a changing climate in itself would increase or decrease the attractiveness of green (vegetated) SuDS as an option for reducing risk.

What are the economic costs of climate change, i.e. the effect on the outcome?
Economic costs of climate change on GI. The quantified economic benefits of green spaces are dominated by their recreational and aesthetic benefits (e.g. Holzinger et al., 2014: Dennis and James, 2016). Climate change is likely to have a relatively modest impact on recreational potential: though there are potential costs from extreme events on GI, leading to reduced access, as well as restoration and repair costs, notably from wind-storms and droughts. Climate change could also affect the costs of maintaining GI, because of vegetative growth and higher maintenance costs. One study suggests suggests (Hudson et al., 2003) that maintenance costs could increase significantly by mid-century (20% by the 2020s, 30% to 40% by the 2050s) compared to current (though these might well be offset by additional benefits, i.e. enhanced sequestration).

Change in demand (for non-climate ecosystem services). It is more difficult to estimate how much climate change might affect the demand for broader ecosystem services associated with GI, how this translates into additional GI demand, and the economic costs or benefits of this. There is some indication it could increase outdoor recreational demand, for example, from rising tourism activity in the UK (e.g. Ciscar et al., 2014), although these studies focus more on non-urban effects. Climate change will increase the demand for CO_2 sequestration, especially under more ambitious mitigation scenarios (such as net zero, CCC, 2019) and climate change has the potential to actually increase sequestration benefits of GI (from longer growing seasons and CO_2 fertilisation (Hudson, 2003), however, as above, urban sequestration does has lower cost-effectiveness than rural options. Climate change could have some potential impacts on air quality, notably with the potential to increase ozone (Hames et al., 2012), but existing air quality legislation and policy focus on reducing air pollution means that future air pollution (e.g. by 2040) will be very much lower than today, thus overall demand for air quality improvements will be much lower.

Change in demand for climate related ecosystem services. Climate change could clearly increase the demand for urban adaptation, which could include urban GI. This is explored further below.

What are the potential additional adaptation options to address impacts on the outcome?
The case study has looked at two types of adaptation, the first focused on protecting GI investments and the second on GI as an adaptation option in its own right.

Adaptation options to make green infrastructure climate resilient. There are a number of potential options to make GI climate smart, though these are often quite specific to the particular scheme. There has been some analysis of the use of more resilient plant species (e.g. de Sousa et al., 2016) and enhanced management of green areas, examples being species choice to make green roofs more drought-resistant or SuDS that are better able to cope with increased heavy precipitations/ peak flows. For tree species, there is the existing forestry adaptation literature. (Frontier Economics, 2013b; Forestry Commission; Tree Health Resilience Strategy (Defra, 2018c))

Green infrastructure as an adaptation option. The role of green infrastructure as an adaptation option requires an analysis of the relative attractiveness compared to other options. While effectiveness is site, context and location specificity, the literature suggests:

- There are a range of urban green options that move in scale from small-scale urban planting through to major urban green spaces. The literature reports that cooling benefits from green space options could reduce local temperature by 1- 2°C (Tapper, 2019: Bowler et al, 2010; Kingsborough et al. 2017), although some studies report higher values at the localised scale (Coutts et al., 2016a: Coutts et al., 2016b; Thom et al., 2016), or if very large areas of urban land are converted to green.
- There is more literature on green roofs. These provide multiple benefits, including reduced heating demand, but they can also include cooling benefits. However, the reported cooling potential of green roofs varies. There are some studies that report very high cooling within buildings (internal temperatures) especially for systems designed for hot climates (e.g. Coutts et al., 2013), however,

within the UK, benefits are often based on reducing winter heating demand (not summer cooling). There are also studies that look at the potential ambient cooling of green roofs i.e. outdoors (e.g. Satamouris, 2014), which find low or negligible low levels of ambient cooling, although other studies (e.g. Meyers et al. 2015)) that assume very high take-up of green roofs find higher results (noting that while this may be possible for new developments, it not realistic for the existing English housing stock).

- There are also a number of natural flood management options, although many of these focus on coastal and rural options. In the urban context, SuDS are the main option (while noting the green areas above have potential for some flood management). There are some studies that identify an effective role for urban natural flood management and for nuisance flooding (Frontier Economics et al., 2013c), but other studies highlight the potential limits for more major flood events (Dadson, 2017; McVittae et al, 2017.

<u>Mapping green infrastructure to the early priorities for adaptation.</u> The study has also considered how GI aligns to the three early priorities for adaptation.

- No and low-regret. GI has considerable potential as a win-win option, due to the wide number of co-benefits (see earlier analysis of ecosystem services).
- Early decisions with a long life-time. There is a good argument for making new GI climate resilient, noting this would be easier if undertaken during design, and that it may have greater flexibility than grey infrastructure (but that it might not (on its own) provide sufficiently high levels of resilience for major extreme events).
- Early preparation for long-term climate change. Urban heat in major cities in England is likely to be a major future issue, and there is a very strong case for enhancing the analysis, research and monitoring of urban green space and UHI, and using information to feed back into policy.

<u>Barriers.</u> The study has assessed why the uptake of urban GI in England has been low to date, to help understand additional adaptation that could help enhance uptake. A number of barriers have been identified (Byrne and Yang, 2009; Demuzere et al., 2014; Watkiss and Cimato, 2017), including information barriers; institutional barriers; policy barriers and financial and economic barriers. The case study has looked at the role for adaptation to address these barriers, and enhance uptake, drawing on some of the literature for success factors for ecosystem-based adaptation (Ecofys, 2017). An important finding is that additional adaptation action is needed (beyond GI standards) to deliver GI adaptation, and enhance the role for GI as an adaptation option.

What are the benefits and potential costs of adaptation?

The final section looked at the potential costs and benefits of adaptation. Following above, this considers two assessments. First, the costs and benefits of climate smarting green infrastructure. Second, the costs and benefits of green infrastructure as an adaptation option.

<u>Options to make green infrastructure climate resilient.</u> There is very little information to allow a cost-benefit analysis of climate-smarting new green infrastructure, although there are some relevant lessons from the forestry sector (e.g. Frontier Economics et al., 2013c) for green spaces.

<u>Green infrastructure as an adaptation option</u>

The case study has reviewed the literature on costs and benefits of green infrastructure options:

- The benefit to cost ratio of green urban spaces shows a large range, which are very site and context specific, however, studies report that recreational benefits dominate the current benefits (Holzinger et al., 2014: Dennis and James, 2016) and cooling benefits are currently low in economic terms. The analysis of the costs and benefits of green space as an adaptation option (Liu et al. 2016; Mendizabal and Peña, 2016, Loibl et al, 2015) do show positive benefit to cost ratios (BCRs) for small urban schemes, driven by the overall benefits (not just cooling). However, they often find new green space has low benefit to cost ratios, due to the high opportunity costs associated with land-use (and land-use values) in major urban centres (where land has to be used to make room for the new GI). This means that it can be more difficult for schemes to be economically justifiable based on adaptation benefits alone (although green space can increase property values around the scheme) especially as the larger cooling benefits arise in the future, and are low in present value terms after discounting. It is more likely that schemes can be justified when all ecosystem service benefits are included. Smaller schemes can address some of the cost barriers, but have much lower / or more localised cooling effect.

- There are some studies of the benefit to cost ratio for green roofs (Nurmi et al., 2013: Meyers et al., 2015; Mahdiyar et al., 2016: Bianchini and Hewage, 2012; Bouwer et al., 2018). In most cases, these show modest or low benefit to cost ratios, with a low proportion of these benefits from adaptation (internal cooling). Further, many of these benefits are non-market in nature, and thus their private financial attractiveness is low.
- The benefit to cost ratios for SuDS have been studied Ossa-Moreno et al. 2017), and guidance existing for estimation (Benefit of SuDS Tool (BeST) (UKCIRIA)), although the financial case alone does not appear to incentivise adaptation.

Overall, the economic analysis highlights that these options do not have significantly greater attractiveness than conventional adaptation options, but this is partly because the economic analysis tends to penalise many of the characteristics of GI (slow establishment and lower early benefits, discounted long-term benefits). Further, many of their benefits arise from non-market values, which makes them less attractive from a private investment viewpoint. When the full range of benefits are included – particularly the more intangible but real non-market values such as health, amenity, recreational, cultural and environmental regulatory benefits – they have positive benefit to cost ratios. This points to the need for GI to be advanced as an option that address multiple objectives (rather than as exclusively adaptation options).

Key policy messages

This case study looks at the outcome in the 25 Year Environment Plan (25YEP) to 'green our towns and cities by creating green infrastructure'. It considers the potential effect of climate change on the outcome (creating more GI), but also how climate change might alter the demand for GI, due to its adaptation benefits, and thus make the outcome potentially easier to achieve. The first key policy message is that the current Government goal for increasing green infrastructure has largely ignored the potential effects of climate change on the outcome, and the role of GI for adaptation. This is highlighted as a gap. In terms of the actual 25YEP outcome, the analysis finds it is unlikely that climate change will make the actual delivery of the 25YEP goal for more GI (in terms of hectares or number of schemes) more difficult to achieve, because it won't affect the introduction of schemes directly. However, climate change could 1) affect the anticipated benefits of GI, and 2) alter the future demand for GI (making the original outcome more likely to be achieved). For the first of these effects, the study finds that climate change is likely to have a fairly modest negative impact on most of the ecosystem services provided by GI (amenity, physical health) but could have important implications on its adaptation benefits. There is little evidence on the size of these effects, but a recommendation here is that 'climate smarting' new GI could be beneficial (although further analysis to understand the costs and benefits of this is recommended). For the second effect, climate change is projected to increase the demand for some of the broader ecosystem service benefits provided by GI, notably recreation: this could enhance the demand and potentially uptake of GI in a warmer climate, making the Government outcome easier to achieve. Climate change could also, more obviously, increase the demand for urban adaptation, through autonomous or planned action, but this will only lead to an increased implementation of GI if this option has benefits over conventional adaptation options. To investigate the latter, the study has investigated the effectiveness of GI for adaptation, and its costs and benefits, relative to other urban options. This finds that when only GI adaptation benefits are considered, e.g. cooling benefits, GI options are not that favourable in cost-benefit terms. However, when GI co-benefits are included (i.e. recreational, other ecosystem services), then economic benefits increase, and there is a higher justification (in economic terms) for GI schemes. This points to the need for GI to be advanced as options that address multiple objectives (rather than as exclusively adaptation options). Finally, the current policy focus for GI is on design standards, but an analysis in the review identifies that there are other barriers that need to be addressed to incentivise scale-up.

3. Ensuring marine fisheries produce maximum sustainable yield, while protecting the environment

What is the objective and outcome?

The 25 Year Environment Plan (HMG, 2018) has a key theme of ensuring clean, productive and biologically diverse seas and oceans. The plan includes a target for 'ensuring that all fish stocks are recovered to and maintained at levels that can produce their maximum sustainable yield'. The plan also refers to the need to restore and protect the marine ecosystem. Following the 25YEP, Defra has also produced a White Paper (Defra, 2018b), the consultation document on *Sustainable Fisheries for Future Generations*. This sets out the aim to build a sustainable UK fishing industry by taking responsibility for managing fisheries resources within UK waters, while continuing to protect and improve the marine environment. We have therefore considered a fisheries outcome of ensuring that all marine fish stocks (in UK waters) are recovered to and maintained at levels that can produce their maximum sustainable yield (MSY), while protecting the wider marine environment.

This outcome is still quite broad, and neither the 25YEP nor the White Paper set specific targets or deadlines (for achieving MSY). For this reason, this study has developed a broad logical framework to better articulate the outcome.

It is stressed that the impact of Brexit will have large consequences for the sector, but as these are extremely difficult to predict currently, we have focused the analysis on the 25YEP and Fisheries White Paper goals as they are presented.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The study has looked at the impacts of climate change on the sustainability of fisheries, to investigate how climate change (considering 2 and 4^{o}C scenarios) might affect the outcome of maintaining maximum sustainable yield of fish stocks (in UK waters). It is stressed that these effects need to be seen against the background of existing fishing activities that dominate many fish stocks, i.e. climate change is an additional threat multiplier, and further, that the analysis of these changes is uncertain.

There are a large number of pathways by which climate change could affect the outcome (Barange et al., 2014; Barange et al., 2018). While most of the focus in the literature has been on sea temperatures and species shifts (e.g. Cheung et al., 2010: Cheung et al., 2013), extreme temperature events are also important (Smale et al., 2019). The potential effects of climate change on fisheries may be direct (on landed species) or indirect, through the ecosystem, for example affecting species lower down in the food chain or changing marine habitats. Ocean acidification also poses a major threat to shellfish species (Mangi et al., 2018) and climate change could also have impacts on fishing activities (distance travelled) and safety at sea (marine storms) (Woolf et al, 2013). Climate change is likely to impact on the marine environment and ecosystems services these provide, thus affecting the secondary goal of protecting the wider marine environment.

These changes are projected to lead to alterations in fish populations: sizes, juvenile recruitment, and geographical distribution, affecting maximum sustainable yield and catch potential (Brown et al., 2016: Barange et al., 2018). There are also likely to be impacts on fishing fleets: distance travelled, catch type, and values of catch (Frontier Economics, 2013). The overall net impact could be positive or negative, and will vary by marine zone.

Studies on climate change impacts on fisheries in the UK indicate that on average, changes in catch potential for species could range from -15% to -18% for a 2°C degree pathway by the middle and the end of century respectively (RCP 2.6); and -18% and -35% by middle and end of century under a 4°C pathway (RCP 8.5) compared to current levels (Barange et al., 2018). In England, it has been estimated that impacts on potential catch relative to present (1991-2000 baseline) level will be around -20% in both climate scenarios up to 2050s, but diverge significantly after then, with more significant reductions under a 4°C degree scenario by the end of the century (-60%), mostly due to a decline in shellfish stock and landings (Fernandes et al., 2017).

The analysis of risks has also considered thresholds and the potential for lock-in. There are clearly many thresholds associated with the marine environment, and the suitability for species. These also include extreme temperature thresholds. The study has also identified an interesting issue of lock-in (i.e. the potential for large increases in future risk from a lack of early policy action that are difficult or costly to reverse later) with marine protected areas (MPAs), where these are set up on the basis of biogenic habitats. This is because they are chosen based on their historic marine climate suitability. With climate change, the potential suitability of these areas (for some species) is likely to change. Many features for which MPAs have been designated are potentially vulnerable to climate change, meaning the ongoing utility of MPAs as they are currently designated could be affected. This highlights the need to consider climate change when looking at future MPA siting and reasons for the designation.

What are the economic costs of climate change, i.e. the effect on the outcome?
Given that the information on future impacts on fisheries from climate change is uncertain, it is difficult to estimate the economic costs of these effects. There are some studies that provide partial estimates, and these indicate the losses in revenue from productivity and catch changes could be as much as 20% of current levels by 2050, for England (Barange et al., 2018). The evidence suggests these losses could be driven largely by the negative impacts on shellfish catches (Fernandes et al., 2017). Much larger losses are projected to occur after 2050, i.e. under high emission scenarios, there is a rapid increase in economic costs to the fisheries sector.

What are the potential additional adaptation options to address impacts on the outcome?
Climate change does not feature heavily in the Fisheries White Paper, indeed, there is only one mention of climate change in the entire document, and there is no mention of climate change in the draft Fisheries Bill. The Second National Adaptation Programme (NAP2) (Defra, 2018) does identify some activities in place, for example, the Sea Fish Industry Authority (Seafish) annual climate change updates for the capture fishing industry, and there are plans for climate to be included in forthcoming Marine Plans. However, given the scale of potential impact, there is a clear potential adaptation gap in the policy framework for fisheries.

This study has then considered the potential adaptation options that could be introduced to help deliver the 25YEP/White Paper target, i.e. to close the adaptation deficit. There are a large number of fisheries adaptation options, addressing different risks, but most of these are extensions of existing policy and comprise (Poulain et al., 2018) institutional adaptation (policy, legal, fisheries management and planning [including conservation and protection]), diversification (within and between the sector), risk preparedness and reduction.

These potential options have been considered using a high-level adaptation pathways approach focused on three areas. The first is early low and no regret options that address current risks and build resilience, including information and awareness raising for capture fisheries, ensuring improved fisheries management (taking account of climate change), and maintaining healthy and productive stocks and systems. The second is focused on 'climate-smart' decision making, notably for marine protection areas (noting these could be considered to be low-regret), as these need to be sited / considered with the future climate in mind. These would address the second part of the outcome on protecting the marine environment. The third is on early planning / iterative adaptive management, focusing on monitoring (marine climate, acidification, species abundance and distribution), etc. with a feed back into fisheries policy (e.g. to set maximum catch potential for current species, but also to include new species in policy) and to raise awareness of changes to fisherman, to provide information to help them adapt.

We highlight that there would be large benefits from fisheries policies taking a more adaptive management-based approach, given the uncertainty in the future risks and opportunities from climate change. This is likely to be a key priority for delivering the 25YEP under climate change, i.e. to iteratively monitor and adjust fisheries policy responses, and to pass this information back to fishermen, to support climate smart investment decisions.

What are the benefits and potential costs of adaptation?
The final step has been to consider the costs and benefits of additional adaptation actions. This is challenging, as it is compounded by the lack of information on the economics of adaptation for fisheries. For this case study, we focus on the costs of a number of key adaptation options that could help address the impact of climate change on the 25YEP / Fisheries White Paper goal and target in England.

The first option is to develop an <u>adaptive management approach for the fisheries sector</u> in England. This involves a scale up in monitoring, scientific information and awareness raising. Indicative costs have been assessed, based on the scale-up of current research and monitoring activities, and their potential benefits (based on Costello et al. 2009). This analysis indicates there could be an increase in fishery value (through the value of information) by approximately 10%, which has a positive benefit to cost ratio.

The second option is to further <u>increase Marine Protected Areas</u> to improve the marine environment in the face of climate change, and also enhance fisheries. More marine areas – with full protection – could be required to deliver the same level of ecosystem service function/benefit as now, due to the marginal impact of climate change. The literature indicates MPAs deliver significant benefits (Heal and Rising, 2014; Moran et al., 2008; Kenter et al., 2013; eftec, 2014; European Commission, 2017), both environmental and economic: when used as a fishery management approach alongside quota and effort-based approaches, they can contribute to increasing yields (if they are designed well). The literature indicates that the average break-even point for economic benefits (expressed as landed catch values) of MPAs (where fishing is restricted) is 8.5% of marine area. This would mean that in the UK an additional 195,000 Km^2 should be protected for economic benefits to be realised, at an estimated annual average cost of approximately £73.5 million. It is stressed, however, that additional MPAs need to be designed and sited with future climate change in mind, i.e. to be climate smart.

Finally, there is a question of whether other options might be introduced to ensure maximum sustainable yields are maintained under climate change (option 3). This involves some complex issues because of trade-offs. There are many options that could enhance the efficiency and effectiveness of the fishing industry, and thus help address climate risks, but if the fishing industry is more efficient, it would also then be in a position to increase catch (i.e. this would put greater pressure on maximum sustainable yields). An alternative is to introduce stricter policies to reduce maximum sustainable yields, or to reduce fishing pressure in the short-term to allow stock enhancement and larger MSY later, in effect to build in contingency for climate change. However, this would involve important downsides (catch potential) for the fishing industry. Other than MPAs, the review has not found any obvious answers. The analysis of additional options, and trade-offs, is highlighted as a key question for future analysis.

Key policy messages
Overall, it is considered that climate change could have a material impact on the feasibility of achieving the 25YEP fisheries goal of 'ensuring that all marine fish stocks (in UK waters) are recovered to and maintained at levels that can produce their maximum sustainable yield (MSY), while protecting the wider marine environment'. Climate change has the potential to reduce the maximum sustainable yield, as well as impacting on the marine environment. The studies available suggest a decline in catch potential for England, for example, with up to 60% in a 4°C world by the end of the century. Climate change is therefore likely to make it harder to achieve the outcome, and could constrain the ambitions in the 25YEP. These impacts are likely to be much greater (disproportionately so) under a 4°C pathway. Climate change may also alter the suitability of different marine areas for different species, and thus affect Marine Protected Areas (especially when these have been designated for specific species). However, climate change does not feature heavily in the Fisheries White Paper, indeed, there is only one mention of climate change in the entire document, and there is no mention of climate change in the draft Fisheries Bill. Given the importance of these documents for driving future policy, this omission represents a major policy gap.

This study has identified that there are additional adaptation options that can address these impacts, although further research is needed (especially on the implications of climate change on the achievability of the 25YEP target and the costs and benefits of adaptation to meet this). An initial analysis here identifies that the key early adaptation priority is to enhance existing activities that use adaptive management, improving information (from monitoring, research etc.) to iteratively and flexibly adapt fisheries policy. Initial analysis indicates there could be an increase in fishery value (through the value of information) of approximately 10% from such an approach, with a high positive benefit to cost ratio. This would involve the use of information to inform policy, e.g. in setting maximum catch potential, including new species, combined with information of threats and opportunities to fisherman. We also note that increasing the proportion of 'no-take' Marine Protected Areas around the UK to 8.5% of total area (fully protected MPAs are currently about 3% while all MPAs are 24%) and would have potentially large economic benefits.

4. Restoring vulnerable peatlands

What is the outcome?
The Government has an objective in the 25 Year Environment Plan (HMG, 2018) of 'restoring vulnerable peatlands and ending peat use in horticultural products by 2030'. This applies to all vulnerable peatland (upland and lowland). There is also an additional 25YEP objective to restore 75% of our terrestrial protected sites to favourable condition (which would include protected peatland sites, which forms a significant percentage of upland sites but few lowland sites). The 25YEP sets out the intention 'to create and deliver a new ambitious framework for peat restoration in England', and notes that where it is not appropriate to restore lowland peat, 'we will develop new sustainable management measures to make sure that the topsoil is retained for as long as possible and greenhouse gas emissions are reduced'.

For this analysis, a specific quantified target is needed. An England-specific restoration target and strategy for peatlands are due to be announced soon (probably 2020), but in the meantime the case study uses the targets set out in the UK Peatland Strategy (led by IUCN, 2018), which sets goals to restore one million hectares of degraded peatlands by 2020 and two million hectares by 2040. This is not a Government target, but is consistent with the 25YEP outcome. There is also a joint Ministerial Statement of Intent to enhance (i.e. increase) the natural capital represented by peatlands, and also a 25YEP goal to manage all soils sustainably.

Restoration of degraded peatlands represents both a mitigation response and an adaptation response. In terms of mitigation, restoration can reduce existing intense emissions from actively eroding sites, and reduce the risk of less degraded sites becoming more intense sources due to further degradation. However, because climate change is anticipated to further increase emissions from degraded peatlands, restoration is also an adaptation response in that it will help to protect the carbon store against future pressures – ideally by allowing the peatland itself to adapt (e.g. shifts between plant species), but at least by making it more resistant to climate change pressures. In addition, restoration of peatland provides other ecosystem services and adaptation benefits. For example, smoothing base and peak water flows, both of which may become more erratic if rainfall patterns change, or providing a refuge for plant and animal species threatened by climate change elsewhere.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The majority of peatland sites in England are primarily in poor condition as a result of unsympathetic land management, leading to areas of bare peat, a loss of soil, habitats and biodiversity, and reduced capacity to stabilise base and peak flows of water (Dickie et al., 2015; Evans et al., 2017; Thomson et al., 2018). In this condition, climate change will increase the loss of ecosystem services from peatlands including through the risk of loss of the peat-forming sphagnum moss layer on upland peats from hotter, drier conditions. Intact, functioning peatlands may still be susceptible to climate change, but evidence suggests that they will be more resilient (to it) and may indeed be able to self-adapt (e.g. through changing their vegetation species mix) to continue functioning. The difference in impacts between 2°C and 4°C pathways is difficult to specify, but it is presumed that degradation risks and rates of degradation increase with temperature and that trigger points, such as prolonged droughts or simply more variable patterns of precipitation, may well exist for abrupt shifts in vegetation cover and erosion (Fenner & Freeman, 2011; Carey el al., 2015; Dielman et al., 2016; Li et al., 2016; Swindles et al., 2016). Ultimately, once a site approaches complete depletion of peat, degradation becomes irreversible. Before this point is reached, degradation can generally be reversed, albeit that required actions may be more expensive and take longer to take effect. This suggests that inaction now may potentially lock-in irreversible damage at some sites, and is more likely to incur additional on-going ecosystem service losses and increase later restoration costs.

What are the economic costs of climate change, i.e. the effect on the outcome?

The costs of inaction from climate change is the value of ecosystem services lost due to continuing and worsening degradation, and potential irreversible effects, with the counterfactual being the comparison between the performance of restored and unrestored sites over time i.e. the relative difference rather than absolute performance levels. Valuation of lost ecosystem services are challenging to quantify, but it is possible to use illustrative figures. For example, if non-traded central carbon values are applied to possible emission trajectories (Evans et al., 2017) for the 0.65m ha of (lowland and upland) peatland in England that would contribute to the IUCN target if restored, estimated Present Value costs of emissions by peatlands over the period to 2040 lie in the range of £13.75bn to £16.2bn. Consideration of other degradation losses further increase these estimates (Harlow et al., 2012; Glenk and Martin-Ortega, 2018)), adding perhaps £1.5bn for biodiversity losses to 2040.

What are the potential additional adaptation options to address impacts on the outcome?

It is apparent and well-known that there is a current problem of degraded peatlands already imposing a loss of ecosystem services upon society now, and a longer-term problem with continued and worsening degradation imposing increasing costs. Both of these can be addressed through restoration, with early action having short-term benefits as well as longer-term resilience to climate change. As such, restoration is a low-regret option (CCC, 2013). Moreover, early action is desirable given that restoration to a near-natural, fully-functional state can take decades or longer and that restoration costs increase with the degree of degradation faced.

Restoration typically requires removal of damaging pressures, most notably unsympathetic management practices, but also often remedial structural action. The latter includes blocking of drainage to raise the water table, but can also involve stabilisation and revegetation of bare peat plus reprofiling of gulleys – all of which entail capital investments upfront. Management practices also need to change in order to encourage recovery to occur once structural improvements have been made. This may take the form of changes to land use, such as with cessation of peat extraction, and/or intensity of land use, such as with reductions in livestock numbers. Changing land use, particularly in more productive lowland settings, may reduce some provisioning services (e.g. food production) but gains in other ecosystem services will generally outweigh this.

What are the benefits and potential costs of adaptation?
Comparison of the costs and benefits of restoration needs to account for relative magnitudes but also timing. In particular, capital investment costs are incurred upfront whilst benefits accumulate more slowly over time (as do any opportunity costs). This makes the choice regarding both the time period over which comparisons are made, and the discount rate by which future costs and benefits are translated to an equivalent Present Value, important. In particular, shorter time horizons and higher discount rates will diminish the apparent value of durable ecosystem services derived from a functioning peatland capable of withstanding climate change.

Nevertheless, illustrative cost effectiveness and cost-benefit analysis indicate that restoration is generally worthwhile in most (but not all) cases, for both upland and lowland peatlands. For example, reported cost-benefit ratios (Harlow et al., 2012; Moxey & Moran, 2014; Bright, 2017; CCC, 2013) for different sites range between 1.3:1 and 12:1, depending on the time-horizons and benefits considered. Importantly, the merits of restoration increase if more ecosystem services are included. Net benefits also increase the longer the time-period considered and the greater the assumed pace and extent of climate change: climate change strengthens the case for restoration.

Key policy messages
Immediate restoration of both upland and lowland degraded peatland is a beneficial climate change mitigation and adaptation response, with benefits likely to increase under more rapid and/or severe climate change (although precise relationships are uncertain). Possible tipping points may favour restoration of sites before they degrade rapidly, but restoration of already badly degraded sites offers immediate gains in terms of emissions avoided. However, reliance on voluntary enrolment (rather than regulatory obligations) means that the extent of restoration is affected by the availability of funding for necessary capital investments but also interactions with (especially) agricultural policy support and market returns, both in the uplands and lowlands. The latter gives rise to high opportunity costs for productive lowland sites, and poses a challenge to achieving restoration of fenlands responsible for a disproportionate share of overall peatland emissions.

5. Managing and reducing the impact of plant diseases (plant pathogens)

What is the outcome?
This case study is focused on the biosecurity theme in the 25YEP (HMG, 2018) and the goal and target for 'managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species'. This target is also set out in the 2nd National Adaptation Programme (2018). More detailed actions are listed in the Tree Health Resilience Plan (Defra, 2018c), which includes a focus on resistance, response and recovery, and adaptation. The strategy does highlight the potential role of climate change, but it does not assess how this will affect the strategy's objectives.

There are an extremely large number of possible plant and animal diseases that could be covered by the outcome. To make the study manageable, the case study has focused on four plant-based pathogens that are currently established in England, and that might be exacerbated by climate change. These are:

- *Phytophthora ramorum*, which affects trees and other plants, although the disease is a particular problem in the UK for larch grown for timber;
- *Chalara fraxinea*, a fungus that affects ash trees and leads to dieback;
- *Dothistroma* needle blight of pine, which causes premature needle defoliation and reduces timber yield, and in severe cases, tree mortality; and
- Yellow rust and *septoria* on winter wheat, which leads to yield loss.

These pathogens have been selected due to their potentially significant economic impact and/or the ecological value of the ecosystems that are affected. Due to the absence of a specific 25YEP target on the levels of reduction in (i.e. on whether to manage to acceptable levels, to optimal levels as defined by costs and benefits, or as low as reasonably possible) we have defined a goal. The assumed baseline objective (and outcome) is that the risks from all four of these pathogens would be reduced compared to current levels.

How does climate change affect the outcome, in a 2 vs 4°C pathway?
Changes in the climate can affect the suitability and geographical range for pests and diseases and may also, in combination with changes in extremes, affect the prevalence and intensity of pest and disease outbreaks. The economic costs of these outbreaks can be very high, once established. However, making precise projections of the changes in specific pathogens, and the subsequent impact, is much harder. There is no robust evidence on how climate change will affect each of the pathogens above, and certainly no information to distinguish between 2 and 4°C scenarios. *Phytophthora ramorum* and Yellow rust/Septoria generally favour warmer and wetter conditions over autumn/winter/spring: they might therefore become more prevalent as these conditions are projected by UKCP18 (Sturrock et al., 2011). However, for *septoria*, the increase in warmer drier summers (also projected by UKCP18) could potentially offset these increases (Gouache et al., 2013). Ash die-back is projected to decline under climate scenarios that project warmer, drier, summers (Goberville et al., 2016)) whilst red band needle blight is projected to increase to 2050 as a result of the higher projected winter rainfall (Ray et al., 2017)).

Importantly, this outcome also involves potential lock-in and threshold risks, because once diseases are established (endemic), they are difficult and costly to eradicate, and can cause large economic costs.

What are the economic costs of climate change, i.e. the effect on the outcome?
While the evidence on the likely changes are difficult to project, it is possible to explore the potential economic costs of climate change through some indicative 'what-if' analysis. In the table below we summarise the assumptions made on disease under climate scenarios, and the associated costs.

Disease type	**Disease spread assumptions**	**Additional Costs from climate change from now to 2050** (£m; 2018 constant prices; discounted)
Phytophthora ramorum	Current extent of spread (2010-2018) maintained to 2050. Upper-bound, what-if	67.5
Chalara fraxinea	Range of 15% to 50% increase in spread to 2050	178 to 596
Dothistroma	23% increase in spread to 2050	300
Septoria	2-6% reduction in spread to 2050	- 83 to -245

What are the potential additional adaptation options to address impacts on the outcome?
There are a number of existing actions set out in NAP2 to address pest and disease risks (Defra, 2018). However, these are not extensive, and in some cases, they rely on others (industry, volunteers) to provide monitoring and surveillance. There is very little on how to address future climate challenges – although it does highlight these will be covered in a subsequent Forestry Sector Climate Change Action Plan. However, analysis of the latter Plan (Defra, 2018c) shows it does not have a strong focus on pests and diseases, i.e. there appears to be a gap.

The specific options currently recommended for each of the four pathogens has also been reviewed (Defra, 2014b; GB DNB; HGCA, 2012). On the basis that climate change will make the outcome of managing and reducing pests and diseases probably more challenging, an uplift in adaptation is considered to be warranted to maintain the level of impact from these four diseases at today's levels, or reduce it further. To investigate this, the study has looked at additional adaptation options that could be introduced. We focus on early adaptation priorities– that might be used to make sure that Government outcomes are put back on track - using three key building blocks that comprise a high-level adaptation pathway.

These are:
- Early low- and no-regret options that address current risks and build resilience;
- 'Climate-smart' decisions including decision making under uncertainty (for early decisions with a long life-time / risk of lock-in);
- Early planning / iterative adaptive management, in cases where there are benefits from early activities / or adaptation that involves long lead times.

What are the benefits and potential costs of adaptation?
The case study has examined the possible costs and benefits of adaptation. The analysis has looked at the existing costs and benefits of current adaptation actions to tackle the four pathogens above (Brown and Webber, 2008: Forestry Commission, 2011; Fones and Gurr, 2017), and the potential increased costs and benefits under climate change. For Phytophthora ramorum, comparison of the costs and benefits of identification, felling and replacement of infected larch trees gave a benefit-cost ration of 1:1. Whilst lack of data on adaptation options preclude the possibility of a quantitative cost-benefit analysis (CBA) for ash die-back, it is likely that investment in monitoring and surveillance would be a no-regret option, as it is for many other diseases. For red band needle blight, thinning undergrowth is found to be a cost-efficient option, (i.e. the benefit-cost ratio (BCR) > 1), as long as a certain level of effectiveness is achieved, whilst Septoria on winter wheat can be reduced cost-efficiently using fungicides.

The analysis therefore indicates that it is possible to manage changing pathogen risks, at least to some extent, using existing adaptation options. However, there would be a large resource cost associated with higher management effort and it is possible that public intervention is needed, either in the efficient provision of data and information relating to the pathogen spread, or in the local economic transition away from a reliance on the affected agricultural or forestry-based activity.

More generally, this indicates that once established, managing pathogens and pests is costly. Given that a wide range of pathogens and pests may spread or be introduced as a result of climate change, and given the need for co-ordinated provision of information, there would seem to be a case for an expanded role for Government intervention to provide enhanced monitoring and surveillance and early response. Evidence on the economic justification for such a scale up (SRUC, 2013) suggests this would be highly beneficial, with a benefit to cost ratio of up to 10:1.

Key Policy Messages
The analysis finds that climate change could make the 25YEP outcome of '*managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species*' significantly more difficult for many species, though there could be a reduction in risk from others. The risks to meeting this outcome also involve potential lock-in and threshold effects, because once certain diseases are established (endemic), they are difficult and costly to eradicate, and can cause large economic costs. While the evidence on the likely changes are difficult to estimate, the study has explored potential economic costs through indicative 'what-if' analysis for plant pathogens: this reveals large potential damages from climate change for three of the pathogens (*Phytophthora ramorum*, *Chalara fraxinea* and *Dothistroma)*, but potential benefits from a reduction of *Septoria* on wheat. The damage estimates for these diseases range from the tens to the hundreds of £millions (total benefits to 2050s, discounted), with a similar magnitude of benefit for *Septoria*.

The case study has also looked at adaptation. There are a number of existing actions set out in the NAP to address disease risks, however, it is highlighted that the 25 YEP – and NAP2 – do not outline a measurable goal for managing and reducing the impact of existing plant and animal diseases, e.g. managing to acceptable levels (e.g. based on the balance of costs and benefits) or even to minimal damage (or as close as possible to this). Similarly, the actions in Defra's Tree Health Resilience Strategy (the tables of action) do not seem to match its ambitions for adaptation, and there is very little in the Strategy on how to address future climate challenges. The Strategy does report that such actions will be covered in the Forestry Sector Climate Change Action Plan, however, analysis of this latter document shows it does not have a strong focus on pests and diseases. Therefore, while there are some actions that could help manage changing pathogen risks, we consider there is a gap, and further, given the possible large increase in resource costs and further public intervention needed to tackle future pests (especially as the size of these effects could exceed private actors' past experience), further action is warranted. Based on the analysis, we therefore identify that there is a strong economic argument for greater Government intervention in research, monitoring, awareness raising and co-ordination of reactive response toward potential and emerging threats (including invasive species): this would require enhanced Government action, but is projected to have high economic benefits compared to costs (at least 10:1).

6. Improving the approach to soil management / managing soils sustainably

What is the outcome?
This case study is focused on the soil management theme in the 25YEP (HMG, 2018). The 25YEP set outs the goal/target of '*Improving our approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches'*. This is linked to an action to develop better information on soil health, producing a soil health index and testing this.

The 2nd National Adaptation Programme (NAP2) (Defra, 2018) reflects the focus of the 25YEP on soil quality and repeats the goal and actions above. The NAP2 identifies some of the pathways through which climate could affect soils, citing soil degradation such as erosion, compaction and the decline in organic matter, and highlights that addressing these will lead to healthier soils. It also highlights that adaptation to maintain soil health will have a range of co-benefits including carbon emission reductions.

This case study assesses the potential impact of climate change on the 25YEP/NAP2 goal and action on managing soils sustainably and developing appropriate soil metrics. However, it is highlighted that the target in the 25YEP is extremely broad and not well defined. There is no definition of what is '*managed sustainably*' and no definition of soil health/ quality (noting these will vary significantly by land-use type). This makes it difficult to assess the impact of climate change on the outcome, except in qualitative terms. Furthermore, the pathways by which climate change affect soil quality are extremely complex (Brown et al., 2016), and need to be seen in the context of the multiple factors that affect soil health, including non-climate related risks (which are currently more dominant). To advance the case study, the analysis has focused down on soil health.

It is noted that at the time of this study, the UK is introducing new agricultural policies following the planned withdrawal from the EU. There is currently great uncertainty around the policy landscape post-Brexit, and a combination of trade and agricultural policy will drive farming practice post-Brexit.

How does climate change affect the outcome, in a 2 vs 4°C pathway?
The importance of effective soil management – and soil quality - derives from the fact that soil performs several important underpinning functions: it supports food production, water storage, biodiversity conservation and carbon storage. The ability of soil to perform its multiple functions is reduced when it is degraded (its quality is reduced) or eroded (its quantity is reduced), as can arise from several factors, which include climate change.

The CCRA2 (Brown et al., 2016) identified risks to soils from increased seasonal aridity and wetness. However, climate change can potentially impact on soil quality through a number of pathways (Morison and Matthews, 2016):

- Soil degradation (although this can include multiple processes);
- Soil erosion (from heavy precipitation and extremes);
- Higher rainfall increasing soil compaction;
- Loss of soil organic carbon;
- Multiple climate factors affecting vegetation cover and soil processes, affecting function, water holding capacity, salinization, etc.

The most direct climate pathway is from soil erosion, which leads to the reduced productivity and reduced soil carbon (and increased GHG emissions), but can also lead to downstream impacts such as on water quality (Defra, 2012: Graves et al., 2015). The other factors involve complex pathways where climate is only one of many factors. Note that there are also some potential positive effects as well, from climate change increasing organic matter and biodiversity due to warmer temperatures and higher primary productivity. It is stressed, however, the scale of negative impacts and any positive effects, will be strongly influenced by land management.

There are estimates of current rates of soil erosion in England (Defra, 2012: Graves et al., 2015; POST, 2015), and previous studies have projected that these could increase with climate change, primarily due to changes in rainfall (with estimates of a 20% increase in soil erosion by the end of the century, Cooper et al., 2010). In the medium-term (2050s) there is not much difference in the average and extreme rainfall projected under 2°C versus 4°C pathways, but there is a very large difference due to model uncertainty and variability (Lowe et al., 2018). As these indicate that rainfall projections for England could vary significantly, even in the sign of change, there is considerable uncertainty in the exact changes.

The pathways for other climate change effects on soil, including vegetation cover and soil processes, and the effects on soil health, are not sufficiently well understood to project the detailed effects of climate change.

Nevertheless, climate change clearly has the potential to affect soils, and thus is an important component in soil quality and soil health. In the absence of adaptation, soil health could decline (at least for the component vulnerable to climate change) which could make it be more challenging to achieve the outcome of improved soil health in the 25YEP (though the effect will depend on the exact metric developed). Climate change could also affect the sustainable management of soils, with detrimental effects on the ecosystem services that soil provides.

The case study has also considered the potential for threshold risks for soil quality and also the potential for lock-in. There are a large number of potential thresholds risks associated with soil quality and soil health, but these thresholds are extremely complex, and are likely to be more influenced by other factors. Nonetheless, climate change could be a factor in potential threshold and lock-in risks, notably from soil erosion (especially in the case of unsustainable management). There is a study which has identified unlikely but plausible major tipping points for areas of England, from the impact of climate change on soil erosion leading to major production losses (GFSP, 2017).

What are the economic costs of climate change, i.e. the effect on the outcome?
Soil erosion can lead to a number of economic costs. This includes the direct impacts on reduced agricultural productivity, but also the offsite cost associated with impacts on environmental water quality and drinking water quality. It also includes the loss of soil carbon and increased greenhouse gas emissions.

Defra (2012) (also published as Graves et al. 2015) estimated the annual costs of soil degradation in England and Wales at between £0.9 and £1.4 billion. This reflects total soil degradation. Of this, the annual cost of soil erosion in England and Wales was estimated at £177 million/yr (as the additional input costs to offset losses in productivity). The estimated current cost of compaction was estimated at £472 million per year, about half of which are on-site, and half are offsite. The costs of soil carbon loss were estimated at £566 million/year (based on a carbon price). Soil erosion costs would increase with climate change, under scenarios with higher precipitation and especially higher heavier precipitation. A further study (AECOM, 2015) estimated the potential impacts on soil carbon under climate change for different scenarios, reporting the soil carbon stock could be reduced by up to -12% by 2060, with costs in England of around £30 billion between 2010 and 2060, although there was a large range, which included positive values for some scenarios when positive land use change were included.
There are no robust estimates of the future economic costs of climate change on soil quality or stocks. However, it is possible to provide some indicative estimates by deriving annual totals for the climate change impacts of erosion and compaction. For example, applying the 20% increase identified from the impact of climate change on erosion to the current economic costs of soil erosion indicates potentially large economic costs are possible for England.

What are the potential additional adaptation options to address impacts on the outcome?
The current soil management policy and soil metrics are still being developed, and this makes it difficult to know how much climate change adaptation is being factored in. At the simplest level, an obvious first action is to ensure that the soil health metrics being developed include attributes that could be affected by climate change, and then to ensure that climate information and soil health quality over time are monitored and evaluated (with the linkages between the two being explicitly considered). For example, specific factors that relate to climate change related impacts include soil erosion rates and soil carbon content.

However, the current actions set out for soil health in NAP2 (Defra, 2018) are primarily focused on research and monitoring (with soil metrics yet to be derived). For this to be useful, there will be a need to scale this up, and incentivise the farming sector to act on the information this provides. There is also an opportunity to use this information (on monitoring of soil health) at the national scale, to help inform new policy development, as part of an adaptive management (iterative) approach for developing national agriculture policy, and even, for influencing the incentives in agriculture farm payment systems.

Moving to soil management actions, there are already a set of management practices in place and NAP2 sets out an action to incentivise good soil management practices. These will be focused on wider actions to enhance sustainable management, and thus may not prioritise climate resilience, however, there are many measures that have adaptation co-benefits. Such actions have been advanced through a large international and UK literature on climate smart agriculture (FAO, 2013; POST, 2013; POST, 2017). Such practices aim to deliver triple outcomes of increased productivity (income growth), reduced GHG emissions (mitigation) and enhanced climate resilience (adaptation). Most of these measures are forms of sustainable agricultural land management (SALM) practices, which improve soil water infiltration and holding capacity, as well as nutrient supply and soil biodiversity. They are generally considered to be low-regret (rather than no-regret), because they often have opportunity or transaction costs (FAO, 2011: ECONADAPT, 2017).

While improved awareness of these measures will be important, a key issue will be the incentives introduced through farm payments to incentivise them. As highlighted above, UK is introducing new agricultural policies following the planned withdrawal from the EU. A key opportunity will be to integrate (mainstream) climate aspects in such policy development.

What are the benefits and potential costs of adaptation?
There is relatively little economic evidence on the costs and benefits of soil management techniques in England, although there is a large international literature. The literature that exists suggests that the economic benefit to cost ratios for sustainable soil manageable are modest (Kuhlman et al., 2010; UBA, 2012; SRUC, 2013; ECONADAPT, 2017; IFAD 2018), and the private benefit to cost ratio (the rate of return) are often low, because many benefits are non-market in nature, and there are often additional opportunity costs and barriers. In practice, it can be harder to achieve the triple win (of increasing production, reducing emissions and enhancing resilience) and there are often trade-offs involved. Therefore, while sustainable soil management approaches have potential for reducing climate impacts, their uptake requires these barriers to be addressed. These are likely to go beyond information and awareness raising, though there are obvious opportunities to provide additional incentives through revision of the current farm payment schemes.

Key Policy Messages
This case study is focused on the 25YEP goal by 2030, for all of England’s soils to be managed sustainably, and the 25YEP/NAP2 action to develop better information on soil health and develop a soil health index. However, the overall 25YEP goal is quite broad, and does not define what is ‘sustainably managed’, and there are many factors involved in soil management and soil health, of which climate change is only one. Climate change can lead to soil degradation, soil erosion, compaction, and decline in organic matter, although there are other more complex impacts, including some potential benefits. Climate change could therefore be important in soil health (and affect the outcome above) although factors are important (e.g. land management practice). The impact of soil degradation, erosion, compaction and carbon loss currently has high economic costs, with previous studies estimating annual costs in England and Wales of £0.9 and £1.4 billion. These could increase under climate change, with indicative estimates suggesting up to a 20% increase in soil erosion.

The current soil management policy and soil health metrics are still being developed, and this makes it difficult to know if further adaptation is needed. An obvious priority is to ensure that soil health metrics include attributes that can measure climate change impacts (e.g. soil erosion). However, for this to be useful, there will be a need to use this information and scale up, and to incentivise the farming sector to act on the information. This includes the use of soil health information to inform agricultural policy as part of adaptive management. Beyond this, there are opportunities for soil management which are positive for adaptation. However, these have modest economic benefit to cost ratios, and often are unattractive from a financial (private) perspective, due to the time-periods before benefits arise, because many benefits are non-market, and because there are opportunity costs and potential trade-offs. These are barriers to their uptake, i.e. there are likely to need to be incentives to encourage uptake to ensure the delivery of the 25YEP goal.

7. Ensuring interruptions to water supplies are minimised during prolonged drought.

What is the outcome?

The 25 Year Environment Plan (25 YEP) (HMG, 2018) sets out the goal of boosting the long-term resilience of homes, businesses and infrastructure to climate change. This includes a goal to reduce the risk of drought and it sets a target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. It is also noted that the 25YEP has a goal of making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century, which would apply to water investment decisions.

However, there is very little specific information in the 25YEP on exactly what these targets involve (what is the metric of resilience, and what level to minimise to?), and what actions will be taken to achieve them. These could include ensuring that water companies have measures in place to offset projected deficits under more severe climate scenarios, such that the level of current resilience is maintained; or that there is a level of resilience to a drought with a particular return period e.g. 1 in 500. There is, however, a resilience objective recommended by the National Infrastructure Commission (NIC, 2018b), which is for increasing the current levels of resilience (for droughts) from 1 in 100 to 1 in 500 by 2050 (where resilience means avoiding level 4 restrictions, where supplies can be limited or cut off). The Commission estimated that this would require additional capacity of 4,000Ml/day, considering a medium emissions scenario. Greater levels of adaptation might be required under a more severe climate scenario.

In England, the main organisations responsible for managing drought risks are the water companies, Environment Agency and Defra. The water companies have a requirement to produce Water Resources Management Plans (WRMP), which cover a 25 year planning period, and drought plans, that set out how to manage security of supply during drought events. It is stressed that these plans already include projections of climate change (as a minimum, using the medium emissions scenario).

How does climate change affect the outcome, in a 2 vs 4°C pathway?

This study conducted a literature review to investigate the potential impact of climate change on the 25 YEP outcome. Previous modelling work to support CCRA2 (by HRW, 2015) has already estimated the impact of climate change (medium and high emission UKCP09 scenarios) on the supply-demand balance (with no additional adaptation action). The UK currently has a supply-demand surplus of around 2,000 Ml/d in an average dry year. However, supply-demand deficits are reported by water companies from the 2030s: with projections that 27 water resource zones will have a supply-demand deficit of greater than 5 Ml/d. The water companies are already working to resolve these issues. Looking beyond 2030s, deficits are projected to be widespread by the 2050s under a high population growth and a high climate change scenario, in the absence of any additional adaptation interventions over those currently implemented, increasing further beyond this time.

In England, changes in the supply-demand balances are projected to reach -22% and -41% by the 2050s and 2080s respectively, under high population growth and high climate change projections. The HRW study also projected that supply-demand deficits would continue to be an issue in 2050s and 2080s, even under more ambitious adaptation pathways.

In terms of extremes, current water company plans have typically focused on a 1 in 100 year event, taking account of climate change (although some companies have started applying a 1 in 200 chance of occurrence, as required by the latest water resources planning guidelines). Other recent analysis

(Water UK, 2016) has looked at high climate futures, which include scenarios of drier summers, wetter winters and higher variability (which are indicated by the recent UKCP18 projections). In these cases, the current WRMPs have greater risk of reductions in deployable output.

What are the economic costs of climate change, i.e. the effect on the outcome?
The next step in the analysis has been to assess the potential economic costs of not meeting the outcome (due to climate change). These costs would include:

- The need to implement emergency measures and related costs;
- The impacts on the economy (i.e. foregone revenues of businesses which rely on water supply);
- The direct and indirect impacts on people.

In relation to the first of these, the National Infrastructure Commission Assessment (2018: 2018b) reported that the costs of providing proactive long-term resilience are less than those for relying on emergency response. The NIC compared the short-term emergency costs of providing water during a drought, weighted by their probability of occurrence in the 2020 to 2050 period, with the whole-life costs of building long-term resilience to an equivalent event. The results show that at a national level, the cost of responding to a drought emergency are higher than those of building long-term resilience to the same event.

With respect to the impacts on the economy, previous work on the 2012 drought in England (Defra, 2013) have identified large economic costs. These assessments have also considered the costs that would have occurred under an extended drought (2 years), and estimated that under such a case, turnover losses could have amounted to just under £2.9 billion.

What are the potential additional adaptation options to address impacts on the outcome?
The study has then considered the potential adaptation options to address these potential risks and achieve the outcome. Measures to reduce current risks are already included in the draft WRMPs produced by water companies. These are expected to deliver a higher level of resilience than would otherwise be the case. However, several studies have showed that an increase in the level of investment for enhanced climate resilience is needed to address the potential challenges of future climate change. Furthermore, a broader portfolio of adaptation actions might be needed, for example to include more ambitious demand-level measures to reduce per-capita consumption, and inter-regional transfers between companies. For these measures to become effective, it is necessary to understand the existing barriers to their adoption (behavioural, regulatory, informational) and address them.

What are the benefits and potential costs of adaptation?
Water UK (2016) has estimated that a 'twin track' approach of demand management coupled with appropriate development of new resources and potential transfers is the most suitable strategy for providing drought resilience in the future. They estimated that total costs per annum for all potential future scenarios to maintain resilience at existing levels in England and Wales are between £50 million and £500 million per annum in demand management and new water resource options. If resilience to 'severe drought' is adopted, this increases to between £60 million and £600 million and for resilience to extreme drought (beyond the 1 in 100 year event) at between £80 million and £800 million per annum. Further, they estimated that the costs of maintaining resilience to 'severe' events are less than £4/customer/annum (and only increases to £5/customer/annum under drier climates, as the relative cost increases). The 'central estimate' of the benefit:cost ratio is greater than 10:1 in all cases and remains greater than 4:1, even if lower bound estimates of the benefits are assumed. There is therefore a strong economic argument for considering a strategy that provides resilience to 'extreme' drought (central estimate benefit:cost ratio of greater than 5:1); this would typically cost less than

£8/customer/annum (£10 under drier climates), compared with the 'baseline' worst historic drought resilience.

The benefits of a well-adapted water sector will be higher if all the health and environmental benefits resulting from increasing resilience are included (as highlighted also by NIC 2018b). For example, the figures above do not capture the additional economic gains from addressing social and environmental issues by protecting the ecology of water bodies through adaptation.

Key policy messages

The 25 year environment plan (25 YEP) includes a goal to reduce the risk of drought, with a target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. However, there is very little specific information on the target or actions that will be taken to achieve it. At the same time, the National Infrastructure Commission (NIC) has made recommendations to Government on increasing the resilience to droughts (although this has not yet been accepted by Government). This case study is primarily based on literature review, and has looked at previous work and the potential impact on extremes, i.e. supply/demand availability under more extreme drought events. The current water regulatory framework does include climate resilience, but there is a general anticipation that water companies will need to do more to address challenges by mid-century. Failure to address these issues is reported to lead to very high economic costs. These have been compared to the costs of enhancing resilience, and these show the cost of responding to a drought emergency are consistently higher than those of building long-term resilience to the same event, with upfront investment costs alone. The study has then reviewed the potential adaptation options to address these potential risks and achieve the outcome. Several studies report that an increase in the level of investment for enhanced climate resilience is needed to address the potential challenges of future climate change and that a broader portfolio of adaptation actions might be needed, for example to include more ambitious demand-level measures to reduce per-capita consumption, and inter-regional transfers between companies. For these measures to become effective, it is necessary to address existing barriers to their adoption (behavioural, regulatory, informational). Such an approach would involve potentially large economic costs, but would have a high benefit to cost ratio. There is therefore a strong economic argument for enhancing the strategy to provide resilience to 'extreme' drought and thus help to achieve the 25YEP outcome.

8. Ensuring all policies, programmes and investment decisions take account of climate change (with a focus on new infrastructure investment)

What is the policy objective and outcome?

The 25 Year Environment Plan (HMG, 2018) set out the ambition of taking 'all possible action to mitigate climate change, while adapting to reduce its impact', and for the latter, it set a goal of 'making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century'.

This goal is extremely broad and potentially ambitious, and the 25YEP did not set out how the outcome will be achieved, other than highlighting it would be covered in the 2nd National Adaptation Programme (NAP2). NAP2 (Defra, 2018) adopts a similar goal to the 25YEP (to ensure that all policies, programmes and investment decisions take into account the possible extent of climate change this century), but it also does not set out how the goal will be achieved. The current text of NAP2 only references the 25YEP goal in the business chapter (i.e. for the private sector), and there are no Government actions in detailed action log of NAP2 (the only reference to supporting the action is devolved to the Council for Sustainable Business, which is largely using a voluntary approach). The NAP2 does highlight the work of the Green Finance Taskforce and activities on a potential adaptation standard, but it recommends that the Adaptation Reporting Power (ARP) should use a voluntary reporting approach. At the same time, it is recognised that there are many actions in the NAP2 that will help to deliver the 25YEP goal, such as the Government policy statements, though there is a lack of an overarching framework and specific actions that link back to the goal.

Against this background, this case study has focused on one particular aspect of the 25YEP outcome, and focused down to look at one of the most important policy, programme and investment areas, which is new infrastructure investment (not including flood defence infrastructure which is covered by different policies). For this case study, we therefore adopt an illustrative outcome of making sure that new infrastructure policy, programmes and investment decisions take account of climate change. It is noted that the focus on the infrastructure investment is not explicit in the 25YEP or the NAP2 goal, but it is implicit (as the 25YEP covers 'all').

For this case study, the focus is on new infrastructure programmes and investment decisions, for three reasons. First, new infrastructure has a long life-time and could be exposed to potentially large future climate change impacts. This may result in impacts on assets (risk of damage or failure), operating costs, performance and service / benefits. Second, many infrastructure investment projects involve lock-in, or irreversibility and it is often easier and more cost-effective to build resilience (adaptation) during design (Fankhauser et al., 1999: Warren et al., 2016). Finally, climate risks are now recognised as a financial risk as with the Task Force on Climate-related Financial Disclosure (TCFD, 2017), and the Network for Greening the Financial System (NGFS, 2019), which aim to improve the integration of climate risks into public and private sector decisions. It is stressed that the case study is not considering households, and it is not focused on flood defence infrastructure, but rather new infrastructure, as classed by the CCC in their adaptation progress reports (energy, water supply, road, rail, ports, airports, digital, ICT and telecoms).

In recognition of these risk factors, the international public investment banks and several Governments have introduced climate risk management systems (CRMs) as part of safeguard processes (e.g. ADB, 2014). These assess project investments and assess the level of climate risk during appraisal, and if needed, include adaptation (resilience) measures. This is now mainstreamed in investment financing and in 2017 the Multilateral Development Banks (MDBs) spent $7.4 billion on climate resilient investments, mostly for infrastructure (MDB, 2017). However, the same level of climate risk management has not yet been fully adopted in infrastructure appraisal, investment and financing in the UK, and existing guidance in UK Government (Green Book Supplementary Guidance, HMT, 2009) has had a low uptake in appraisal (OECD, 2015).

How does climate change affect the outcome, in a 2 vs 4°C pathway?

This case study has focused on investment and financing of new infrastructure. It is also noted that in the adaptation context, there are two types of new infrastructure investment:

- Making sure planned infrastructure investments take account of climate change (often referred to as climate smart decisions). This is also sometimes referred to as climate proofing (though this term is not recommended, because it is often not possible, and/or not economically efficient, to complete climate-proof infrastructure against all risks). This is associated with climate risk screening and marginal adaptation to make infrastructure projects more climate resilient. Note this can also apply to major refurbishment or renewal infrastructure projects.
- New climate or adaptation infrastructure investment. This focuses on investments where adaptation is the primary objective, such as infrastructure (e.g. flood defences, water supply infrastructure) to address growing climate risks.

This case study is focused on the first of these, i.e. making sure planned infrastructure policy, programmes and investment decisions take account of climate change, i.e. are climate-smart. However, we also include some discussion on the second. It also considers mitigation as the UK has made commitments to significantly reduce domestic GHG emissions (the Climate Change Act 2008), and has now adopted a net zero target into law (based on CCC, 2019). It is noted that for infrastructure, this will involve public and private programme and investment decisions, through public investment, PPPs, regulated private investment, commercial investment, etc.

The case study has started by investigating the future national infrastructure investment profile. This represents also the potential lock-in risks, i.e. the new infrastructure that will be built in the next few years. In the UK, the National Infrastructure Delivery Plan (NIDP) 2016–2021 sets out the Government's commitment to £483 billion of investment in over 600 infrastructure projects / programmes to 2020-21 and beyond, of which £297 billion is planned by 2020-21 (National Infrastructure and Projects Authority, 2016). Around 50% of the infrastructure Pipeline to 2020-21 will be financed and delivered by the private sector. The average annual investment excluding social infrastructure is £48 billion.

The study has then assessed the potential climate risks to infrastructure. It focuses on new near-term infrastructure, or major refurbishment or renewal, where there is a short-term investment and thus the opportunity to make this more resilient. There are a number of issues of relevance here (Watkiss and Wilby, 2019):

- Lifetime. In general, longer-lived infrastructure has higher risks, as assets built today could be exposed to higher levels of future climate change (and potentially different risks under a 2 vs. 4°C future). However, these generally refer to the technical or engineering lifetime, not the economic / financial lifetime: the latter are much shorter.
- Level of Precaution. Some types of infrastructure merit a high level of precaution, i.e. there may be a strong case for climate over-design, such as with critical infrastructure. In these cases, there are possible major regrets if the investment subsequently fails, which may justify a greater level of resilience in design.
- Economic and financial risk. For Government, economic analysis of infrastructure investment is carried out from the perspective of the entire economy, using social discount rates, while for the private sector, financial analysis is carried out from the perspective of the investor, considering private rate of returns. This leads to greater barriers to invest in long-term resilience in projects led or financed by the private sector.

The size of climate risks also clearly varies with infrastructure type, as well as geographic location. The main risks to infrastructure in England (Dawson et al., 2016) are considered to be from flooding, noting this also dominates current risks, but windstorms are also a major risk, and heat is likely to become more important in the future. In the short-term, the main difference in projections of climate change are from uncertainties across the climate models (i.e. the 10th to 90th probability level range in UKCP18, Lowe et al., 2018) rather than from different emission and warming pathways (i.e. 2°C vs 4°C). In the long-term, existing estimates show a strong increase in risk under 4°C pathways compared to 2°C. There is also a possible risk of stranded assets under higher climate risk futures. Sayers et al (2015) report that infrastructure assets could be subject to significant increases in risk; with the number of sites exposed to the highest chance of flooding (i.e. more frequently that 1:75 years on average) increasing by 30% (under 2°C climate change projection) and 200% (4°C climate change projection) by the 2080s. There is an interesting issue on who bears these risks, especially for PPP projects. If infrastructure investment decisions / finance takes account of climate change, then these impacts are reduced, but if they do not, then the 25YEP outcome could be missed. The case study identifies a gap in current policy.

What are the economic costs of climate change, i.e. the effect on the outcome?
Some of the climate risks to infrastructure are already being addressed, but where these are not, there will be additional costs. Therefore, not achieving the outcome would mean additional costs, affecting not just capital infrastructure, but also the services that infrastructure provides, with the potential for indirect costs. There are not many estimates of the future costs of climate change on infrastructure: most studies are focused on the costs on property damages, and it is also difficult to estimate the full costs including on infrastructure services. The estimates that do exist suggest large increases in

economic costs from current levels, with much higher costs in the long-term in 4°C pathways. Recent reports in the financial markets has also highlighted that properly accounting for physical climate risk could - on average – reduce company values by 2-3% due to the costs of insuring assets (if these risks are not managed and reduced), and more than this in some sectors (Economist, 2019).

What are the potential additional adaptation options to address impacts on the outcome?
The starting point for this step is to review the existing adaptation in place, and the additional actions that might be taken to reduce the outcome gap. It is noted that adaptation action for the infrastructure sector includes not only technical (engineering) options but also regulatory, policy and institutional responses, to enhance the adaptive capacity of infrastructure systems.

The CCRA2 Evidence report (Dawson et al., 2016) highlighted evidence that significant adaptation steps to manage climate change risks have been implemented, or are underway, across most infrastructure sectors. However, it also reported these investments will maintain or, in some instances, reduce climate risks over the next decade or two, and that on longer timeframes, projected changes in climate are likely to outpace current adaptation plans. NAP2 sets out existing activities on infrastructure resilience and there has been further work under the National Flood Resilience Review. Nonetheless, the analysis here identifies that there is a potential adaptation gap, i.e. the difference between the current level of adaptation and the level required to address the risks identified. It is noted also that most attention to date has focused on flood risks, with less consideration of other hazards. There is also a growing concern of the increasing interdependencies of infrastructure, which means that as well as sectoral guidance there is a need to have an integrated approach (Dawson et al., 2016).

While there are many good examples, the systematic inclusion of climate risk management in public investment programmes and decisions is not well advanced, and there are major gaps in the policy landscape for CRM in the private sector. There is a role for the Government to address these gaps, because of its role in developing and financing public programmes and investment decisions, and because it can create the enabling environment for private adaptation, including in public-private partnerships (Cimato and Mullan, 2010: HMG, 2013).

The main focus for the case study is on climate smart early decisions with long life-times and lock in. However, uncertainty (on future scenarios and from uncertainties within and between climate models, i.e. the 10^{th} to 90^{th} probability level range in UKCP18) makes these early investment decisions challenging. It is relatively easy to design a new investment to be resilient to a single future, but much more difficult to design it to cope with deep uncertainty (noting over-designing projects to cope with the most extreme scenario involves the likely mis-allocation of resources and risk of economically inefficient adaptation). In response, there has been a move to decision making under uncertainty (DMUU). This includes (Watkiss et al., 2014) techniques such as adaptive management, real options analysis, robust decision making, portfolio analysis; decision scaling and decision rules. These address uncertainty with various principles (learning, flexibility, robustness, hedging and minimising regrets). However, these methods can be complex to apply, require detailed data, and are time consuming and resource intensive when applied formally, which can limit applicability.

A number of additional adaptation options have been explored. These include:

- Supporting decision-making by providing tools and information;
- Screening climate risks (climate risk management) in public investments;
- Screening climate risks (climate risk management) in private sector investments;
- Enabling infrastructure resilience through policy and regulation;
- Encouraging the disclosure of climate risks/uptake in commercial finance
- Supporting innovative risk spreading (insurance).

What are the benefits and potential costs of adaptation?
The evidence base on the potential costs and benefits of adaptation in this area is low (ECONADAPT, 2017), and estimates are dependent on objective, method, risks and discount rates. Previous studies have derived first order estimates of the costs of adaptation by applying an uplift to infrastructure investment pipelines (e.g. OECD, 2015). Applying this approach to the NIDP economic infrastructure pipeline, using more recent estimates of the uplifts found from project implementation (ADB, 2014b: ECONADAPT, 2017), we estimate that the indicative total adaptation cost of building climate resilience in the current economic project pipeline would be £2.1 billion to £42 billion (primarily over the period to 2021), with an annual cost of £0.2 billion to £4.8 billion. This is a significant amount. Some of this may already be factored into the costs, but it is likely there would still be additional financing needs.

In practice, costs will range significantly with sector and context. There are some studies in the UK on infrastructure resilience costs, but these tend to be focused on the costs of major resilience works, i.e. flood defence measures (e.g. NIC, 2018: EA, 2019), rather than the costs of climate-smarting new infrastructure (although flood protection would provide more comprehensive protection for all assets, including infrastructure). It is also highlighted that there is ongoing work on the economics of infrastructure adaptation within the International Financial Institutions (ADB, 2015: MDBs, 2017: Hallegatte et al., 2019), which highlights that there are different approaches for building resilience, with different costs. The decision on which of these to do is determined by particular climate risk and economics, as well as lifetime, degree of lock in (cost of retrofitting later) and level of precaution. Emerging work is looking to standardise approaches within sectors (Watkiss and Wilby, 2019), to aid this decision-making process. Early experience has also identified financial and implementation challenges with many of the approaches recommended in the literature, i.e. those that use iterative (adaptive) management. This is because there are barriers to these options, due to the need for long-term monitoring and institutional capacity, as well as sequenced financing. A further set of recommendation are therefore included to advance the economics of adaptation, and to investigate how to incentivise adaptive management in financing.

Finally, there is also an issue of ensuring adaptation and mitigation synergies with planned investment in new infrastructure to reduce UK greenhouse gas emissions, consistent with the existing and proposed UK's long term GHG emission commitments (CCC, 2019).

Key Policy messages
This case study assesses whether the Government is on course to achieve this goal, focusing on the area of new infrastructure. It is stressed that the case study is not considering households, and it is not focused on flood defence infrastructure, but rather all other new infrastructure. The analysis looks at policy, programme and investment decisions for infrastructure, noting this involves public and private sectors, and includes all infrastructure investment not just targeted resilience infrastructure (such as flood defences). These investment levels are very large, for example, the average annual investment set out in the National Infrastructure Delivery Plan is £48 billion/year.The analysis finds that the current actions (in the 25YEP and NAP2) are insufficient to deliver the goal. While there is growing action in the public sector, and to a lesser extent in the private sector, there remains a sizeable adaptation gap. It is also noted that other countries and in particular the Multilateral Development Banks have gone further than the UK to date in integrating climate change into new infrastructure design.

Initial analysis in the case study finds that the additional adaptation needed to achieve the 25YEP goal could involve large additional costs (with an annual cost of £0.2 billion to £4.8 billion) and to deliver this efficiently and effectively, there is a need for enhanced appraisal. The benefits of such adaptation actions have not been calculated to date. A number of further adaptation options (to those currently inNAP2) have been identified which could help deliver the goal. These are primarily around creating the enabling environment for climate risk management (CRM) and adaptation appraisal, in both the public and private sectors (including how to incorporate climate risks and adaptation responses in public-private partnerships, PPPs). To support the 25YEP goal, a recommendation is made to revise and disseminate the Green Book supplementary guidance on climate change adaptation, along with support to enhance uptake of climate risk management in public investment decisions (given that there are no solid examples of where it has been used to date in infrastructure investment decisions). It is also highlighted that there is a need for greater Government action to support and enable the private sector to adapt. Underpinning all of this, there is a need to progress the economic appraisal of adaptation, as well as to develop sector specific guidance and norms to help facilitate uptake of effective and efficient resilience measures for new infrastructure. Finally, looking over the period of the 25 YEP, there will need to be more investment in resilience infrastructure, but also a need to ensure synergies with low carbon infrastructure to achieve the long-term emission reductions targets recommended by the Committee on Climate Change in their Net Zero Report (and now adopted by Government into law).

9. Increasing production and exports of English wine

What is the policy objective and outcome?

The 2nd National Adaptation Programme (Defra, 2018) highlights the potential for profitable and productive agriculture and forestry sectors to take the opportunities from climate change. This outcome is focused on one such example opportunity, for English wine production and exports. There is no specific policy objective for English wine production, and this was not identified in NAP2. However, in 2016 the English Wine Round Table with the Wine and Spirit Trade Association and Defra made pledges to increase the hectares of vineyards from 2,000 to 3,000 ha by 2020, and to increase wine production to reach 10 million bottles in 2020, with the ambition that 25% of this would be exported, generating £30 million in export revenues (WSTA, 2016). Looking further, Wines of Great Britain has estimated that in 2040 annual production could reach 40 million bottles (WGB, 2018). This case study focuses on the potential influence of climate change on these outcomes. It is different to others in this study, as it investigates how climate change could make possible these future outcomes easier to achieve, and what action is needed to ensure these opportunities are realised.

This case study uses the 2020 goal (10 million bottles/year) as a current target, with an interim outcome of 20 million bottles per year by 2030, on a pathway to 40 million bottles per year by 2040. An outline logical framework was developed for this, although it is noted that this is a productivity outcome, while the success of the English wine sector will be due to quality as well as quantity. The UK is currently a major wine importer (of the wine consumed, only 0.1% is produced domestically (HoC, 2016)), thus increased production of wine will have positive trade effects, whether this results in increased exports, or reduced imports. It is stressed that the impact of Brexit will clearly have large consequences for the wine sector, but as these are extremely difficult to predict currently, we have not considered the impact of Brexit on this outcome.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The current climate has a major influence on wine suitability, as well as productivity and quality (Irimia, 2012; Jones, 2015). The impact of climate change on wine production in England is generally reported to be positive (Nesbitt et al., 2016; Hannah et al., 2013), because of the shift to a more favourable (warmer) climate for grape growing, therefore making the outcome above potentially easier to achieve, or leading to higher production (exceeding the outcome). The first step has been to assess the effect of climate change on the outcome under a 2 and 4°C world. There are some literature studies on climate change and wine in England. These are generally positive, for example, they report that 2°C of warming is likely to change England into an 'intermediate climate' wine region, i.e. a major positive outcome compared to the current climate (Georgeson and Maslin, 2017). Extrapolating further, 4°C of warming could make England into a 'warm' wine region. Therefore, while climate change could open a range of opportunities for growing different varieties of grapes which are currently cultivated in Europe, the level of warming will affect the type of opportunity.

This study has reviewed the literature to understand the potential effects of climate change on English wine, considering the new UK Climate Projections 2018 (UKCP18, Lowe et al., 2018). The latter reports an increased chance of milder, wetter winters and hotter, drier summers along with (generally) an increase in the frequency and intensity of extremes. Rising temperatures will increase average growing season temperatures, and have positive effects on English wine production (Georgeson and Maslin, 2017) (and probably quality). However, wine is also affected by temperature variability and extremes, notably from the frequency and intensity of mid-winter low temperature, late spring frosts, and the influence of excessive summer heat (Fraga et al. 2012; Jones, 2015; Mosedale et al. 2015; Nesbitt et al., 2016). The effects of climate change on these events (frequency and intensity) in England is more uncertain, and is not necessarily positive. There will also be changes from the amount and timing of rainfall and water availability (Jones et al., 2015). These may be positive, but could also include some downside risks from too much, or too little rainfall: these depend strongly on the timing of rainfall during the growing cycle. There are also possible changes in the range and prevalence of pests and diseases. Finally, CO_2 concentration levels from climate change will also have an influence on wine productivity and quality, although these effects are complicated (Fraga et al., 2012; Schultz, 2010; Wramneby et al. 2010). Therefore, while there is support for a positive effect of climate change on English wine (and the outcomes above), other changes could have negative impacts. As an example, higher yielding years might involve warm springs and autumns and the absence of frosts at critical times, while low yielding years might involve wet and cold weather during flowering, wet and cold growing seasons, and/or spring frosts. It is stressed that climate change will also have impacts on wine growing regions in Europe, and for many of these areas there are large projected impacts from climate change (Hannah et al., 2013): this will also have important implications for English wine (on both the supply side and in terms of comparative advantage, as well as in terms of demand for wines and prices).

What are the economic costs of climate change, i.e. the effect on the outcome?
The case study has quantified, in monetary terms, the possible effects of climate change on the outcome. We have found no available studies that have assessed the economic benefits of climate change on wine production in England, and there are only a few studies on the estimated changes in productivity. To explore this area, the case study has therefore undertaken some sensitivity analysis. The starting point is to look at the economic value of achieving the baseline outcome. Using the retail value of the bottles produced – 10 million bottles in 2020 would be worth between £57.9 million and £200 million (for average and high value bottles). An increase to 20 million bottles in 2030 would be associated with a retail value (current prices) of between £116 million and £500 million, and 40 million bottles in 2040 at between £231 m and £1 billion (average and high value bottles respectively). This does not include the export revenues, nor the wider benefits to the economy (duties, VAT, income taxes and employment). However, it is noted that the short-term production levels, the 2020 goal, will be very challenging to achieve as it would require increasing production above current levels (which are approximately 4 – 5 million bottles) significantly. The achievement of the 2030 and 2040 targets is considered more feasible, requiring an annual (CAGR) 7% increase in bottle production.

The next step is look at 1) how climate change might make the outcome more easily achievable or increase production above the target and 2) the potential risks of climate variability on the outcome. The study has undertaken ‘what-if’ assessments of the potential financial benefits. Current production in English vineyards is much lower than in Europe - climate is a major factor in this (Nesbitt et al., 2016) though not the only reason.

The case study has undertaken a sensitivity analysis. This assumes that climate change leads to a 10% to 25% increase in production (due to climate change) above the 2030 target, i.e. an additional 2 to 5 million bottles in the year 2030. This would have an annual retail value of between £10.8 million to £50 million (10%) and 26.95 million up to £100 million (25%), with the range reflecting average and high value bottles prices. Similarly, a 10% increase above the 2040 target (4 million bottles in the year

2040) would translate to additional revenues worth between £21.6 million and £80 million in 2040 (current prices). Finally, a 25% increase would lead to benefits of between £53.9million and £200 million, and a 50% increase, between £107.8 million and £400 million in 2040. These would increase gradually from current levels, with production increasing on average year by year (noting high annual production variability). The cumulative financial benefits (up to 2040) from climate change could therefore be very large. There is also a further benefit if climate change impacts on wine growing areas in other countries negatively (as projected), creating increased export opportunities for England.

However, there is also the potential for downside risks to increase under climate change in England. As set out above, increased climate variability can have negative impacts on wine production and quality, and could offset some of the benefits resulting from a warmer climate, although there is insufficient information to estimate how important these changes might be. Further, there are a number of threshold effects: while there is likely to be a fall in lower temperature threshold levels for wine growing, possible threshold risks are identified around water availability, and the temperature suitability ranges (and heat limits) for some current colder temperature wines.

Finally, it is also highlighted that the expansion of cultivated area for wine (new planting) involves long life-times and considerable lock-in, because it involves land-use change and high capital investment. The payback period on wine is longer than for many other agricultural crops, because of the time to mature. This means that early decisions on new expansion areas in the short- and medium-term need to consider the medium and even longer-term climate.

What are the potential additional adaptation options to address impacts on the outcome?
The case study has reviewed the existing activities for mainstreaming climate change in the sector. There is an active programme of support to help the wine industry develop opportunities, but the review here has not found a strong climate component to current activities. The case study has therefore investigated further adaptation options that could be introduced to seize the opportunity presented by a warming climate, as well as to reduce risks associated with possible climate variability.

Adaptation options have been identified and prioritised to identify early options (i.e. for the next five years or so). In terms of the opportunities from climate change, the immediate focus is for the Government to provide the enabling environment for the wine industry to take advantage of the positive changes in suitability and productivity. In 2016, Defra pledged to gather and make available information on soil types, water resources, and infrastructure networks to identify the best areas of land for production; and the Government has identified 75,000 acres across the country suitable for sparkling wine production. That is the equivalent of the Champagne region. However, work on this is still at a very early stage, and further work is needed to expand this analysis to take account of climate change. This is particularly important given the lock-in involved with the expansion of wine production areas, i.e. for wine investment decisions in the next decade.

In terms of the risks of climate change, climate variability already affects the English wine sector (Nesbitt et al., 2016). Enhanced adaptation to address current climate variability would be a no- or low-regret response. Winegrowers already have to address these risks, and adapting to variable conditions is a part of good viticulture practice, but the benefits of enhanced measures is highlighted. There are many lessons that can be drawn from other countries that already experience higher variability (including extremes that would be new for the UK, such as heat). The case study has reviewed some of these options, drawing lessons from existing practice in France (e.g. Neethling et al., 2014): this provides potential options for adoption in England, including for managing water deficits.

In terms of early actions to address long-term change, an enhanced focus on monitoring, information and surveillance is highlighted, for both climate as well as pests and diseases. There is a clear role for

Government to support these early actions, to address existing information barriers and create an enabling environment for the private sector (for opportunities and risks from a changing climate).

What are the benefits and potential costs of adaptation?
Finally, the study has undertaken a high-level analysis of the potential costs and benefits of additional early adaptation. This indicates that under a scenario where wine growers were able to realise the benefits of climate change due to better information (and appropriate response), and at the same time introduce adaptation measures to address potential variability risks, there would be very large economic benefits (£0.6 billion present value by 2040, around $70mpv/year), and a high benefit to cost ratio.

Key policy messages
Climate change is projected to increase the achievability of these outcomes, improving the agro-climatic conditions and productivity of English wine. By 2040, climate change could mean that England has become an 'intermediate climate' wine area, with higher suitability than today. After 2040, there are different future wine climates depending on a 2 vs. 4°C pathway. However, wine is also affected by climate variability, which along with a potential decline in summer precipitation, could have negative impacts. It is also highlighted that decisions to expand wine production in the short-term involve long life-times and lock-in (land-use change) and so decisions on new vineyards/varieties need to consider the future climate. The study has also assessed potential adaptation options. In terms of opportunities, the immediate priority is for the Government to create the enabling environment for the wine industry to take advantage of enhanced suitability. There is also a need to increase the uptake of no and low-regret options to address variability, noting there are examples from current wine growing countries. Finally, given the changes in wine suitability, there is an early priority to enhance monitoring, information and surveillance, and to provide iterative support over time to the wine sector. The key conclusion is that climate change could help increase the achievability of production outcomes, but only if Government creates the enabling environment. Such action was found to lead to large economic benefits for the English wine sector, with a high benefit to cost ratio.

10. Ensuring the food supply chain is resilient

What is the outcome?
Food system resilience (also sometimes referred to as food supply chain resilience) is defined by Global Food Security (GFS, 2018) as the system's capacity to maintain a desired state of food security when exposed to stresses and shocks. The 2nd National Adaptation Programme (Defra, 2018), has a specific action to "Ensure a food supply chain which is resilient to the effects of a changing climate". This considers both domestic and international food supply chains.

This case study focuses on the NAP2 action above (the outcome) and considers how climate change could affect food supply chain resilience. It also assesses the potential adaptation options to maintain and enhance resilience, and thus ensure the outcome is achieved.

It is highlighted that there are already activities in this area. In the 2018 Cabinet Office Resilience Sector Plans (Cabinet Office, 2018), the Government set out how it and the sector will work together to ensure the resilience of food supply. This builds on recent research into the resilience of food supply (with the Food Chain Emergency Liaison Group) and building resilience in supply chains to extreme weather events. Furthermore, food supply is included as one of the 13 Critical National Infrastructure sectors. NAP2 sets out that Defra produces an annual Sector Resilience plan and is currently carrying out a review of the UK Food Security Assessment, due to be published in 2019. Climate change will be considered and highlighted as a risk (and possible opportunity) in this review. It is also noted that the impact of Brexit will have very large consequences for this sector, but as these are extremely difficult to predict currently, we have not considered the impact of Brexit on the outcome.

How does climate change affect the outcome, in a 2 vs 4°C pathway?
The UK imports food from over 180 countries (which comprises around 50% of food consumed) and this ensures that absolute UK food supply is resilient to supply interruptions from specific countries and from disruption to domestic UK production – although this does leads to new risks (Defra, 2017b; Defra, 2018). Current climate risks for the food supply chain primarily arise from extreme events (Tröltzsch et al., 2018), and these risks are generally managed in the short term by rationing through price or quantity and in the long term by supply diversification and switching sources of supply (UK Foresight, 2011).

Climate change will affect the productivity of food production (supply), and patterns of extreme events, and so it will potentially affect the delivery of the outcome (a resilient food supply chain). These impacts could include (UK Food security Assessment, 2010; Porter et al., 2014; GSF, 2012; 2018):

- Negative impacts on food prices from effects on production in domestic and global food markets.
- Changes in production of primary food produce, both from changes in agro-climatic shifts, but also from changes in the patterns of extremes. The literature generally reports that these changes will be modest for 2°C of warming, but are generally negative (for many regions) above this. This means there will be major differences between 2 and 4°C futures. These effects may also arise from changes in pest and disease prevalence and range, impacts on food manufacturing, etc.
- Damage to facilities, buildings, equipment and products involved in the food production process, including loss of water and power for production;
- Disruption to the transportation of raw materials, labour, capital or finished goods and services associated with the food supply chain.

Climate change could lead to a 20% (mean) food price rise in 2050 globally, but with a large range from 0% to 60% (Nelson et al., 2014) across the models. - yield losses and price impacts rise more sharply in later years under higher warming scenarios. However, this needs to be translated into food supply chain effects. In the short to medium term (to 2040), the potential impacts vary most strongly with climate uncertainty (i.e. the 10th to 90th range from UKCP18, Lowe et al., 2018) and are likely to be dominated by extremes and shocks. For example, Allianz Global Corporate & Specialty (2012) estimates that 70% of damages by extreme weather events are linked to supply chain and procurement risks, such as disruptions and delays in delivery. Allianz Global Corporate & Specialty (2012) estimates that 70% of damages by extreme weather events are linked to supply chain and procurement risks, such as disruptions and delays in delivery. Beyond this time, i.e. after 2050, the impacts are projected to vary strongly with the future emission path (i.e. 2°C vs 4°C). However, the risks from climate change to the food supply chain in England are likely to manifest themselves in the price levels of food products rather than their physical availability. Our expert judgement is that although there are market mechanisms currently in place to mitigate the effects of food price hikes and volatility, the short-term economic and social costs from climate related disruption could be significant.

Compared to other risks, there is much less lock-in invested in global supply chains, because of the potential to shift to alternative suppliers over the relative short-term (although there is lot of lock-in for producers, because of land-use change). However, there are a number of threshold risks that are associated with food supply chains and recent studies have considered climate and socio-economic tipping points (GFSP, 2017) could have significant effects on UK Food production areas, as well as on food security.

What are the economic costs of climate change, i.e. the effect on the outcome?
Ray et al. (2015) estimated that, globally, for substantial areas of the global breadbaskets, climate variability accounts for roughly a third of the observed yield variability. In the context of the outcome and the short-term policy focus, it is likely that there could be short-term price increases as a result of

such national or international extreme weather events, but these will be of short duration. Recent historical examples in the global wheat market provide evidence of such effects, with short-run (< 1 year) price increases of 40% (JRF, 2016b) observed for major shocks in 2006-2008 and 2010-11. This level of impact gives an indication of possible levels for future periods. These events are likely to result in greater price volatility with associated costs both for the consumer (in periods of higher prices) and producer (where prices are uncertain leading to less investment in agricultural productivity), and have been observed in UK analysis (JRF, 2016b). In principle, such costs could be quantified using macro-economic simulations, and under alternative climate scenarios; in practice, to date, these have not been undertaken.

What are the potential additional adaptation options to address impacts on the outcome?
As highlighted above, there are already actions being taken to build the resilience of food supply chains (CCC, 2017; Defra, 2018). Most of the focus has been on the private sector. Businesses will take adaptation actions when the benefits of doing so outweigh their (private) costs (Cimato and Mullan, 2010), however, the great complexity of supply chains and their multi-staged processes, coupled with the uncertainty around climate change impacts, indicates that the private sector might struggle to take all the appropriate actions. The Government could therefore play a role in removing some of the barriers to enable and encourage private sector adaptation, as well as ensuring a higher level of resilience along supply chains e.g. for infrastructure. Since many supply chains have international dimensions, there is a role for a multi-national co-ordinated regulatory structure in the food commodity markets that are most vulnerable to climate-related supply-side shocks. As a further example, under the auspices of the current Food Sector Resilience Plan, Government could further encourage the development and up-take of insurance instruments that protect both domestic and international actors in food supply chains. Finally, open trade policies could be pursued in order to encourage diversification of suppliers of critical food commodities/products.

The case study has identified a range of adaptation options that might be effective in reducing food supply chain impacts and building resilience. It is highlighted that these adaptation options may be undertaken by a range of actors, both domestically and internationally. These include early low and no-regret options, as well as a need to make sure infrastructure and land-use decisions are climate-smart. It also includes a greater focus on adaptive management, research and learning. For the latter, one early priority is to identify possible hot spots (regions/countries which already show vulnerability to weather events and food production and transport disruptions), and how these might change under longer-term 2^{o}C vs. 4^{o}C pathways. This would help understand the scale of future vulnerability of the UK market under different scenarios, and provide a stronger rationale for action.

What are the benefits and potential costs of adaptation?
There are some aspects of climate change risks and responses that have been quantified for food supply chain resilience, but there is little information on the associated costs and benefits (in aggregate). However, for each identified measure, we identify some key features of the economic data required. This is highlighted as an area for future case study analysis.

Key policy messages
Climate change will make it more challenging to deliver the NAP2 outcome on ensuring a resilient food supply chain. In the absence of adaptation, this is most likely to be felt through greater price volatility with associated costs, rather than as supply availability. While there are already activities in place to manage these risks, the potential size of climate change effects indicates that there would be benefits in scaling up responses, particular with a role for Government to remove the barriers to enable and encourage private sector adaptation, and to encourage a higher level of resilience along supply chains.

5. Discussion and Recommendations

Impacts of climate change on the outcomes

The key finding of the study is that in nearly all cases, climate change will make existing Government outcomes more challenging to achieve. This is the most important finding of the study. In most cases (but not all), there is insufficient consideration of climate change risks in current policies and activities, i.e. climate change is not being adequately mainstreamed. As a result, it is likely that many Government outcomes will be not be met due to a lack of appreciation of the risks. There were, however, two exceptions to this finding. The first was for English wine production, which was chosen specifically to consider a potential benefit on an outcome. The second was for green infrastructure, where climate change might influence the demand for the outcome (more GI), because of its potential role as an adaptation option.

The study also provides a number of key findings.

Outcome based analysis

The first conclusion was that the application of this approach – assessing the potential impacts of climate change on Government outcomes - was challenging for a number of reasons:

- Most of the existing Government outcomes considered did not have a published logical framework, and most did not have well defined and measurable outcomes. This made it difficult to assess the impact of climate change or adaptation.
- There was often a mismatch in timing between the long time-periods involved in climate change, versus the short-term focus of departmental objectives and outcomes. Where targets were long-term (e.g. in the 25 Year Environment Plan) they were often aspirational (and not defined quantitatively).
- The impacts of climate change were often quite uncertain, and varied strongly with the climate projections, which made it harder to assess the potential impacts on the outcome.
- There was often not good (quantitative) information on the benefits of existing and future adaptation (on risks), and it was often difficult to assess the case for additional adaptation, i.e. in addition to what is set out in NAP2.
- Assessing the costs and benefits of adaptation was particularly difficult, due to the lack of existing quantitative information, and the need to think about decisions under uncertainty.

Nonetheless, a number of findings emerged from the analysis of the case studies, set out below.

Defining measurable outcomes

To understand what the outcomes mean and how progress is being made in achieving them, there is a need for clearer Government objectives, and a solid theory of change and logical framework with defined and measurable outcomes. In nearly every case, the existing Government outcomes did not meet these criteria. This was particularly true for many of the targets in the 25 Year Environment Plan, but it was also the case for NAP2. As an example, both these documents outline a goal of 'resilience' in many areas, but do not define what resilience is (or how it will be measured), and they do not define a target level of resilience (i.e. to maintain current levels, to reduce to the optimal level based on costs and benefits, to prevent all future risk, etc.). In the absence of concrete outcomes, the study team and CCC secretariat had to build up a theory of change and to further define each outcome, to allow a more quantitative analysis. Following from this, a first recommendation is that Government targets, especially in the climate and resilience domain (and notably in the 25YEP and NAP), need to move away from aspirational goals towards more defined and measurable outcomes. This will also help stimulate the necessary policy discussion and stakeholder dialogue on what target levels are appropriate.

Moving beyond 2 versus 4°C to uncertainty

An interesting finding, widely acknowledged in the scientific literature, but less so in policy making, is that there is little difference between 2 and 4°C scenarios before 2050, and thus on short-term outcomes. This is because of the time lag in the climate system. This therefore applies to the longer targets in the 25YEP target (i.e. to 2043). The main differences (between 2 and 4°C futures) only arise after the mid-century. However, there is a very large difference in short-and medium-term impacts across the range of climate model projections, driven by model uncertainty and natural variability (i.e. between the 10th to 90th percentile values in the UKCP18 climate projections), and, this can make a dramatic difference to the achievability of outcomes and it influences the level of adaptation needed significantly, even in the near-term.

This can be seen clearly in the plot below, using data from the UKCP18 projections (Lowe et al, 2018) for the change in average temperature and precipitation. There is very little difference in the mid-century climate (2041-2060) between the 2 and 4°C pathways (as captured by RCP2.6 and RCP8.5). This is shown below as the 2°C (RCP2.6, green circles) and 4°C (RCP8.5, red triangles). However, there is a huge difference across the probabilistic-like projections, e.g. between the 10th, 50th and 90th. (shown from right to left). As an example, taking the 50th value, there is only 0.4°C of difference in warming between a 2 and 4 pathway in the 2050s, and only a 2 to 4% difference in rainfall change. In contrast, even for a single RCP scenario, there is over 1.5°C of difference between the 10th and 90th, and the rainfall potentially differs in sign.

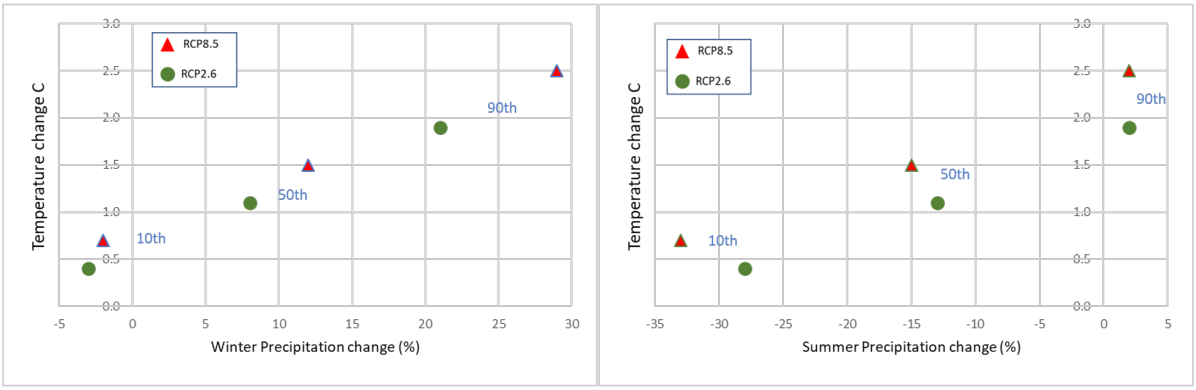


Figure 3 Plot of Annual Temperature change versus Winter Precipitation (top) and Summer Precipitation – for the 2041 – 2060 period, relative to 1981-2000 for RCP2.6 (green) and RCP8.5 (red) from left to right, 10th, 50th, 90th. Source UKCP18.

It is recognised that the issue of climate change uncertainty is complex, and often can act to confuse stakeholders, making it less likely that they take action. At the same time, there is an important mitigation story to advance, that highlights the need for UK mitigation as part of the contribution to global policy commitments, notably the Paris Agreement 2015 which agreed the goal of 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C' [Article 2a]. For this reason, this study, and the CCRA2 and CCRA3 have used a policy narrative about the differences between 2 versus 4°C pathways.

It is stressed that based on current emissions and mitigation pledges (UNEP, 2018), the anticipated level of global warming is approximately 3°C by 2100, with warming continuing afterwards: this means that if the current emissions gap (between current pathways and those necessary to achieve the necessary emission reductions) is not closed by 2030, it is very likely that the goal of limiting warming to below 2°C will be out of reach. This highlights that for Government policy, the consideration of both

2°C and 4°C pathway is paramount, i.e. it is not sufficient to plan for 2°C only. However, in terms of the impact on existing Government outcomes, there is a much larger difference likely, depending on which climate future emerges (as project by the range across the models).

This suggests that to manage risks, Government policy should therefore consider more than just the central (50^{th}) estimates. This is something that has rarely been undertaken to date - the case studies show that many existing adaptation policy responses have mainstreamed using central projections, and thus may be missing important (and likely) risks of climate change on outcomes. This highlights there is a need for policy to consider uncertainty (not just 2 vs 4°C central values). It is stressed, however, that the consideration of more extreme outcomes (high emission pathways, 90th values) should not be taken as signal to over-design to all possible futures, because this could be a very costly and highly inefficient response, instead it requires the consideration of these outcomes and consideration of risk aversion and decision making under uncertainty.

Lock-in

In nearly every case, the activities associated with Government outcomes– even over the next five years - involve a risk of lock-in. This means that decisions associated with the policy in the current policy cycle (or action not taken) will lead to increased climate risks in the future, that will be difficult or expensive to address later. For example, there is a large portfolio of new infrastructure planned under the National Infrastructure Delivery Plan (£483 billion to 20/21 and beyond), that is long-lived and will be exposed to future climate change: the opportunity for climate smart design of this infrastructure is now. Similarly, there are a large number of new houses planned (Budget 2017 set out an ambition to deliver 300,000 new homes a year in England) and these could be built with consideration of overheating risks, otherwise they will lock-in future risks (for example, measures to reduce over-heating in houses are much more expensive to retrofit option than to include in new build, (Wood Plc, 2019: Defra, 2017)). Even for potential opportunities, there is a need to plan for the future not just the current climate, for example, land-use change for new wine production needs to consider the changing climate in varietal choice, given the high capital expenditure and long time periods involved. This finding has important implications. It emphasises the urgent need to increase adaptation action now, even in the short-term. The study has explored the potential costs of this lock-in risk, and finds that in many cases, the lack of early action could be very significant in economic terms, but also that it could be avoided by making sure current investment and policy decisions are climate smart.

Early Additional Adaptation

There are cost-effective early adaptation options that can address climate risks, i.e. that can shift existing Government outcomes back on track. However, the case studies identify that currently, there is insufficient adaptation happening. Importantly, very little of the necessary adaptation will happen autonomously, i.e. the market and individuals will not deliver it on their own. In all cases, the case studies found there is a clear rationale for further Government intervention, even though this often only requires Government to create the enabling environment, i.e. it does not necessarily require a large increase in public adaptation budgets.

Iterative climate risk management / Adaptive management

For many outcomes, there is a critical opportunity (now) to introduce iterative climate risk management – often called adaptive management - to ensure a cycle of learning and revision to inform future policy cycle and responses. This is considered particularly important for a number of areas where there are long-term risk or opportunity pathways (fisheries policy, animal and plant disease, soil health, and wine production).

These approaches are sometimes referred to as adaptation pathways, but recent review (as part of the CCRA3) has found this term is used in for several different methods, some of which are more suited to the project level[4]. For Government outcomes, the main focus is to introduce the need to evaluate and review adaptation over time, as part of iterative approaches.

Is Climate Mainstreaming Working?

One final question that follows from the analysis above is why this adaptation gap exists. The UK is now on its 3rd UK CCRA cycle. However, the mainstreaming approach used by the UK Government does not appear to be necessarily delivering an optimal level of adaptation, and as a consequence, this looks likely to affect the delivery of existing Government objectives.

Recent analysis has reviewed the lessons (the critical factors) for successful mainstreaming (OECD, 2015:WRI, 2018). This identifies:

- A science-first (technical) approach for adaptation tends to lead to insufficient focus on mainstreaming and insufficient consideration of institutional and organisational issues, i.e. the actual delivery of adaptation.
- Effective mainstreaming requires the identification of suitable entry points in the policy process, notably in sector policies and programmes. There are also key window of opportunity, when these policies are being developed, when mainstreaming is most likely to succeed.
- The presence of a high-level national champion and/or the involvement of strong Ministries (such as economic and planning ministries, i.e. ideally Treasury or Cabinet Office) are important.
- There needs to be the finance availability to fund the marginal costs of climate mainstreaming: with a recognition that an additional cost is likely to be involved.
- Technical assistance and capacity building support are important in effectively delivering mainstreaming across Government, especially in departments that have not historically been a major focus for climate risks.
- Policy frameworks (and commitments) are needed to help push forward the process of mainstreaming.
- The presence of co-ordination mechanisms across Government, that support mainstreaming goals, are important, and finally;
- There is a need for information and tools.

An initial review as part of this study has identified that at the time the 1st CCRA was being developed (around the year 2008), almost all of these success factors were in place. At the current time (2019), the picture is more mixed. The underlying legal and policy frameworks for climate adaptation in the UK remain strong (with the Climate Act and CCRA cycle) and there is information on risks from the UKCP18 and CCRA Evidence reports. However, this does not appear to be translating into effective domestic adaptation action. To illustrate, not even the 25YEP has adequately integrated climate change, and this has subsequently led to insufficient uptake in subsequent policy, as for example, with the omission of climate change in the new fisheries policy, or the potential for a missed opportunity to use Green Infrastructure as an urban adaptation option. This indicates that further action is needed to integrate climate change (to mainstream) in Government policy, programmes and investment decisions. Based on the analysis here, we recommend that this might be advanced through a greater focus on climate risk assessment in Government policy appraisal and evaluation, including regulatory impact assessment.

[4] For example, this includes methods that identify thresholds that act as adaptation tipping points or turning points (Werner et al, 2013). These are often presented as dynamic adaptation route maps (also called adaptation pathways): these route maps show a number of alternative pathways and options, such as studies for Thames Estuary 2100 study, (EA, 2011: Reeder and Ranger, 2011) and in the Netherlands, with Dynamic adaptation policy pathways, Haasnoot et al 2013.

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Appendix 1. Long list of Possible outcomes

NAP2 / Progress report chapter	Adaptation Priority	Relevant Outcomes
Natural environment	Terrestrial habitats	25YEP: (by 2043) restore 75% of our one million hectares of terrestrial protected sites to favourable condition, securing their wildlife value for the long term
Natural environment People and the built environment	Terrestrial habitats Freshwater habitats	25YEP: (by 2043) creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits
		25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
		25YEP: (by 2043) increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042
		25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
	Freshwater habitats Marine and coastal habitats	25YEP: (by 2043) reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per our River Basin Management Plans
		25YEP: (by 2043) restore 75% of our one million hectares of freshwater protected sites to favourable condition, securing their wildlife value for the long term
		25YEP: reducing the damaging abstraction of water from rivers and groundwater, ensuring that by 2021 the proportion of water bodies with enough water to support environmental standards increases from 82% to 90% for surface water bodies and from 72% to 77% for groundwater bodies
		25YEP: (by 2043) reversing the loss of marine biodiversity and, where practicable, restoring it
	Marine and coastal habitats Farmed countryside	25 YEP: (by 2043) increasing the proportion of protected and well-managed seas, and better managing existing protected sites
		25 YEP: (by 2043) ensuring seafloor habitats are productive and sufficiently extensive to support healthy, sustainable ecosystems
		25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
		25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
	Farmed countryside Soil health and carbon sequestration	25YEP: (by 2043) creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits
		25YEP: (by 2043) restore 75% of our one million hectares of terrestrial protected sites to favourable condition, securing their wildlife value for the long term
		25YEP: by 2030 we want all of England's soils to be managed sustainably
	Water management	
	Crops and livestock	25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
	Crops and livestock Commercial forestry	25YEP: (by 2043) continuing to cut greenhouse gas emissions including from land use, land use change, and agriculture

		25YEP: (by 2043) ensuring that food is produced sustainably and profitably
		25YEP: reaching the detailed goals to be set out in the Tree Health Resilience Plan of 2018
	Commercial forestry Commercial fisheries and aquaculture	25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
		25YEP: (by 2043) increasing timber supplies
		25YEP: (by 2043) managing and reducing the impact of existing plant and animal diseases; lowering the risk of new ones and tackling invasive non-native species
	Commercial fisheries and aquaculture River and coastal flood alleviation	25YEP: (by 2043) ensuring seafloor habitats are productive and sufficiently extensive to support healthy, sustainable ecosystems
		25YEP: (by 2043) ensuring that all fish stocks are recovered to and maintained at levels that can produce their maximum sustainable yield
		25YEP: (by 2043) making sure populations of key species are sustainable with appropriate age structures
		25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
People and the built environment Infrastructure	River and coastal flood alleviation Development in areas at risk of river and coastal flooding	25YEP: (by 2043) making sure that decisions on land use, including development, reflect the level of current and future flood risk
		25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Surface water flood alleviation	25YEP: (by 2043) making sure that there are high quality, accessible, natural spaces close to where people live and work, particularly in urban areas
	Surface water flood alleviation Development and surface water flood risk	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
		25YEP: (by 2043) making sure that decisions on land use, including development, reflect the level of current and future flood risk
	Development and surface water flood risk Property-level flood resilience	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
		25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Capacity of people and communities to recover from flooding	25YEP: (by 2043) making sure everyone is able to access the information they need to assess any risks to their lives and livelihoods, health and prosperity posed by flooding and coastal erosion
	Coastal change risk management	25YEP: (by 2043) making sure everyone is able to access the information they need to assess any risks to their lives and livelihoods, health and prosperity posed by flooding and coastal erosion
	Water demand in the built environment	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Health impacts from heat and cold	25YEP: (by 2043) making sure that there are high quality, accessible, natural spaces close to where people live and work, particularly in urban areas
	Health impacts from heat and cold Pathogens, air quality and UV radiation	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
		25YEP: minimising by 2030 the harmful bacteria in our designated bathing waters
	Pathogens, air quality and UV radiation Effectiveness of the emergency planning system	25YEP: meeting legally binding targets to reduce emissions of five damaging air pollutants; this should halve the effects of air pollution on health by 2030
	Design and location of new infrastructure	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure

Infrastructure Business	Resilience: Energy	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Resilience: Public water supply	25YEP: (by 2043) ensuring interruptions to water supplies are minimised during prolonged dry weather and drought
	Resilience: Public water supply Resilience: Ports and airports	25YEP: minimising the amount of water lost through leakage year on year, with water companies expected to reduce leakage by at least an average of 15% by 2025
		25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Resilience: Road and rail	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Resilience: Digital and ICT	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Infrastructure interdependencies	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Business impacts from extreme weather	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
Business Local Government	Supply chain interruptions	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Water demand by industry	25YEP: (by 2043) boosting (increasing from today) the long-term resilience of our homes, businesses and infrastructure
	Business opportunities from climate change	25YEP: (by 2043) making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century
	Adaptive capacity of local Government	
National Government	Successful delivery of the National Adaptation Programme	25YEP: (by 2043) making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century
	Successful delivery of the National Adaptation Programme	25YEP: (by 2043) implementing a sustainable and effective second National Adaptation Programme