Adaptation in the UK: a decision-making process

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Summary and implications for policymakers

Climate change is one of the most significant challenges we face. Changes in climate will impact the UK population, environment and economy in many ways; including health, water supplies, food, ecosystems and damages from extreme weather. The only viable approach to limit the long-term impacts of climate change is to reduce global greenhouse gas emissions. But, due to the lags in the climate system, the world is already committed to further impacts from historical emissions alone. The only way to reduce these impacts is through adaptation. This will involve a diverse range a measures, from new crop varieties to sea walls, undertaken across the UK by individuals, organisations and public bodies. Some adaptation will be reactive, but the greatest benefits will come from reducing risks and seizing opportunities before the impacts occur. This will require planning and foresight about how climate will change.

This report contributes to the theoretical framework of the Committee on Climate Change Adaptation Sub-Committee's work on assessing the preparedness of the UK to meet the risks and opportunities arising from climate change. It discusses a framework for adaptation decision making, developing the major work commissioned by the UK Climate Impacts Programme (UKCIP), the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency (EA) in 2003 (Willows and Connell, 2003), and examines the implications for adaptation planning across four case studies: the food sector; the water sector; flooding; and ecosystems and biodiversity. This report extends previous work on adaptation planning by providing up-to-date, comprehensive and pragmatic guidance on approaches to decision-making under deep uncertainty. It also includes new guidance on scoping the problem and identifying relevant information, interpreting uncertain projections and selecting appropriate decision-making methods.

This report focuses on the planning process; in particular, how one can make good adaptation decisions with the information available today. What is a 'good' adaptation decision will depend on the objectives of the case, but in many cases will be characterised as a decision that avoids exposure to potentially costly maladaptation, is informed and robust. The fact that there are information gaps is important. One of the main reasons that adaptation planning is difficult is that it is impossible to predict with certainty the future conditions that we need to adapt to. In many cases, this will mean that decision-makers adopt strategies which keep options open, reduce potential regrets and account for new information over time. An additional challenge, particularly for public policy decisions, is how to weigh up adaptation options against diverse sets of economic, environmental and social objectives. These factors highlight the need for a structured decision-analysis approach to adaptation planning that is mainstreamed into broader decision making.

This report maps out a process whereby understanding the nature of the decision, in particular the context, risks, objectives, constraints and options, a decision-maker can identify the appropriate adaptation strategy. The framework proposed (Figure S.1) is in the spirit of Willows and Connell (2003), but with a more explicit treatment of the role of risk information in the process itself. The modifications are aligned with the recommendations of the supplementary guidance to the HM Treasury Green Book on **Accounting for the Effects of Climate Change** and recent academic literature.

The report applies the framework to four case studies (Box S.1) and concludes that:

- **In many cases a range of 'no-regrets' options are available;** defined here as options that will provide benefits under any climate change scenario and do not limit flexibility to cope with future climate change[1] (Box S.2).
- **Only in a few cases will a decision-maker be forced to make the difficult choice between potentially 'high-regrets' options due to climate change uncertainties,** where the benefits of options depend strongly on uncertain future climate states. These will usually be limited to urgent, long-lived and inflexible decisions with high sunk costs[2] (e.g. some infrastructure investments with high capital costs). Of course, as in decision making in other areas, difficult choices may still need to be made in managing trade-offs between different objectives and constraints.

[1] The definition of no-regrets is narrower than in some other studies. It does not imply that options are also no-regrets in terms of costs or trade-offs with other investments.

[2] Sunk costs are costs that once incurred can not be recovered and so could be considered irreversible investments. This includes, for example, most public infrastructure.

- **In many cases of long-lived decisions, such as public infrastructure projects, flexible options are available and can be shown to be desirable.** For example, even in the case of the upgrade to the Thames Barrier, a decision with high sunk-costs, long lead-times and a lifetime of 100 years, an approach was identified that is robust to climate change uncertainties.

Figure S.1: The framework for adaptation decision-making.

Box S.1. Summary of high-level findings from the case studies

In Chapter IV, the framework proposed is applied, albeit at a high level, to four case studies to identify key risks and decision factors, and draw broad conclusions for decision-making. The analysis shows that each case presents unique challenges, but also exhibits similarities that can be used to draw out general rules for decision-making. Key findings for each case study are summarised below.

Flooding:

Unique characteristics and challenges: Flooding is a case of high levels of current exposure; highly uncertain changes in risk due both to climate change and non-climate factors, and many hard-infrastructure investments with high sunk-costs. For inland flooding, the most important near-term driver of risk is likely to be land-use change and development. In the longer term, climate change could become a significant driver of increasing risks, but the magnitude of changes is highly uncertain. In coastal regions, sea level rise and changes in storminess could lead to discernable adjustments in risk in the medium-term.

Implications for decision-making: The ambiguities in future flood risk projections and high potential sensitivities of decisions to climate change make adaptation planning in this sector a process of decision-making under deep uncertainty.

- This is an area involving many long-lived decisions with high sunk costs that are likely to be sensitive to climate change uncertainties. An urgent need of adaptation planning is to assess the benefits of incorporating flexibility into decisions that are already in the pipeline to avoid locking in future vulnerability and potential maladaptation.
- This is also an area of plentiful ‘no-regrets’ adaptation options, which give significant benefits in terms of reducing risk and are not sensitive to climate change uncertainties, including: measures to reduce current vulnerability to weather and climate; and measures to manage other drivers of risk, including risk-averse land planning (avoiding new building in high risk areas) and avoiding decisions that would worsen drainage (e.g. paving over green spaces in cities).
- Some adaptation measures are ‘low-regrets’ and have significant co-benefits; for example, natural ecosystem-based flood control.

These decisions may involve challenging trade-offs with other objectives, such as targets for new housing and the need for economic development. To tackle these trade-offs requires a holistic approach where adaptation planning is mainstreamed into broader decision making.

The Water Sector:

Unique characteristics and challenges: the water sector has many similar characteristics to flooding, however non-climate drivers, such as increases in demand, are likely to be of equal or greater importance than climate change, at least in the medium-term.

Implications for decision-making: Like flood management, the water sector is an area with long-term infrastructure and high potential sensitivity of decisions to climate change. However, there are many no-regrets options available to cope with climate change and other risk drivers that have been demonstrated to be reliable and beneficial in water supply management.

- Managing current climate variability: including enhancing resilience through building supply networks between regions
- Managing other risk drivers: including leakage reduction and demand management through, for example, education, metering, re-use and water-efficient equipment. These can be faster to implement and more flexible than supply-based adaptations.

A number of studies have demonstrated that these flexible options can ‘buy time’ before investing in more irreversible infrastructure options, allowing robustness to climate change uncertainties, and in some cases can even be more cost-effective in the near-term.

The Food Sector

Unique characteristics and challenges: the food sector is a case with many short-lived adaptation options that are less sensitive to climate change uncertainties. Autonomous adaptation is likely to be dominant. It is also one of the few areas where well-planned adaptation could increase productivity above current levels in a warmer world. However, it is also unique in that it is exposed to the global impacts of climate change on agricultural productivity and ecosystems, and global changes in demand. In the near-term, the sector is likely to continue to be affected by a range of climate and non-climate shocks, including extreme weather, fluctuations in demand and pests and diseases. In the longer-term, climate change could begin to have discernable effects.

Implications for decision-making: adaptation in the food sector, in general, will likely be less sensitive to climate change uncertainties than other areas, for example:

- Many of the adaptations in this sector are short-lived, autonomous and reactive, such as changing crop varieties. However, there is a role for government in overcoming any barriers to effective autonomous adaptation
- A broad range of anticipatory, no-regrets actions are available and have immediate benefits, such as sustainable farming practices, improving water efficiency and research and development. Other no-regrets options relate to managing non-climate drivers of changes, for example, enhancing the resilience of the food sector to global shocks through diversification and managing other systematic pressures, such as land conversion for biofuels production.
- Some adaptation options represent ‘tougher choices’, such as measures to increase the UK’s food security; these entail trade-offs and have uncertain benefits.

Adaptation in the food sector could have significant co-benefits or trade-offs with other areas given that agricultural practices and land conversion have significant impacts on flood hazard, water quality and ecosystems. This points towards the need for a holistic, cross-sectoral approach to decision making.

Ecosystems and Biodiversity

Unique characteristics and challenges: this is an area already impacted by climate change and where climate change could lead to significant and irreversible impacts even in the near-term. It is an area where there have already been significant declines in the past as a result of long-term stresses, such as pollution and land conversion.

Implications for decision-making: Ecosystems and biodiversity is an area of significant present and future sensitivity to climate and other non-climatic drivers of risk. However, many of the adaptation options available are no- or low-regrets, such as measures to reduce non-climatic sources of harm, enhancing resilience to current weather and conserving existing protected areas and other high-quality habitats. Many measures can also have significant co-benefits with other sectors through the ecosystem services they provide and so might be considered win-wins, for example, natural environment solutions to flood management. The immediate sensitivity to climate and non-climate risks and the potential for irreversible impacts suggests the need for an urgent and thorough analysis of appropriate adaptation strategies.

A key factor in decision-making will be how to value ecosystem services and biodiversity. This is important in evaluating common trade-offs with other objectives, particularly those related to other risk drivers, such as land uses and levels of pollution. Different stakeholders tend to have differing views on the value of ecosystems and this can lead to challenges in decision-making.

These findings have important implications for adaptation planning. For example, they suggest that **only in a few cases is a resource-intensive decision-analysis process necessarily** required. Detailed quantitative analysis to rank options will typically only be required where the choice between options is sensitive to assumptions (including climate change uncertainties) and where there are significant potential trade-offs to be assessed between different objectives and decision criteria. **These types of decisions are typically relevant to public or large private (e.g. water and utilities companies) sector organisations involved in planning long-lived infrastructure projects with high sunk costs, or long-term sector-level planning and regulation.**

For many decisions, such as local-scale autonomous adaptation, desirable 'no-regrets' or 'win-win' solutions are often available, reducing the sensitivity to uncertainties. In such cases, a detailed quantitative appraisal of options may be unnecessary in decision making. A structured decision-making process as laid out in the report enables a decision-maker to establish the level of sensitivity to uncertainties and identify where more detailed assessment is required and what decision tools are appropriate. In any case, **transparency of the analysis is crucial in a planning process; this includes making assumptions and any sensitivity clear and providing appropriate qualitative and quantitative evidence to support conclusions.**

Where sensitivities to climate change are high, **long-term adaptation planning will often be a process of decision-making under deep uncertainty.** For example, climate projections at the spatial and temporal scales relevant to decision making are often highly uncertain, conditional on models with known flaws, and sensitive to the unknown future emissions pathway. Decision methods that reflect the true extent of the uncertainty about the future and rigorously account for attitudes towards this uncertainty are important tools for designing successful strategies. Examples include robustness-based approaches and real options analyses.

A broad conclusion of the report is that while in some cases adaptation will be challenging (and this is particularly true for public sector decision making), in many cases the most significant of these challenges will come not from climate change itself, but from agreeing and prioritising objectives, resolving trade-offs and conflicts and overcoming the political, social, economic and institutional barriers to implementation. These challenges are not unique to adaptation; they are encountered in many areas of policy, risk management and decision-making. Climate change adaptation does however present some unique challenges. Firstly, the scale, speed and extent of the potential adaptations required; this will become increasingly challenging as the world continues to warm and can only be moderated through reducing greenhouse gas emissions. A second challenge is the need to anticipate uncertain future climate changes. This report has mapped out a series of simple options and approaches to help overcome this uncertainty, including no-regrets and flexible options. Where 'hard choices' are present, decision theory has provided a set of tools to help decision makers appraise a most effective response to suit their needs and preferences.

Adaptation is not an objective or process that should be considered in isolation. **Adaptation is one part of broader decision making, for example it is an integral part of sustainable developme**nt, land use planning, resource and risk management, and environmental sustainability. Adaptation in isolation will miss important synergies and trade-offs with other areas; it would be less able to effectively seize co-benefits with other policies and measures, such as ecosystem restoration and mainstreaming climate-resilience into new developments, and managing complex trade-offs across sectors, for example, between land-use development, flood risk management, agriculture and water quality. Risks, opportunities, objectives and measures should be considered within the context of the broader goals and strategies of an organisation.

For the remainder of this summary, conclusions are presented in the context of questions that often arise in discussions on adaptation planning:

1. How can one prioritise adaptation measures and what should be done first?
2. How can one weigh up the benefits of incorporating flexibility/robustness into adaptation plans to deal with uncertainties?
3. What does a well-prepared organisation look like today?
4. What are the priorities for building a knowledge base for adaptation
5. How can one make good decisions where analytical resources are constrained?

Finally, while planning is a crucial foundation for adaptation, it is only the first step in a wider process. Successful adaptation will require an iterative sequence of monitoring, planning, action and review. The goal of the planning stage is to select and sequence adaptation options, in order to reduce risks and seize opportunities in ways that best meet the objectives.

How can one prioritise adaptation measures and what should be done first?

Prioritisation of adaptation measures aims to ensure: (i) the best allocation of resources between projects and (ii) the best sequencing of actions over time within a project, to meet the adaptation objectives. There is no one-size-fits-all best strategy; prioritisation between projects and over time will depend on the nature of the problem, the interaction of risks and options and crucially, the objectives of adaptation.

The report does identify a number of urgent adaptations with relevance across all sectors, actors and scales. In particular, like mitigation, a delay in some forms of adaptation could mean greater costs down the line. For example, policy and spending decisions are made every day that could increase future vulnerability to climate change or reduce flexibility to adapt, for example, new public infrastructure and property developments, potentially locking in unnecessary future costs. In addition, in some highly vulnerable areas like ecosystems, inaction could result in severe and potentially irreversible impacts even on short timescales. This report identifies three types of action that should be high priority today:

1. Action in areas where any delay could lock-in irreversible impacts or limit flexibility to cope with future climate change (Box S.2).
2. Building the human and institutional capacity to carry out adaptation effectively, including decision-processes and skills. This includes formalising decision-making frameworks, objectives and constraints, engaging relevant stakeholders and agreeing appropriate processes; e.g. who will make the decisions, what frameworks will be followed and how will stakeholders be involved? Once this is in place, a process of structuring the problem (Figure S.1, Chapter III) can help to identify how and where capacity is needed; for example, identifying what capabilities will be required to develop and implement strategies, including relevant skills and institutional and regulatory structures.
3. Developing the knowledge base for adaptation. Identifying and filling knowledge gaps. This might include, for example, research into current vulnerability, future sensitivity and adaptation options; and building long-term monitoring systems to monitor the effectiveness of adaptation and detect any changes that might indicate the need to refine or revise plans.
4. Taking opportunities to seize adaptations that will have immediate benefits, such as no-regrets and win-win options (Box S.2).

Box S.2. Top priorities in adaptation over the near-term (e.g. the next five years)

Seizing the opportunities for 'no-regrets' and 'flexible' options will require urgent, comprehensive and cross-sector planning and implementation. The most urgent priorities for adaptation planning over the coming years include:

1 **Identifying and managing risks in sectors or actors with high sensitivity to weather and climate change in the near-term.** This includes identifying potential near term thresholds in impacts and possible irreversible outcomes and evaluating options to manage these. For example, a number of ecosystems are already showing signs of increased vulnerability to climate and susceptibility to mean climate changes. These systems incorporate a number of feedback mechanisms and thresholds that mean that they could be negatively and irreversibly impacted by even small changes in climate.

2 **Identify any adjustments, measures, investments and policies that could increase potential vulnerability to climate change or reduce the flexibility to adapt, and evaluate approaches to enhance robustness to climate change uncertainties.** This includes, for example: new long-lived projects, such as infrastructure or new housing developments; and policies that might create barriers to autonomous adaptation, such as subsidies.

In addition, it may be desirable to implement some adaptation measures today, for example:

3 **No-regrets' measures** that provide benefits under any climate scenario[3]. For example:

i) Measures that provide benefits in managing current weather and climate variability, *such as: providing risk information and monitoring; insurance systems; research and development; and conserving existing high-value ecosystems.*

ii) Measures associated with managing non-climate related drivers of risk, *such as reduced leakage in water systems; enhanced planning and building controls; rebuilding soil fertility; and water quality management.*

iii) Short-lived adaptations with immediate benefits, *for example where climate has already changed or the system is iv) Broader measures aimed at reducing vulnerability and building resilience to shocks and general stresses, such as early warning systems, water transfer networks between regions, and capacity building (skills and information).*

iv) Broader measures aimed at reducing vulnerability and building resilience to shocks and general stresses, *such as early warning systems, water transfer networks between regions, and capacity building (skills and information).*

4 **Measures with significant co-benefits across sectors,** such as ecosystem solutions to flood control and water quality.

5 **Measures and policies that promote autonomous adaptation,** for example, raising awareness and providing information, or removing broader barriers to autonomous adaptation, such as agricultural subsidies.

6 **Options that have long lead times before they can be applied,** such as research and development of new technologies (e.g. new crop varieties); restoring degraded habitats to create ecosystem networks; and upgraded water supply systems.

In contrast, longer-term adaptation options will also include adjustments, measures or policies that are desirable to deal with the potentially bigger impacts of future climate change, but have shorter lead-times meaning that they do not need to be implemented until later. Longer-term plans may also include the regular review of decisions delayed in waiting for better information; for example, this could be appropriate for long-term investments with high sunk-costs (such as public infrastructure) where it is costly to engineer in flexibility to cope with the range of possible future climates.

[3] This is a narrow definition of no-regrets and does not imply 'no-regrets' in terms of zero costs or zero trade-offs with other investments.

Only by working through a structured decision-making framework can adaptation options be rigorously and unambiguously prioritised and sequenced. At a national level, the prioritisation of adaptation investments will particularly depend on national economic, environmental and social objectives. There is an urgent need to formalise these objectives with stakeholders and establish a process for regular review. It is important to build a shared understanding of what is to be achieved through adaptation and what would be considered 'good' adaptation. For example, is it a certain cost-benefit ratio for an investment, or specific non-monetary targets related to the protection of people, properties or the environment? The RCEP 2010 report highlighted the need for a "deep and broad public discourse". Mapping objectives and relevant societal preferences would be a valuable outcome of such a discourse. Objectives must be expressed in ways that allow them to be measurable and comparable to other (non-adaptation) objectives, that is, mainstreamed as part of non-climate objectives. This is important in measuring success and evaluating trade-offs between different allocations of resources.

How can one weigh up the benefits of incorporating flexibility/robustness into adaptation plans to deal with uncertainties?

Where the sensitivity of plans to climate change-related uncertainties is high, one approach is to design strategies that are robust to changes in the future. This has the benefit of reducing the risk of maladaptation and in many cases building in robustness will have the immediate benefit of reducing current vulnerability. There are two broad ways of incorporating robustness in a strategy:

- Physically building in flexibility into the measure from the start so that it can cope with a broader range of climates, such as building a flood wall with larger foundations so that it can be heightened if necessary rather than replaced
- Building a flexible adaptation process over time (i.e. monitoring, learning and review), for example, sequencing strategies so that no-regrets options are taken earlier, and more inflexible measures are delayed in anticipation of better information, with regular monitoring and review.

However, incorporating flexibility can incur additional up-front costs or some productivity trade-off. For this reason, there is often a trade-off to be made between incurring additional costs now to incorporate flexibility and risking future costs from maladaptation (Box II.2). An example would be weighing up the costs of building a flood wall with larger foundations today, against the risk associated with potential future costs from replacing the wall before the end of its useful lifetime.

A range of decision methods are available to help decision makers weigh up these options, for example: real options theory allows a decision-maker to evaluate the benefits of delaying action or incorporating physical flexibility; while robustness-based approaches can allow decision-makers to weigh the costs of sacrificing potential productivity against the benefits of decreased vulnerability to a wide range of possible future climatic changes. In some cases the appraisal process can be resource-intensive and complex. The appropriate level of trade-off between robustness and optimised returns will depend largely on the objectives of adaptation and societal preferences, as well as the level of confidence in projections. It is important that these aspects are well-defined. Each of these factors will change over time.

What does a well-prepared organisation look like today?

An objective of the Adaptation Sub-Committee is to assess the preparedness of the UK to meet the risks and opportunities arising from climate change. One element of preparedness is the quality and comprehensiveness of adaptation plans and whether these plans are being implemented effectively. This includes:

1. Agreed adaptation objectives with stakeholders and followed a structured and transparent appraisal and decision process to develop appropriate adaptation plans. The organisation will have completed a rigorous planning process (Figure S.1), employing methods appropriate to the decision (Figure III.4), to arrive at a ranking of adaptation options that identifies what to do and when: for example, urgent versus longer-term actions (Box S.2) and identifying synergies and trade-offs with other areas.
2. Formulated implementation strategies: adaptation plans will have been used to formulate long-term strategies that identify appropriate measures and policies, set out clear implementation plans, and define how the effectiveness of adaptation will be monitored and plans revised accordingly.
3. Developed appropriate decision-making and implementation capacities; identified knowledge gaps and taken appropriate steps to fill them. Important steps here are described in the previous question.

4 Delivered adaptation strategies in accordance with plans; in particular, taking appropriate actions to implement near-term priorities (Box S.2).

5 Monitoring and evaluating progress, and reviewing and revising adaptation plans as necessary.

The second element of preparedness is the effectiveness of the adaptation actions of the organisation, in particular, whether actions have been successful in achieving their objectives as laid out in adaptation plans. This might be measured as progress against a set of indicators, such as: tangible progress in reducing vulnerability to current weather, incorporating adjustments that promote flexibility to climate change uncertainties into long-lived infrastructure, improvements in early warning systems, reductions in demand for water, or developing new crop varieties; or less tangible progress, such as raising awareness and improving autonomous adaptive capacity through information and regulatory frameworks.

What are the priorities for building a knowledge base for adaptation?

Research to narrow the uncertainties involved in adaptation planning can significantly improve decisions. Where a number of knowledge gaps are identified, resources should be allocated based on the value of the respective investments in improving the decision. In general, the most valuable information in a decision process will be the information that the appraisal of an option is most sensitive to; for example, the most significant drivers of change and potential thresholds in impacts. There will always be uncertainty in adaptation decisions and therefore building a knowledge base can only aim to improve decision making in the face of uncertainty.

In most cases, understanding current and past climate variability and non-climate drivers of risks can be of most immediate value in informing decision-making. This information is often lacking, but of importance to decisions, and so returns on investments could be high. Similarly, significant improvements could be made through research into societal preferences relevant to adaptation and developing a better understanding of the benefits of some more poorly understood forms of adaptation measures. For example, available evidence suggests that restoring natural ecosystems can have significant benefits in terms of flood control (e.g. by reducing run-off or as natural barriers), but this option is not used extensively today, partly due to lack of information, skills and experience.

One should also compare the value of improvement in decisions with the cost of that improvement. For example, while continued investment to refine probabilistic climate projections is important, these research programmes are costly and, as a result of the many irreducible uncertainties, are unlikely to yield significant reductions in levels of uncertainty in the near-term. Further work is required to establish how the greatest value could be derived in better understanding climate for adaptation. For example, the case studies suggest that research to elicit levels of confidence in projections and explore plausible upper and lower bounds on projections might give greater returns for investment in terms of improved decision support (for example, Box II.3 demonstrates the value of the 'high-end' sea level rise scenario given by UKCP09).

A structured decision process can help in identifying knowledge gaps and prioritise investments in research. Further research is required in this area, particularly to inform national-scale investments in adaptation research programmes.

How can one make informed decisions where analytical resources are constrained?

Resource constraints can be an important barrier to good decision-making. In particular, individuals and businesses may not have the capacity to conduct lengthy and detailed adaptation assessments. There are broadly two ways in which adaptation planning can become more complex: firstly, where the sensitivity of decisions to deeply uncertain information is high; and secondly, where there is a diverse set of objectives to be met, particularly where potential synergies and difficult trade-offs must be analysed. This will usually only apply in cases of long-lived large infrastructure and buildings, and sector-level planning and regulation, and therefore, will typically be limited to public and large private-sector organisations (e.g. water and utility companies).

The public sector can play an important role in alleviating some of these barriers by providing guidance and examples. While there is no one-size-fits-all solution to adaptation, there are generic rules and tools that can be applied to aid the process, which apply equally to simple and complex decisions. For example, the conclusions summarised in Box S.2. More detailed sector-level and actor-specific analyses and case studies would be beneficial to further refine these rules. Some good examples of such guidance are already available; for example, the project appraisal guidance given by the EA and Defra, the ‘Adaptation Wizard’ of UKCIP, and the UKCIP-EA-Defra guidance on risk and decision-making (Willows and Connell, 2003). To be most effective, this guidance requires regular review and testing in the light of new information.

Adaptation in the UK: a decision-making process

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Introduction

Climate change is one of the most significant challenges we face. Changes in climate will impact the UK population, environment and economy in many ways; including health, water supplies, food, ecosystems and damages from extreme weather, such as flooding, droughts and storms. The only viable approach to limit the long-term impacts of climate change is to reduce global greenhouse gas emissions. But, due to the lags in the climate system, the world is already committed to further changes from historical emissions alone. The only way to reduce the impacts of the unavoidable climate change is through adaptation.

Adaptation can be defined as a series of measures and policies that aim to reduce the adverse impacts of climate change and take advantage of any new opportunities. Both adaptation planning and implementation are rarely one-offs, but an iterative sequence of monitoring, planning, action and review. This report focuses on adaptation planning; in particular, how one can make good adaptation decisions with the information available today. The fact that there are information gaps is important. The main reason why adaptation is difficult is that there is little certainty about the future climate. In many cases, this will mean that decision-makers adopt strategies which keep options open, reduce regrets and account for expected future learning. An additional challenge, particularly for public policy decisions, is how to weigh up adaptation options against diverse sets of national economic and social objectives. These characteristics highlight the need for a structured decision-analysis approach to adaptation planning.

This report contributes to the theoretical framework of the UK Adaptation Sub-Committee's (ASC) work on assessing the preparedness of the UK to meet the risks and opportunities arising from climate change[4]. This will be the focus of the ASC's work for 2010/11. The foundational indicator of a well-prepared organisation is the quality of its adaptation plans: the comprehensiveness of its mapping of factors that will influence adaptation decisions; the rigor of its appraisal of these factors and their uncertainties; and the appropriateness of methods used to come to decisions. The objective of this report is to develop a framework for decision-making that is applicable to adaptation planning by actors in both the public and private sectors, as well as forming the foundation of an assessment of preparedness. Further, the report aims to map out the challenges of decision-making in adaptation and provide guidance on appropriate tools and processes. The approaches developed are applied to four UK-based case studies: the food sector, flooding, the water sector and ecosystems and biodiversity, and are used to draw generic rules for decision-making.

There is a rich and growing literature related to adaptation planning. Important advancements presented in this report include comprehensive and pragmatic guidance on appropriate methods to deal with uncertainty in decision-making, and a fuller exploration of how the nature of the problem influences the appraisal of options and appropriate decision methods. The framework presented here is analogous to the comprehensive, 'risk-based' decision-making framework developed by the UK Climate Impacts Programme (UKCIP), the Environment Agency (EA) and Department for Environment, Food and Rural Affairs (Defra) (Willows and Connell, 2003). Here, a refinement is made to make the framework more explicitly a 'policy-first' approach. This approach is similar to that recommended by the supplementary guidance to the HM Treasury Green Book on Accounting for the Effects of Climate Change (HM Treasury and Defra 2009) and in recent academic literature (for example, Dessai et al. 2009). The framework is applied to the four case studies and used to draw general rules for adaptation planning that, for example, identify what types of decisions are sensitive to climate change uncertainties and where the greatest value of information lies.

This report provides further advancement towards comprehensive, rigorous, and up-to-date guidance on decision making under deep uncertainty, i.e. making decisions when it is difficult or impossible to make quantitative estimates of the probabilities of alternative future conditions. Since climate projections at the spatial and temporal scales relevant to adaptation decision making are often highly uncertain, conditional on models with known flaws, and highly sensitive to the unknown future emissions pathway, decision methods that reflect the true extent of the uncertainty about the future and rigorously account for attitudes towards uncertainty are

[4] Under the Climate Change Act 2008, the Adaptation Sub-Committee is required to provide an assessment of the progress made towards implementing the objectives, proposals and policies set out in the UK Government's Adaptation Programme.

important tools for designing successful adaptation strategies. This report provides two worked examples demonstrating the sensitivity of decisions to uncertainty and the application of decision-methods aimed at managing these uncertainties.

This report does not provide an in-depth discussion on the important issue of the role of public policy and institutional capacity in adaptation. Thus the report provides complementary guidance to that provided by the recent report of the Royal Commission on Environmental Pollution (RCEP) on Adapting Institutions to Climate Change and Defra (2010). In addition, the framework assumes that current levels of resilience to extremes, governance and institutional capacity are strong. This may not be the case in, for example, the least developed countries; in such circumstances more emphasis may be required on building institutional capacities, developing broader economic and social resilience and issues of financing adaptation (World Bank, 2009).

The report begins by providing a motivation for adaptation planning and highlights the importance of understanding uncertainty when making decisions. Chapter III presents the framework for adaptation decision-making and identifies some generic rules and tools to assist in evaluating options and making decisions. Chapter IV applies this framework to the four case studies to draw high-level conclusions on the sensitivity of adaptation plans to uncertainties and the sequencing of adaptation options in light of drivers and uncertainties. Three technical annexes support the conclusions of the research: the first introduces the role of decision theory in adaptation and gives an overview of decision methods; the second gives simple quantitative examples of the application of different decision methods to demonstrate their sensitivities; and the final annex provides the full assessment of the four case studies.

This research was conducted by the **Centre for Climate Change Economics and Policy (CCCEP) and the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science (LSE),** in consultation with a number of experts on decision-making and sector-level adaptation. The Ecosystems case study was contributed by Alice Hardiman from the Royal Society for the Protection of Birds. The research was sponsored by the secretariat to the ASC.

The three technical annexes accompanying this research are available for download online through the websites of the CCCEP (www.cccep.ac.uk) and the Grantham Research Institute on Climate Change and the Environment (lse.ac.uk/GranthamInstitute). For further information, contact Dr Nicola Ranger (n.ranger@lse.ac.uk)

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II Climate change and adaptation planning

II.A. Overview of Climate Change in the UK

Climate change will fundamentally alter the pattern of weather risks and impact people, the environment and the economy both directly and indirectly. In the UK, the conclusions of climate science and modelling point toward warmer temperatures, wetter winters and drier summers across most of the country (Jenkins et al., 2009). The frequency and intensity of extreme weather, such as droughts, heat waves and heavy rainfall, will change, leading to greater risk of damage and disruption in some areas. The sectors most vulnerable to changes in climate are likely to be the same as those vulnerable to weather today, including agriculture, insurance, utilities, public health and the built environment (Parry et al., 2007). The natural environment is likely to be particularly vulnerable as its adaptive capacity is lower.

The scale of impacts in these sectors and their effects on local people, the environment and economies will vary between regions. Some regions will see reductions in risk, others increases, and a few could become susceptible to risks never before experienced. Not all the changes will be negative however. For example, current projections suggest a potential increase in agricultural productivity and reduction in cold-related deaths.

In the long term, as global temperatures continue to rise, impacts could become increasingly negative and more extensive across sectors. In decades to come, the UK will also be increasingly influenced by the effects of climate change elsewhere in the world; for example, changing locations of food production and extreme weather will affect commodity prices and patterns of trade. In the longer run, the UK could be affected by changing patterns of migration and economic production linked to climate. These types of global changes are difficult to predict and will be heavily influenced by local risk management and non-climate drivers, including changing demographics and economic development.

The extent to which changes in weather and climate, globally and locally, impact the UK will depend on its ability to adapt to those changes.

II.B. The Role of Adaptation

Adaptation is defined by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as a series of adjustments, measures or policies, **to reduce the vulnerability or enhance the resilience of a system to observed or expected climate change** (Adger et al. 2007), **reducing damages and maximising potential opportunities**. This includes, for example, investments in flood defences to reduce vulnerability to storm surge; changing crop varieties to those suitable for the warmer climate; or land planning policies to steer development away from floodplains. Economic analyses have demonstrated that in many cases well-planned adaptive measures can cost-effectively avert a large fraction of future losses due to unavoidable climate change over the next few decades (e.g. Climate Works Foundation, 2009; Agrawala and Fankhauser, 2008; Fankhauser and Schmidt-Traub, 2010).

Recognising the economic, environmental and social benefits of adaptation, the UK's Climate Change Act 2008[5] sets out a legislative framework for adaptation, specifying responsibilities as well as requiring a 5-yearly National Climate Change Risk Assessment and a Government programme for adaptation. The Department for Environment, Food and Rural Affairs (Defra) laid out plans for the first phase of the Programme (2008-2011) encompassing four streams: providing the evidence; raising awareness; ensuring and measuring progress; and embedding adaptation into Government policy and process (Defra, 2008). In March 2010, further principles were published (Defra and DECC, 2010) and individual Government departments published their Departmental Adaptation Plans (DAPs), setting out their key risks and priorities on climate change[6]. The objective of this report is to describe a series of processes and tools aimed at supporting decision-makers in both private and public sectors in developing adaptation strategies.

Human and natural systems have been adapting to climate for centuries. For example, today across most of the world, systems and technologies are in place to reduce risks associated with weather, be they sea walls, drought-resistant crops, insurance systems or community-scale social safety nets. What makes adaptation different today is that decision makers can no longer rely on historical weather as an adequate guide to the future (Hallegatte 2008). In many cases, there is not enough information about the future we need to adapt to. However, delaying decisions now can mean greater costs down the line. Adaptation planning therefore requires us to make decisions in ways that manage time-evolving, spatially heterogeneous and highly uncertain risks. A further challenge of adaptation, particularly for

[5] www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_6#pt4

[6] DAPs can be accessed at: www.defra.gov.uk/environment/climate/programme/across-government.htm. These contain plans relating to both adaptation and mitigation.

public policy but also large organisations, is how to balance disparate objectives (e.g. risk reduction and economic development) and manage diverse sets of preferences, for example, differing public attitudes to risk and the distribution of costs and benefits of actions. This further set of challenges is also present in many forms of climate risk management today, but is often made more complex by the presence of uncertainty and the scale of the potential risks. A framework for adaptation planning must provide a structure to deal with each of these challenges as well as being compatible and integrated with broader decision making.

II.C. Rationale for Planning Adaptation and an Anticipatory Approach

Adaptation takes place in physical, ecological and human systems. However, only human systems can anticipate and respond to expected changes (known as, *anticipatory adaptation*). There are significant advantages to anticipatory adaptation, both in terms of the protection of life and reduction in economic costs.

A close analogy is disaster risk management, where it is understood that anticipatory (ex-ante) measures that aim to reduce risk and promote resilience before a disaster strikes, have significant benefits over reactive (ex-post) measures, such as humanitarian assistance, that aim to reduce the impacts of a disaster after it occurs (e.g. treat injuries and reduce the chance of disease and malnutrition) and speed recovery. While both ex-ante and ex-post measures are required, economic analyses provide evidence that by investing in ex-ante measures, the costs of impacts and ex-post measures (as well as lives lost and disruption caused) can be significantly reduced (World Bank, 2009). For example, between 1960 and 2000, China spent US$3.15 billion on flood control, averting potential losses of US$12 billion, while in India, risk management and preparedness in Andhra Pradesh yielded a benefit/cost ratio of more than 13 (Stern, 2007).

With climate change, additional benefits of anticipatory adaptation come from reducing the costs associated with potential maladaptation (Box II.1), such as prematurely replacing infrastructure that was built in a way that was unsuitable for the climate over its lifetime. This is particularly relevant for decisions involving long-lived infrastructure and buildings, regulation and sector-level planning (Fankhauser et al. 1999). Anticipatory action can also have benefits where technological innovation is required to reduce future impacts (e.g. developing new drought resistant crop varieties in view of expected future increases in drought occurrence).

Box II.1: The Cost of Maladaptation

Maladaptation could come from:

- **Inaction:** for example, a failure to adjust water resources management to account for climate changes.
- **Over-adaptation:** where adjustments are made that are proven to be unnecessary given the climate realised, e.g. a sea defence built to withstand 4m of sea level rise that never emerges.
- **Under-adaptation:** where adjustments are ‘not enough’; they do not achieve the maximum potential reduction in losses for the realised climate.
- **Incorrect adaptation:** where adjustments are made, but are later found to be either not adaptive or counter-adaptive, actually increasing impacts above what they could have been given improved ex-ante adaptation. For example, a policy instrument that aims to incentivise adaptation but is either ineffective or counter productive.

These outcomes could arise from the analysis of climate change uncertainties, conflicting objectives, or general poor planning and implementation.

Each of these cases may imply unnecessary costs. For example, for over-adaptation, additional costs are incurred through unnecessary investments and their associated opportunity cost. For under-adaptation, there are unnecessary damages and risks to people and the environment, as well as potential additional costs of retrofitting or replacing capital prematurely to withstand a different realised climate.

Adaptation plans should however also recognise and promote autonomous (individual) and reactive adaptation, where it is effective, efficient, equitable and legitimate (Willows and Connell, 2003). Reactive adaptation has an important role to play, particularly in decisions with short lead-times and short lifetimes, such as changing crop varieties and responding to extreme weather, such as flooding and droughts. Facilitating reactive adaptation is particularly important in allowing the natural environment and ecosystems to adapt naturally to climate change. For physical and ecological systems, adaptation can only be reactive, unless assisted by human interventions. At a public policy level, plans might also seek to promote autonomous adaptation by, for example, raising awareness and providing information, setting in place appropriate regulatory frameworks and financial incentives (Defra, 2010).

II.D. Climate Change and Uncertainty

Anticipatory adaptation requires some foresight about the future; the quality of projections of future conditions creates challenges to decision-making.

Predicting future impacts and the effectiveness of different adaptation options is a task fraught with uncertainty. Uncertainty balloons at each step of the analysis, from predicting global greenhouse gas and aerosol emissions, to their impact on the global carbon cycle, the effects on the global climate, then downscaling to regional and local changes, modelling the physical and economic impacts and then finally, calculating the benefits of different adaptation options (Figure II.1). The sources of uncertainty vary at each step and not all can be quantified with confidence, they include: aleatory uncertainty, from natural, unpredictable variations stemming, for example, from the chaotic nature of the climate (Stainforth et al. 2007a, b); and epistemic uncertainty, from a lack of knowledge about the system, such as uncertainties in modelling the response of regional climates to global greenhouse gas levels and in modelling the effects of warming on biological systems, such as crops and ecosystems. Aleatory uncertainties can be quantified but not reduced, whereas epistemic uncertainties can be quantified and reduced if more information is obtained. A further type of uncertainty comes from forecasting of human systems, such as demographics, economic growth, land-use and global emissions. Impact estimates are highly sensitive to these uncertainties; however, the level of long-range foresight is limited and these uncertainties are largely irreducible (Lempert et al. 2003, Adger et al. 2007).

One of the more well-studied sources of uncertainty is the climate projections themselves. Current science and modelling can give some information about future climate changes, but it is not yet possible to predict them with a high degree of confidence, particularly at a local scale and at longer prediction lead-times. All projections are conditional on the assumptions and structure of the model approach used to generate them.

Levels of confidence vary by the type of impact. Levels of confidence are lower for impacts related to small-scale climate phenomena, such as precipitation and extreme events (storm surges, flooding, droughts and heat waves) (Randall et al., 2007). Arguably, estimates of the likelihood of projections could be classed as ambiguous given the considerable secondary uncertainty not captured by modelling studies (Dessai et al. 2009, Stainforth et al. 2007a & b, Hallegatte 2008).

Despite the focus on climate modelling in uncertainty estimation, this is not necessarily the largest source of uncertainty, particularly in the near-term. For example, many of the non-climate factors are not amenable to prediction, such as future cultural preferences and global trade patterns.

[7] This definition of risk, while being consistent the definition used in most adaptation and risk management literature, is different to that used in decision theory, where the term risk refers to a known probability distribution of an event (i.e. the opposite of ambiguity as defined here).

Continued research to help to narrow uncertainties is important. Research priorities should reflect areas of the highest value of information in adaptation (Section III.B) and in particular, where there are greatest benefits from improved information. For example, while continued investment to improve climate projections is important for long-term decision-making, it is unlikely to yield significant reductions in uncertainty in the next five years. For example, Hallegatte (2008) suggests that improved knowledge does not necessarily imply narrower projection ranges; the inclusion of previously missing processes (such as the dynamics of ice sheets or carbon cycle feedbacks) has increased the quantified uncertainty range, even though these uncertainty estimates may have a higher confidence[8]. Dessai et al. 2009 argue that "the accuracy of climate predictions is limited by fundamental, irreducible uncertainty". For near-term decision-making, the greatest value might be derived from investing in areas of more 'reducible' uncertainties that also have a significant baring on decisions, for example, better understanding the current vulnerability of systems to weather, and studying the costs and benefits of more poorly understood adaptations through pilot projects.

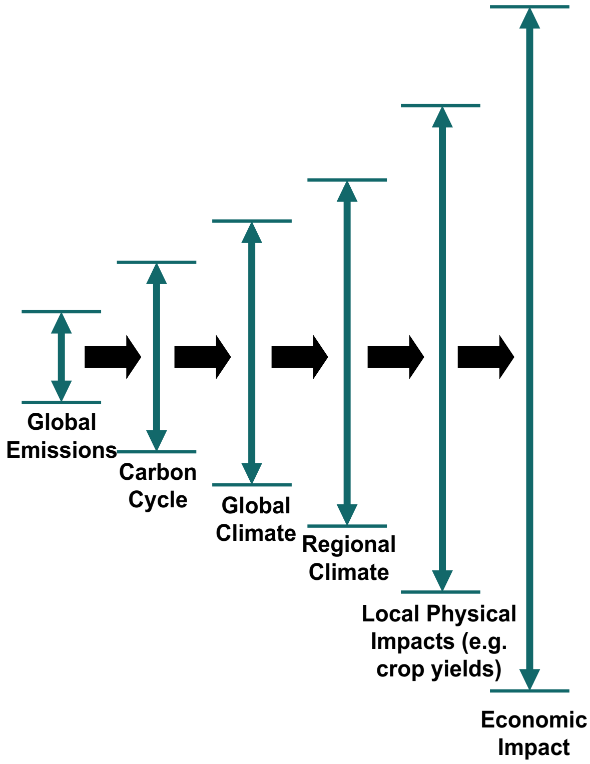


Figure II.1: The 'explosion' of uncertainty from global emissions to local economic impacts (adapted from Jones 2000)

Risk: The product of the probability of an event occurring and its severity[7].

Uncertainty: An expression of the degree to which a quantity (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable.

Ambiguity: Incomplete probabilities, or multiple inconsistent probabilities.

[8] A narrowing of uncertainty ranges also does not always equate to a higher level of confidence in the projections. For example, in the context of stratospheric ozone policy, O'Neill et al. (2006) describes that uncertainty about the chemical processes involved appeared to decrease from the late 1970s to the mid-1980s, but due to missing science, predictions of ozone depletion were actually narrowing in on what turned out to be the wrong answer.

II.E. Adaptation Decision-Making and Uncertainty

These uncertainties do not prevent anticipatory adaptation; accurate and precise predictions are not a pre-requisite for adaptation. A number of approaches are available to enable a decision-maker to manage uncertainty. These frameworks aim to provide a rigorous intellectual structure to facilitate the appraisal of adaptation options and plans. They can be applied on a variety of scales, from individual decisions to sector-based and national adaptation planning. This section aims to give a broad overview of approaches to decision-making discussed in the literature and discuss how the proposed framework (Chapter III) fits into this context.

Summary of terms used in the Decision-Making Framework:

Decision Criteria: The quantities of interest or relevance to stakeholders in a decision – i.e. their objectives. These could include a combination of economic performance, failure rates, risk levels, or measures of environmental quality.

Decision Factors: The full-range of external factors that could influence a decision, for example, the risks and uncertainties, the decision-criteria and the available adaptation options and their characteristics.

Options Appraisal: A method for quantifying the performance of an adaptation option by aggregating its effects (measured in terms of the decision criteria) into a numerical value. These will depend on stakeholder preferences and ethical judgements, e.g. attitudes to risk, and discounting behaviour.

Decision Method: A method for choosing between adaptation options, based on their appraisals.

Decision Process: The full set of activities relating to decision-making, from defining the problem and identifying potential solutions, to evaluating these solutions and making a decision.

Optimisation of returns and robustness in decision-making

Adaptation planning aims to avoid a situation in which a system is more 'maladapted' to the climate than is desirable and as a result, incur additional costs or fail to seize climate-related opportunities. The uncertainties in projections mean that a decision maker cannot estimate with certainty how decisions should be made today to maximise future productivity or minimise costs. For example, it is not possible to predict exactly how high a sea wall should be to maximize net benefits over the next 50 years.

There are two approaches to cope with this. The first involves optimising a strategy based on the best available probabilities of different outcomes to maximise expected utility; hereafter 'optimising returns'[9]. The second involves making a strategy that is robust to the uncertainties (in the available probability distributions); that is, is beneficial under any future scenario. Both strategies involve trade-offs. In the first strategy, there is the risk of maladaptation and this risk will increase with the level of uncertainty in projections. In the second, there tends to be some additional upfront cost or productivity trade-off associated with robustness. In reality, the choice is not which of these two strategies to adopt, but what is the best level of trade-off along a continuous scale between optimising returns and robustness (Lempert and Collins, 2007). Approaches to decision-making under uncertainty enable one to determine where a strategy should sit along this scale.

Arguments for robustness: Optimisation approaches typically require a high level of knowledge of the likelihood of different outcomes (Annex A). Where confidence in projections of future climate is low, a decision-maker may therefore adopt a robustness-based approach to avoid potential maladaptation.

Robustness: An adaptation option's ability to perform adequately across a wide variety of possible futures

Flexibility: An adaptation option's ability to be adjusted to new information or circumstances in the future

[9] Returns' is meant in the most general sense and the optimisation includes adjustment for the decision-makers attitude to risk.

There are many approaches to make adaptation strategies robust to uncertainties:

- One approach is to **use measures that are suitable over the full range of plausible futures**. This could be a no-regrets[10] measure, for example, an early warning system for flooding. It might also be a measure that is designed from the outset to cope with a range of climates, for example, a new house with a cooling system that operates effectively over the full range of future maximum summer temperatures predicted by models today. These types of designs can be costly and in some cases, infeasible (Hallegatte, 2008).
- Another approach is to **build in the option to adjust an adaptation measure if required**; i.e. build flexibility into an adaptation measure. Examples include building a flood wall or reservoir with larger foundations so that it can be heightened if necessary rather than replaced.
- A complementary approach **is to build flexibility into the decision process itself over time through waiting and learning**. For example, sequencing adaptation strategies so that no-regrets options are taken earlier and more inflexible measures are delayed in anticipation of better information. This approach is suggested by Ahmad et al. 2001, which concludes that, given the uncertainties and potential for maladaptation, the "proper mode to conduct analyses to support adaptation decisions… is sequential decision-making under uncertainty and considering future learning" and as part of this decision makers should identify options that will leave the system in "the best possible position for revising those strategies at later dates in light of new information", that is, avoiding strategies that might limit future flexibility.

Strategies that reduce flexibility in decisions can limit robustness to uncertainties and leave one exposed to maladaptation. For example, decisions involving high sunk-costs[11], such as building new homes in a flood plain or investing in a new reservoir, which will provide benefits only under a limited set of future climate scenarios. A robustness-based strategy would evaluate the benefits of avoiding such decisions by designing in flexibility or delaying them until more information was available.

Arguments for optimisation of returns: robustness-based strategies may not always be desirable as flexibility typically incurs additional costs or some productivity trade-off. For example, building a flood wall with larger foundations will come at a higher cost; designing a building to cope with a broader range of climates will be more complex and require greater investment; a health-care system that invests in measures to account for a range of possible future climate-related diseases across all plausible futures may be less well equipped to deal with any one individually. Similarly, delaying action in anticipation of better information might incur costs that are larger than the benefits of waiting. For example, delaying the building of a much-needed major reservoir could leave a water resource zone more vulnerable to climate-related shocks. Box II.2 outlines some of the economic conditions for incorporating flexibility; other preferences may also play a role in determining desirability, for example, the risk of failure. The following chapter and Annex A present a number of tools for evaluating the benefits of flexibility.

The aim of a decision-making process is to enable a decision-maker to evaluate such trade-offs within a rigorous and consistent framework that makes assumptions explicit.

[10] No-regrets measures are those that are beneficial under any climate scenario

[11] Sunk costs are costs that once incurred can not be recovered and so could be considered irreversible investments. This includes, for example, most public infrastructure.

Box II.2: Economic Conditions for Incorporating Flexibility

- **Building in physical flexibility:** For decisions with high sunk costs and long lifetimes, engineering in precautionary adjustments at the start will often be cheaper than running the risk of premature scrapping or expensive retrofitting. In general, *building in flexibility could be a desirable option where the expected benefits are greater than the additional cost*.
- **Waiting and learning,** is potentially desirable, for example, where engineering in extra flexibility is costly and/or where there is a highly uncertain chance of a high climate risk scenario, the likelihood of which there is reason to expect will be clarified over time (i.e. further information that will enable a better decision). *In general, waiting may be desirable if the costs incurred by delay (i.e. avoided impacts or other trade-offs) are outweighed by the expected benefits of waiting*.

Based on Fankhauser et al. 1999

Processes for decision-making

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change identified a number of approaches born out of CCIAV assessments ('climate change impacts, adaptation and vulnerability' assessments) that are becoming incorporated into mainstream decision-making (Carter et al. 2007), these include:

Impact-based' approaches: evaluating the expected impacts of climate change and then identifying adaptation options to reduce any resulting vulnerability

Adaptation-based' and 'vulnerability-based' approaches: identifies processes affecting vulnerability and adaptive capacity, normally independent of any specific future climate forecast. For example, these approaches will identify measures required to improve the resilience or robustness of a system to any climatic changes or shocks and so have little sensitivity to climate uncertainties.

'Risk-management approaches': focus directly on decision-making and offer a framework for incorporating all approaches as well as confronting uncertainty.

The impacts-based approach is a *science-first*[12] process (Figure II.2). These assessments take a linear approach of prediction then action; beginning with producing projections of changes in emissions and ending in exploring the economic and non-monetary effects of a range of adaptation options. Conversely, the adaptation-based, vulnerability-based and risk-management approaches are examples of *policy-first*[13] processes. A policy-first process typically begin at the scale of the adaptation problem, specifying objectives and constraints, identifying viable adaptation strategies and only then assessing the desirability of these against a set of objectives and future projections.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change

Adaptive Capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequencesthe available adaptation options and their characteristics.

Vulnerability: Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Reproduced from the glossary to Working Group II of the IPCC AR4

[12] Otherwise known as 'top-down' or 'predict-then-act' in the literature

[13] Otherwise known as 'bottom-up' or 'access-risk-of-policy' in the literature

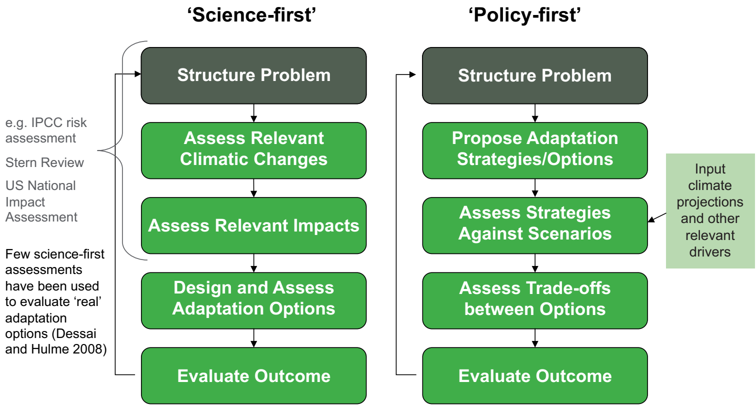


Figure II.2 Comparison of stages involved in science-first and policy-first approaches to identifying and evaluating adaptation options. Adapted from Dessai and Hulme 2008.

The main difference between the science-first and policy-first processes is the ordering of the stages of analysis. This difference appears subtle, but has significant implications for the way that uncertainty is managed and the efficiency of the process. On a purely practical point, in a science-first approach, where the detailed climate and risk analysis comes before the adaptation options identification, experience tells us that the analyst can often find that the risk analysis is missing some element or information that is required to assess the benefits of different options (that can only be known once the options are identified). This means that the analysis must be repeated. This problem is avoided with a policy-first approach.

In addition, Carter et al. 2007 concluded that the science-first process is much more exposed to a ballooning of uncertainties (illustrated in Figure II.1). This means that the range of impacts and their implied adaptation responses can become impracticable (Wilby and Dessai 2009, Dessai et al. 2005). The science-first approach also places a lot of faith in the ability of climate and impacts models to generate high quality information that can be meaningfully deployed in adaptation planning. Decisions tend to be based on optimising decisions against subjective probability distributions. This means that under conditions of ambiguity, the solution can become overly sensitive to inadequate sampling of different plausible scenarios (e.g. using only one emissions scenario) and secondary uncertainties in estimates of likelihoods of different outcomes (Annex A.2). Box II.3 gives an example to demonstrate the effect of secondary uncertainties in climate projections in making adaptation decisions.

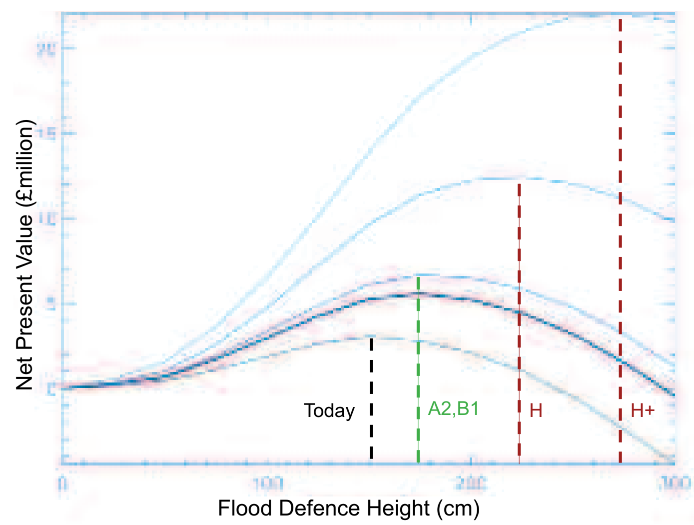
Box II.3: The Influence of Ambiguity in Climate Projections on Decisions

In cases where the benefits of adaptation options are sensitive to the scale and direction of future climate change, the high level of uncertainty in climate projections can lead to challenges in choosing between different adaptation options. To illustrate this, this illustration takes the example of a village on the East coast of the UK that is exposed to storm surges and potential inundation due to sea level rise (details in Annex B.1). An adaptation planner must access how high to build a new sea wall and whether some people should retreat from the coast. In this simplified example, only one risk driver and source of uncertainty is considered: sea-level rise.

Climate science indicates that projections of sea level rise are ambiguous (e.g. Lowe et al. 2009), so much so that the UK Climate Projections 2009 (UKCP09) did not specify probabilities in their projections of future sea level rise. Here, to illustrate the sensitivity of decisions to ambiguous probabilistic projections, distributions are fitted to the projections for two emissions scenarios A2 (high) and B1 (low) and their implications for the optimal height of a sea wall are calculated using a science-first process and an

Box II.3: The Influence of Ambiguity in Climate Projections on Decisions

expected value analysis. The figure below shows the results. It shows the net present value[14] of a sea wall of defined height under different sea level rise scenarios. The peak of the curve indicates the maximum net present value – the optimal sea wall height under the assumptions. The figure suggests that today (the lowest curve) the one would build a wall of 150cm, whereas under the A2 and B1 climate change scenarios one would build a slightly higher wall of 175cm. This small (25cm) difference indicates the sensitivity to climate change is relatively low.



Simulated net present value of the flood defence versus its height (assuming 2% annual discount rate). The figures show results for the four sea level rise projections and assuming no sea level rise.

As long as the planner has confidence in the projections, the decision is simple. However, Lowe et al. 2009 shows that projections of future sea levels are ambiguous. Recognising the secondary uncertainties in sea level rise projections, UKCP09 also gave a high-end estimate of just under 2m by 2100, for use in sensitivity testing in adaptation (Lowe et al. 2009). Based on this scenario, two further distributions of sea level rise are generated and used recalculate the optimal sea wall height. Under these scenarios, the strategies become more sensitive; the wall would need to be around 225-275cm and a retreat strategy becomes the best solution.

This raises interesting questions about the extent to which a decision maker trusts the two main probabilistic projections (B1 and A2). With a high level of confidence in projections, one might choose to go ahead and build the 175cm wall. However, it later science shows that today's projections under-predict sea level rise (for example, due to missing processes in the model) and the projection should have been closer to H (or even H+) then there would be additional costs incurred in retrofitting or replacing the sea wall, or in scrapping the sea wall in favour of retreat. Expected value analysis allows us to identify such sensitivities but does not help in managing them. Other types of analysis, such as a real-options approach can provide a solution.

In Annex B.1, a simple real-options analysis is used to explore whether the decision-maker would benefit from going ahead today and building the 175cm sea wall or waiting for more information before acting. The analysis suggests that if the probability of 2m sea level rise in 2100 was more than 20% (based, for example, on an expert elicitation) it would be beneficial to wait. Chapter III gives a real example of such an approach in the Thames Estuary 2100 project.

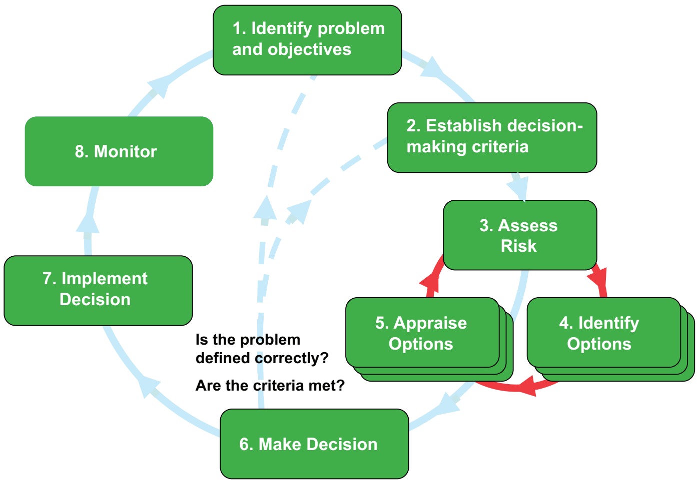
14 The net present value of the sea wall is the total discounted benefit of wall over time minus its cost.

Policy-first processes can simplify and focus an adaptation assessment by identifying the inputs that have the **highest value of information**. In this way, they help to constrain the explosion of uncertainty by incorporating only the information that is important to the decision, i.e. the benefits of adaptation options that are both feasible and appropriate given the objectives and constraints.

The science-first process can be too sensitive to secondary uncertainties and does not allocate analytical and computational resources as efficiently as in a policy-first process. By beginning with a careful analysis of feasible adaptation options and their characteristics, it is possible to identify much more accurately what kind of information will be useful for deciding between these options. It is only then, if at all, that it becomes necessary to consult detailed quantitative climate predictions. The following chapter gives a real example of a policy-first process; based on the analysis conducted for the Thames 2100 project (Haigh and Fisher, 2010).

The approach advocated in Chapter III is a policy-first process. It is close in spirit to the risk-management approach. These tend to use a more structured decision-making framework than the adaptation or vulnerability-based approaches and aim to identify and manage important risks (e.g. Jones et al. 2001). For example, analysing the risk of exceeding the temperature threshold at which aquatic life in a river is threatened and exploring adaptation options (e.g. Wilby 2009). However, examples of risk management approaches in the academic literature are often 'top heavy' in their dependence on climate projections and so tend to underemphasise the efficiency gains it is possible to achieve by identifying information relevant to assessing feasible adaptation options.

Figure II.3. The adaptation decision-making approach advocated by the UK Climate Impacts Programme (Willows and Connell, 2003).



The comprehensive decision making framework put forward by UKCIP with the EA and Defra (Willows and Connell 2003) is an example of a risk-management approach that does emphasise the efficiency gains possible through identifying relevant high-value information. The process is reproduced in Figure III.3. Willows and Connell also makes the important advance of showing adaptation as an iterative process, rather than a one-off assessment.

From Figure II.3, the Willows and Connell process looks similar to a science-first process (Figure II.2) in that risks are assessed (step 3) before options are identified (step 4). However, an important distinction is that Willows and Connell emphasises a *'tiered risk assessment'* approach (indicated by the cycle around steps 3 to 5 in Figure II.3), which encourages the decision-maker to move from the broad to the focussed in terms of risk assessment (rather than jumping into the most detailed assessment as in a science-first process), 'spiralling in' through a cyclical process on a set of viable adaptation options. A tiered risk assessment will create a significant improvement in the efficiency of resource allocation over a science-first process. Three stages of risk assessment are described:

1. **Risk screening:** a preliminary 'light-touch' risk assessment that can help a decision maker to identify the important risk drivers in a decision – for example, to what extent climate

change is important – and therefore, in step 4, the broad types of adaptation options that might be appropriate. Note that in Chapter IV risk screening is applied to four case studies. Willow and Connell suggest that key objectives for this tier are to understand the lifetime of the decision and what climate and other variables are likely to be important, and then to use climate projections to make broad judgements on how future climate changes might affect the decision and levels of confidence in these projections.

2. **Qualitative or generic quantitative risk assessment**: the aim of this step is to characterise the risks in more detail and prioritise them. Here, the decision-maker will build a more complete picture of the nature of risks and their dependencies, the levels of confidence in projections, and importantly the sensitivities of the decision to different scenarios and uncertainties. This assessment will be more detailed than in tier 1, but not involve detailed calculations; for example, it might involve qualitative judgements and back-of-envelope calculations based on a review of relevant climate projections from a number of sources. This additional information allows the decision-maker to refine the adaptation options and their appraisal (step 5).
3. **Specific quantitative risk assessment**: in this final step detailed projections are used to provide a quantitative assessment of the benefits of different adaptation options given uncertainty. It is undertaken only where appropriate data exists, for example, trustworthy climate projections at relevant scales. Willows and Connell state that this final tier is *"essential where the choice between options, or the effective management of the risk, will be improved by detailed quantitative assessment of the risk or uncertainties, including exploring the sensitivity of the assessment to key assumptions".*

Willows and Connell emphasise that not all decision-making processes will need to complete all three tiers. It will depend on the level of decision (e.g. policy, programme or project), the level of scientific understanding, and the importance of climate change as a driver of risk. For example, the risk assessment would stop at tier 1 if the risk screening showed that climate change is not an important driver of the decision.

The framework set out in Chapter III builds on the Willows and Connell framework, supplementing some components and incorporating others more directly. For example, it provides pragmatic guidance, showing more explicitly, for example, that the lifetime of adaptation options is often important in determining the appropriate level of risk assessment; if an adaptation option has a lifetime of only five years, then climate change is less likely to be an important driver, whereas it could be more important for options with lifetimes of more than ten or twenty years. The level of confidence in projections is also shown to be important. For example, if the level of confidence in detailed projections is low then there is unlikely to be additional value in a detailed quantitative assessment (tier 3) over a more qualitative assessment (tier 2).

Chapter III also provides complementary guidance on decision analytical approaches for appraising adaptation options and making decisions (steps 5 and 6). In particular, Chapter III and Technical Annex A provide a comprehensive, rigorous, and up-to-date treatment of decision making under deep uncertainty, i.e. when it is difficult or impossible to make detailed quantitative estimates of the probabilities of alternative climate conditions being realized. Decision making under deep uncertainty features briefly in the UKCIP report; this report provides a much more thorough treatment. It shows, for example, that given the nature of uncertainties in future outcomes, decision methods that reflect the true extent of the uncertainty about future impacts and rigorously account for attitudes towards this uncertainty are important tools for designing successful adaptation strategies. Chapter III also provides complementary guidance on identifying high value information in a decision.

The framework laid out in Chapter III can be applied to all adaptation problems, but is presented in a way aimed more at the informed user, for example, government, NGOs, corporates and utilities companies. The authors also refer the reader to the UKCIP website (www.ukcip.org.uk), which provides a range of complementary tools, specifically designed to be 'user-friendly' for all, for example: the *Adaptation Wizard*, a step-by-step online tool for planners; the *UK Climate Projections 2009;* guidance on *'identifying adaptation options'*, and the *BRAIN*, a database of impacts and adaptation information.

III. A Framework for Adaptation Decision-Making

This chapter presents a generic framework for adaptation decision-making. Given that climate impacts at the spatial and temporal scales relevant to most adaptations are highly uncertain, successful adaptation planning requires an intellectual framework capable of accounting for uncertain inputs. Moreover, many anticipatory adaptations have a public component to them, and are thus dependent on judgements about public attitudes to risk, inequality, and the distribution of policy effects over time. These characteristics point towards the need for a structured decision-analysis approach to adaptation planning, where uncertainties can be dealt with in a formal analytical framework that makes assumptions explicit.

The outcome of a decision-making process is a quantitative appraisal of different options that can enable an adaptation planner to develop strategies that detail which measures should be implemented and when. A well-structured process will allow decision-makers to assess the priority of investments and adjustments against other projects and also inform the sequencing of measures, helping to identify near-term versus long-term needs and where, for example, measures might be delayed in anticipation of better information (i.e. waiting and learning).

This Chapter describes such a generic decision-making framework for adaptation planning. This framework is designed to be applicable to a wide range of adaptation questions, from focussed adaptation projects to policymaking and national adaptation plans. The report also provides up-to-date, comprehensive and pragmatic guidance on a series of decision-making tools for dealing with uncertainty as part of a rigorous formal framework which makes ethical and information assumptions explicit. A vital part of any decision analysis is to ensure that the tools used are suited to the application. Using inappropriate tools can lead to poor decisions. This chapter and Annex A provide guidance on when it is appropriate to use different methods of decision analysis to decide between adaptation options. These sections do not aim to give a comprehensive list of tools, but hope to provide a useful starting point for decision-makers as well as some general principles. At the end of this chapter, there is additional guidance on identifying high-value information in a decision-process. This is useful in allocating analytical resources and identifying future research priorities.

While this report focuses on adaptation, adaptation objectives and decisions should not be considered in isolation, but within the broader context of goals and strategies of an organisation (or individual). For example, adaptation is one integral part of sustainable development, land use planning, resource and risk management, and environmental sustainability. Adaptation considered in isolation will miss important synergies and trade-offs with other areas; it would be less able to effectively seize co-benefits with other policies and measures, such as ecosystem restoration and mainstreaming climate-resilience into new developments, and managing complex trade-offs across sectors, for example, between land-use development, flood risk management, agriculture and water quality. Risks, opportunities, objectives and measures should be considered within the context of broader goals and strategies of an organisation.

III.A. The decision-making framework

Figure III.1 provides an illustration of the proposed framework for adaptation decision making. The process involves five steps that are grouped into three stages: (i) structuring the problem; (ii) appraising solutions; and (iii) implementation. Figure III.1 emphasises that adaptation is not a one-off, but an iterative process involving planning, implementation and review. In Figure III.1 this is indicated by the grey arrow that joins step five back to step one. The frequency of review will depend on the decision, but should be planned and regular. A review might also be triggered by an observation, new information or a change in adaptation objectives and constraints.

As discussed in the previous Chapter, this framework is in the spirit of that developed by the UKCIP, EA and Defra (Willows and Connell, 2003). A key difference in the structure presented in Figure III.1 from the Willows and Connell framework is that the tiered risk assessment approach advocated by Willows and Connell (Section II.E) is made more explicit in the process itself. For example,

- the first tier of Willow and Connell's risk assessment on *'risk screening'* is emphasised so that it has become a top-level stage of the process; that is, *'1b. Assess current vulnerability and identify potential future sensitivities'*. The new phrasing of this step makes the important point that current vulnerability to weather and the roles of different risk drivers (climate and non-climate) today can be a valuable guide to future risk and adaptation options.
- The second and third tiers of Willow and Connell's risk assessment are integrated into *'2. Assess individual adaptation options'*; this makes more explicit the point made

by Willow and Connell that *"immediate progression to potentially complex and data intensive quantitative techniques of risk assessment is not recommended"*.

The structure suggested here emphasises the need to identify adaptation options before beginning the risk assessment and so can help to improve the efficiency of resource use in an assessment. The information given in this chapter is not designed to be a substitute to Willows and Connell 2003 and in a number of places the text will refer the reader that work. Finally, this modified approach follows along the lines of the recommendations made in the supplementary guidance to the HM Treasury Green Book on *Accounting for the Effects of Climate Change* (HMT and Defra 2009).

Figure III.1: A generic framework for adaptation decision-making

In the following sections, the chapter progresses through this process step-by-step and explain each stage in detail. This chapter focuses on the two planning stages: 'structure the problem' and 'appraise solutions'; the authors refer the reader to Willows and Connell for more detailed guidance on the implementation stage.

III.A.i. Structuring the problem

Structuring the problem is a crucial first step in any decision-making process. It sets the context and allows a decision-maker to identify sensitivities in the decision and choose appropriate approaches to appraise options and come to a decision. There are three parts to structuring the problem: defining adaptation objectives and constraints; assessing current vulnerability and identifying potential future sensitivities; and defining and characterising adaptation options. These three parts are not necessarily independent; for example, identifying potential future sensitivities will require one to understand current vulnerability to weather and other stressors and have an understanding of the objectives of adaptation; but in some cases a better understanding of future sensitivities may suggest a need to re-evaluate objectives. At the end of this stage, the decision maker should have a comprehensive picture of the nature of the adaptation problem. Figure III.2 describes the components of these, and their associated external decision factors that have a bearing on the decision.

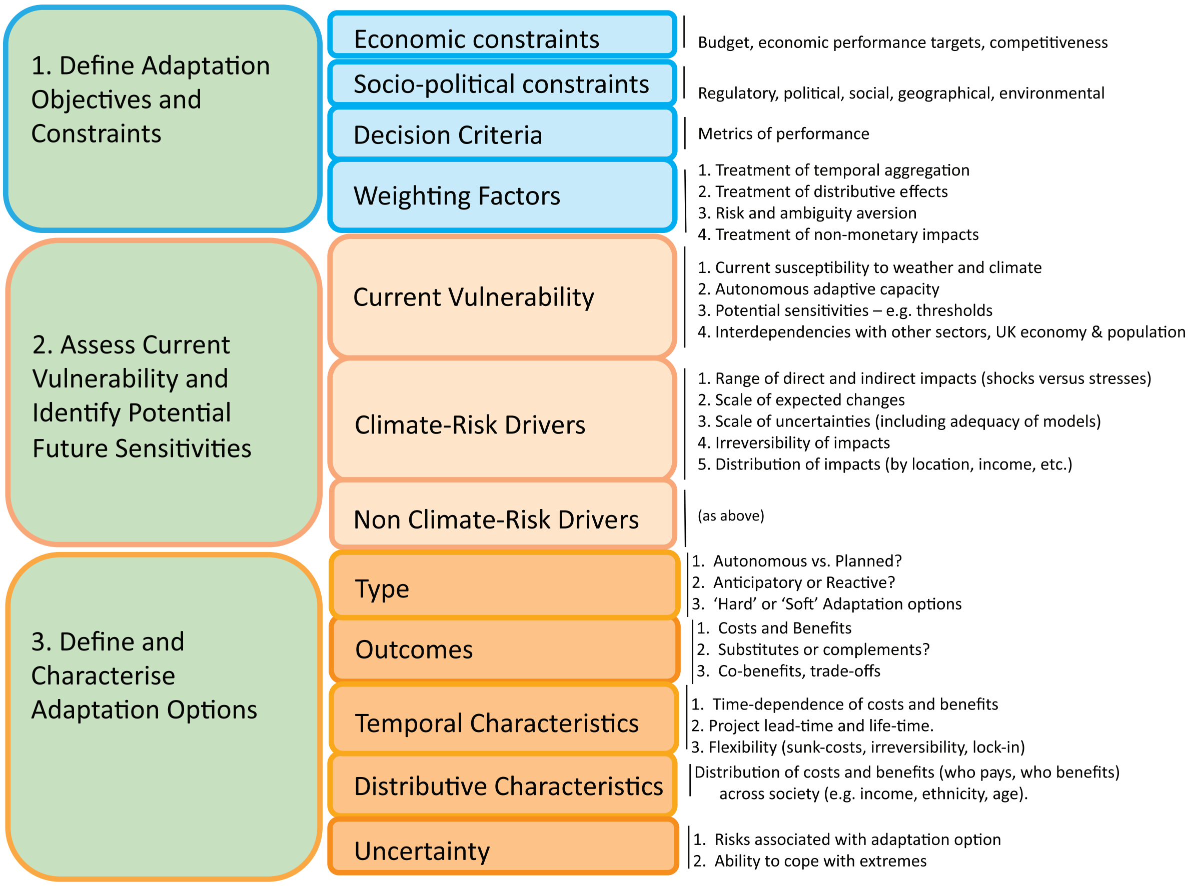
Define adaptation objectives and constraints: The first step in any decision analysis is to define the relevant objectives and constraints. The reason for this is that to best inform decisions, risks and options should be assessed in the context of their impact on a set of objectives. Objectives are not necessarily adaptation-specific and in fact using broader objectives can be useful in helping to mainstream adaptation into organisational decision making. They might be broader risk or resource management objectives; for example an objective might be to ensure no further loss of UK biodiversity, to maintain current water supply standards in a catchment region, or to achieve a 5:1 benefit to cost ratio on all new flood protection projects over their lifetime.

A process of forming objectives might begin identifying stakeholders and understanding their concerns (Box III.1). An important outcome of stakeholder engagement is to map what would be considered 'successful' adaptation and translate this into quantifiable and measurable *decision criteria* that can be used to appraise adaptation options. For example, stakeholders may wish to be protected up to a tolerable risk level, maximize the net present value of their investments, or achieve conservation or environmental quality targets.

Setting and prioritising adaptation objectives will not be a trivial process, particularly for national adaptation policy decisions. For example, in some cases, there may be difficult trade-offs to make between adaptation objectives (e.g. public spending on different projects), and also between adaptation and non-climate objectives (e.g. the need for new affordable housing in flood-exposed towns versus the need to reduce flood risk). Identifying and prioritising objectives require extensive engagement and negotiation between groups of stakeholders, both within government (i.e. between departments) and between government, the private sector and the public. These challenges are not new. For example, HM Treasury and the Cabinet Office have laid out five key principles for government action in managing risks to the public that could help to guide such a process: openness and transparency; involvement; proportionality and consistency; evidence and responsibility[15].

15 www.hm-treasury.gov.uk/managing_risks_public.htm

Figure III.2 Summary of decision factors relevant to the three steps involved in 'structuring the problem'



At this stage of the analysis it is also vital to identify all relevant constraints on action, including economic, political, geographical, and environmental constraints. An example would be a budgetary constraint or a constraint imposed by regulation (for example, levels of water abstraction from rivers are regulated to protect ecosystems and this is an important constraint on identifying new water sources). An upfront identification of constraints ensures that decision resources are efficiently allocated, since potential adaptation options that do not satisfy these constraints can be discarded immediately.

Box III.1: Stakeholder Engagement in Decision-Making

Structured decision analysis is complementary to public and stakeholder engagement. Stakeholders play an important role in the decision process, particularly in public policymaking applications, by: defining the problem and all its relevant attributes; and by evaluating the adaptation options. Stakeholders should be integral to the process and engaged throughout. A decision process like that presented in Figure III.1 can provide a structure to engagement, allowing decision-makers to elicit operationally useful information. The authors refer the reader to Willows and Connell 2003 for more detailed information on designing stakeholder engagement.

Assess current vulnerability: Understanding current vulnerability can help decision-makers understand levels of adaptive capacity, future susceptibilities to changing weather patterns and also to identify *no-regrets* adaptation options (i.e. options that provide benefits under any future climate change scenario, Box III.4). This involves, for example, identifying if and how the system has been affected by weather in the past (e.g. a hot summer, flooding or wind damage) and mapping the pathways through which climate and other stressors can affect the system. It is also helpful in identifying thresholds that may lead to a significant increase in impact; for example, relevant temperature thresholds for the survival of fish species in a lake, or design risk-standards for existing public infrastructure. The decision analysis is likely to be particularly sensitive around such thresholds. Finally, understanding historical vulnerability to other factors, such as land-use change or changes in demand, can also be helpful in identifying potential future sensitivities.

Assess potential future sensitivities: This stage involves horizon scanning/risk screening to identify where the system might be sensitive to future changes in climate and other factors, such as ecosystem decline, increasing demand or land-use change. The word *sensitive* is used broadly to include *vulnerable* or at risk. This will involve obtaining high-level (i.e. non-detailed) information about the scale of the potential changes (both climate and non-climate) that may materialise and putting this together with an understanding of the current and historical vulnerability of the system (from the previous step) to map out if and where the system may be impacted in the future. For example, robust qualitative conclusions from climate science (e.g. wetter winters and dryer summers in the future), and reasonable assumptions about non-climate drivers (e.g. water demand will grow with increases in population and economic activity), can then help us to estimate how historical vulnerabilities might be scaled up or down in the future. Identifying sensitivities enable the decision-maker to identify where adaptation may be required and what solutions are able to have a material effect on these impacts.

At this stage, information on risk drivers need only be high-level. This is a key difference from the ‘science-first’ approaches used in many risk assessment exercises (Chapter II). At this stage, future projections should not be treated as exact and significant time should not be spent on generating quantitative future scenarios. The focus should be on the sensitivity of the system itself over time, rather than the climate – be it a flood plain, population, water catchment region or ecosystem. For example, in using projections, the goal here is to sketch out a rough range of possible future outcomes for the system that can aid in identifying appropriate adaptation options. Some ‘rough’ projections are needed as time spent characterizing solutions that are too weak or too strong for the range of possible impacts will be wasted. More detailed information is collected later in the process – staggering the data gathering in this way means that data can be tailored to the decision structure.

At this stage, one should also assess the uncertainties involved in projections. With an understanding of the characteristics of information and relevant objectives, it is possible to identify the appropriate decision methods – guidance provided in Section III.C.

Identify potential solutions: The information about objectives, constraints and the plausible range of impacts collected in the previous steps is now used to identify feasible and appropriate adaptation options (Annex A.2) and their characteristics. Here, *feasible* means technically feasible and suitable for the case, and *appropriate* means in line with meeting the objectives and constraints and effective in reducing current and future vulnerability. A list of the characteristics of options to be identified is given in Figure III.2. It may be helpful to break them down using the following questions:

- **Type**: Who is required to implement the option and does it require anticipatory action?
- **Outcomes**: What are the costs and benefits and how do these change under different climate change scenarios? What impacts can it cope with? How do the options identified interact with one another, and existing practices? Are they substitutes or complements, are there any co-benefits or trade-offs?
- **Temporal Characteristics:** How do costs and benefits vary with time? What is the lifetime of the measure, when can it be implemented and how long does this take (lead time)? How flexible is the option? Can it be adjusted to account for new information in the future, does it entail sunk costs?
- **Distributive Characteristics**: How are the costs and benefits of a measure distributed across individuals? (who pays versus who benefits)
- **Uncertainty**: Are there any risks associated with the adaptation options? Are the costs and benefits certain? Is there certainty about its ability to cope with the range of future climate change and in particular, extremes?

An important part of structuring the decision problem and evaluating solutions is separating potential 'no-regrets' from those that are more sensitive to uncertainties around climate change and other drivers. **In the majority of situations, a range of 'no-regrets' options are available**, either as complements or substitutes to other types of options. The sector-level analyses in Chapter IV suggest that **there are few cases of true 'inflexible' options, where potentially 'high-regrets' decisions must be made**.

Box III.2. Categories of Adaptation Options

The case study analyses described in Chapter IV and Annex C led to the identification of a number of categories of adaptation options, in terms of their sensitivity to climate change uncertainties[16]. These are described below.

<u>No-regrets</u>**: No-regrets options are defined here as those that provide benefits under any climate scenario.** This is a narrow definition of no-regrets and does not imply 'no-regrets' in terms of zero costs or zero trade-offs with other investments.

Four broad types of no-regrets adaptation measures are identified:

- **Measures associated with managing current climate variability**, such as providing risk information and monitoring; insurance systems; research and development; or conserving existing high-value ecosystems;
- **Measures associated with managing non-climate-related drivers of risk**, such as reducing leakage in water systems; enhanced planning and building regulation controls; building natural drainage systems in urban areas; rebuilding soil fertility; and water quality management;
- **Short-lived adaptations** (i.e. those with a lifetime shorter than the timescale on which climate change is expected to affect decisions – perhaps 5-10 years in most cases), such as changing crop varieties in agriculture;
- **Broader measures aimed at reducing vulnerability and building resilience to shocks and general stresses**, such as early warning systems and emergency response for flooding; building water transfer networks between regions; and capacity **building (skills, knowledge and information).**

These options will be no-regrets as long as they do not limit flexibility to cope with future climate change. 'No-regrets' does not necessarily mean desirable; options should be evaluated against all relevant criteria as desirability will vary by case. Many of these types of options represent good sustainable development practices.

<u>**'Low' or 'no-regrets' options with significant co-benefits:**</u> this includes measures that as well as being effective forms of adaptation for the target application also have co-benefits. For example: habitat conservation can be beneficial in supporting ecosystem adaptation, but may also enrich recreation opportunities; rebuilding soil fertility can enhance agricultural productivity and improve water quality; and rebuilding wetlands enhances ecosystem adaptation and can reduce flood risk. In general, the benefits of these types of options tend to be relatively insensitive to climate change uncertainties.

<u>Flexible Options</u>**: Flexible adaptation options are those that perform under a range of plausible climates.** There are broadly two types of flexible options:

- Broadening the coping range from the start: for example, where the capacity of a water storage system is increased in anticipation of drier conditions.

16 This categorisation, derived from the next Chapter, is analogous to previous work, for example the guidance of the UKCIP on 'identifying adaptation options'.

- Allowing for possible mid-lifetime adjustments: for example, building a sea wall with larger foundations to allow for strengthening if required.

In most cases, flexible options are available and can be desirable (Chapter IV).

Inflexible Options: Where flexibility to perform under a range of plausible climates is not technically feasible and/or desirable. **These will usually be limited to urgent, long-lived options with high sunk costs (e.g. some forms of hard infrastructure).** Inflexible options will mainly be found in public sector decision-making, but could arise for private actors involved in building hard infrastructure, such as energy and water companies.

III.A.ii. Appraising solutions

By the end of the previous stage, the decision maker will have built a complete picture of the nature of the adaptation problem; the objectives and constraints, the key drivers of risk today and in the future, the key sensitivities of the system to be adapted and the range of feasible and potentially desirable adaptation options. This next stage involves more specific qualitative and quantitative assessment to help a decision maker choose between different options, based on the decision factors identified in the first stage, and consider the sequencing of options over time[17].

This second stage of the assessment need not occur in all cases, or could be conducted at a generic quantitative (e.g. back-of-envelope)/qualitative level rather than a detailed quantitative level. For example, if *'structuring the problem'* identified clear solutions then additional analyses may not be required. This might be the case where the decision maker is working with a well-defined single objective, the number of options is small and options are no-regrets.

Detailed qualitative or quantitative analysis will typically only be required where the choice between options is more subtle, more sensitive to assumptions (including climate change uncertainties) and where there are significant potential trade-offs to be assessed between different objectives and decision criteria. These types of decisions are more common to the public or large private (e.g. water and utilities companies) sectors organisations involved in planning long-lived infrastructure projects with high sunk costs, or long-term sector-level planning and regulation.

Following through a structured decision-making process, as laid out here, enables a decision-maker to identify where more detailed assessment is required and what decision tools are appropriate. **An important consideration at the beginning of the 'assess solutions' stage is if and where additional analyses can improve the decision**.

In all cases, **transparency of the analysis is crucial in a planning process; this includes making any assumptions and their sensitivity clear and providing appropriate qualitative and quantitative evidence to support conclusions.**

Assess individual adaptation options: The goal of this step is to compute/produce a set of metrics that can be used to compare and rank the adaptation options. As discussed above, the level of detail of this analysis will depend on the case and available data; in particular, how much value (i.e. improved decision making) can be gained through additional analyses.

The metrics computed will be linked with the objectives and the chosen decision method. For example, where economic criteria are important, a decision maker will rank options in terms of their benefits and costs over time, as a function of different climate change scenarios. In other cases, metrics might represent concern for riskiness, distributive consequences, or impacts on non-monetary environmental concerns. It is important to test the sensitivity of these metrics to any assumptions. For example, how would different assumptions about social discount rates, or preferences concerning the

17 This stage is analogous to 'tiers' two and three of the UKCIP-EA-Defra framework (Willows and Connell, 2003).

valuation of ecosystems, affect the relevant metrics. **The output of this stage should be a set of measures that completely characterize the performance of the adaptation options, and which can be fed directly into a method of decision analysis**.

In some cases, detailed quantitative analysis of the scale and likelihood of risks may be required in order to evaluate the effectiveness of options. Where there is high sensitivity of decisions to risk, it is crucial to identify projections that are both trustworthy and fit-for-purpose; For example, today probabilistic projections are increasingly becoming available, but these rarely represent the full range of uncertainty and are conditional on the specific modelling approach used to generate them; that is, they have *residual uncertainties*. Hall (2007) warns that improper consideration of the residual uncertainties of probabilistic climate information in adaptation planning could lead to maladaptation. This does not mean that they should not be ignored, but interpreted with full consideration of residual uncertainties. Box II.3 provides an example of the effects of residual uncertainty on decisions in the case of coastal flood risk management. Box III.3 gives some guidance on identifying 'fit-for-purpose' climate projections.

Box III.3. Identifying 'fit-for-purpose' projections

The climate and non-climate projections used in decision analysis must be fit-for-purpose. The *'best available projections'* or *'state of the art'* is not always the same as fit-for-purpose. Inappropriate use of projections can lead to maladaptation. This discussion aims to provide a simple framework that can help a decision-maker assess whether a set of information is appropriate for decision-making.

To be fit-for-purpose, projections should be: robust, relevant and informative[18]. Key questions a decision-maker should ask are:

- **Robustness**: is the information likely to change over time in ways that could affect the decision? (i.e. will there be some learning over time?)
- **Relevance**: does the basis for the information (i.e. the climate and economic modelling) include all the necessary processes and factors at appropriate scales needed to represent the changes that the decision is sensitive to? For example, high-resolution cloud physics or appropriate topography.
- **Informativeness**: is the information provided on the necessary spatial and temporal scales, and with the correct variables, to inform the decision? If not, how does this affect the decision process?

The answers to these questions will vary significantly between regions, timescales and decision types. A negative answer to any of these questions does not mean that adaptation should be abandoned but does have implications for the way that information is interpreted. For example, where climate projections are expected to change over time (i.e. low robustness) there may be a case for an approach of waiting and learning before taking irreversible decisions. Real options and robustness-based analyses can help a decision-maker to weigh up the benefits of waiting in such cases.

In many cases, the level of understanding and detail required to answer the questions above and correctly interpret projections can only be provided from experts. In some cases, interpretation can be controversial and will require consulting multiple experts. In cases where sensitivity is high, this is likely to be a worthwhile step. For example, working with experts may help to define levels of confidence in projections and plausible upper and lower bounds on projections. This can be valuable in assessing the sensitivity of conclusions to projections (e.g. Box II.3). Analyses can be strengthened by gathering information on the timescales and levels of likely improvements in projections and on what timescales there will be observable signals that would allow a narrowing of uncertainty over the pathway of future changes. This can be informative in designing strategies that wait for better information before acting (Section II.E).

[18] The RRI Framework is based on a presentation by Professor Leonard Smith, LSE, at the Royal Society on *The Science of UK Climate Projection - UKCP09 and beyond* on 15th October 2009

Decision Analysis: In this final step, decision methods are applied to grade the effectiveness of options in the context of the combined objectives of adaptation (e.g. objectively evaluating outcomes against multiple criteria) and considering uncertainty. From this, decision-makers can generate plans to implement one or several 'best' options and specifying what should be implemented, where and when.

Decision analyses usually take as inputs information about the risks and opportunities faced and the options available to us, and generate rules for action that respect the desire for consistency, and basic rationality criteria. They will take the quantitative metrics of appraisal for each measure calculated in the previous step and use them to rank the measures according to a chosen decision method. The recommendations that emerge from a good decision analysis need not be a simple 'pick option A'. Rather, if the adaptation options are flexible, or if there are several options of different lifetimes and effectiveness, the outcome of the decision analysis should be a set of conditional implementation rules, i.e. rules of the form 'If X occurs by date Y, then do Z'. Section III.C provides detailed guidance on appropriate decision-methods.

The grading of different options can be sensitive to the choice of decision method. For this reason, it is vital to assess how the adaptation plan generated depends on the underlying assumptions of the analysis and choice of decision method (guidance in Section III.C). In particular, it is very important to check that the decision rules are robust to those assumptions in the model which are known to be unlikely to hold. For example, a cost-benefit style analysis should at the least conduct a sensitivity analysis in order to see how the ranking of adaptation options depends on assumptions about the magnitude and likelihood of future impacts, and other parameters, such as the discount rate (e.g. the example given in Box II.3 and Annex B.1).

If the ranking of options is highly sensitive to parameters whose values there is reason to doubt it may be necessary to apply modified decision methods that assess the robustness of decisions to violated assumptions, to favour those options that admit a degree of flexibility, or to pick options that are less sensitive to known unknowns. Conducting such robustness checks may require several of the decision process steps, e.g. the appraisal of adaptation options, to be iterated.

Monitor, Evaluate and Review Adaptation Plans: Planning is only the first step. Adaptation is an interative process of planning, implementation and review. This is indicated by the arrow circling back to step one in Figure III.1. It is important to monitor, evaluate and regularly review the performance of adaptation plans. Where there is some flexibility in an adaptation plan, either in terms of sequencing of options or possible adjustments in measures, plans should be responsive to new information; for example, a given level of impact might trigger implementation of an adaptation measure. The context of the adaptation problem may also change and strategies should be responsive to such changes, for example, objectives and constraints may change (e.g. level of risk aversion or the value of ecosystems may increase over time) or more effective adaptation options may become available.

Figure III.3. The planning phase of the decision-making framework with a summary of suggested actions for each step of the analysis.

Structure the Problem	Context: Define Adaptation Objectives and Constraints	• Identify and engage relevant stakeholders • Agree decision-making process and relevant planning time horizon • Define the constraints: environmental, regulatory, budgetary, political • Agree objectives of adaptation – what is successful adaptation? How does this relate to existing objectives? e.g. biodiversity targets) • Establish and prioritise decision criteria, e.g. cost/benefit thresholds and/or non-monetary targets (e.g. lives saved), robustness, equity concerns, attitudes to risk
	Assess Current Vulnerability and Identify Potential Future Sensitivities	• Assess current sensitivity of the system to weather and climate, and other external factors, including key thresholds and dependencies – e.g. has the system been affected by past weather events; what is the path through which weather could affect the system; how is this aggravated or improved by other external factors, like land use change or demand? • Future risk screening: at a broad level, what types of external factors (climate and non-climate changes, like land-use change), could effect the system over the planning horizon; broadly, how might these effect my objectives, what is the plausible range of impacts over time?
	Define and Characterise Adaptation Options	• What adaptation measures are appropriate and viable to manage the scale of changes expected and given my constraints/objectives? • What are their characteristics? E.g. lifetimes (see Figure III.3)
Appraise Solutions	Assess Individual Adaptation Options	• Consider what types and level of analysis is necessary to rank and/or sequence different adaptation options and identify relevant and fit-for-purpose information • Assess (quantitatively or qualitatively, as appropriate) how the performance of adaptation measures varies under different plausible future scenarios against the various decision criteria (e.g. cost/benefits; non-monetary benefits; robustness, riskiness and trade-offs). Identify 'no-regrets' measures. • Risk Assessment: identify any thresholds in climate change that are important to choosing between options. Collect and characterise knowledge about the likelihood of crossing these thresholds
	Decision Analysis to Generate Implementation Plans (What, Where, When)	• Using an established decision rule, rank the performance of adaptation options against the adaptation objectives and constraints. • Produce a plan of which options to implement, and when. Test the robustness of this plan to underlying assumptions. • Make a recommendation

III.B. How can one identify high value information in a decision?

Identifying the most valuable information in a decision is useful in determining where resources should be focussed in collecting data or commissioning additional research to narrow uncertainties. The most valuable information will be the information that the decision is most sensitive to. This will come out of the *structuring the problem* phase of the process as it is defined by the interplay between (i) decision criteria and constraints, (ii) current vulnerability and future risks and (iii) the characteristics of available adaptation options. The high-level analyses (Chapter IV) suggest that in many cases the highest value information is likely to come through understanding current vulnerability, historical climate variability and non-climate drivers of risks. For example:

- Where the lifetime of adaptation options is relatively short, as in the majority of cases for the food sector, the dominant driver of the decision will likely be current climate variability.
- Similarly, in many cases, options may be available that have benefits under any climate scenario, for example, some options involved in building resilience to climate-related shocks, or measures that aid in managing current climate variability, such as, insurance systems or conservation of high value habitats.
- In other cases, non-climate-related risks may be the dominant driver of decisions, and so resources might be best focussed on better understanding these. For example, increases in demand are likely to be the dominant driver of increases in water stress in the UK, particularly in the short-term.

A reason why understanding current vulnerability and historical climate variability is so important is that this can provide useful information about future sensitivities. Also, in some cases, better managing to current climate risks will be an effective form of adaptation. For example, in the short to medium-term, in some cases, the impacts of climate change may not be significantly different from the impacts observed today from natural climate variability and anthropogenic climate changes to date, and so. Examples include river flows, surface runoff and peak wind speeds, where the effects of climate change are unlikely to be discernable from natural climate variability and other drivers at a local scale (Box IV.4). Even where climate change has already had a discernable influence, the impacts may not change significantly over the next five to ten years[19] and so better managing the current level of risk will still be an effective form of adaptation. There are exceptions to this. For example, ecosystems, where thresholds in damage could be exceeded at even slow rates of change and low amounts of absolute temperature rise (Parry et al. 2007).

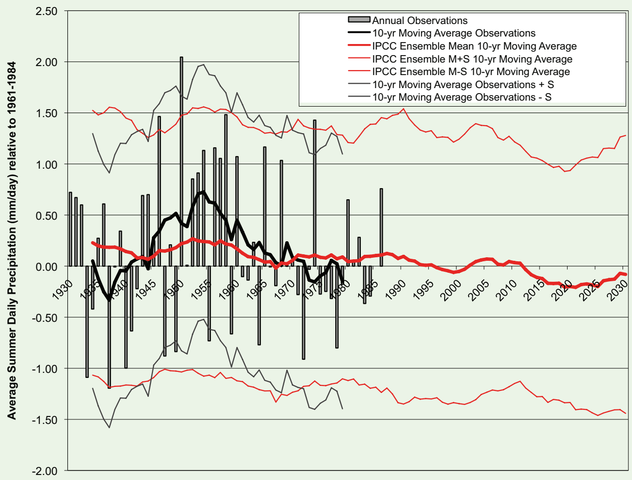
There are other exceptions. In general, decisions that will be potentially sensitive to climatic changes are longer-term decisions, for example, long-lived hard-infrastructure and sector-level planning and regulation with long-run implications (such as, building regulations and land-use controls, and investments in research and development). In such cases, more detailed probabilistic climate change projections may be of value. This is not necessarily true in all cases. Where there is a low level of confidence in the likelihood estimates of different projections, it may be desirable to adopt a flexibility or robustness-based approach. For example, real options theory explicitly recognises that projections change over time as more knowledge is developed and allow decision-makers to evaluate the benefits of delaying action or incorporating physical flexibility (Annex A.4). Robustness-based approaches can allow decision-makers to weigh-up the benefits of sacrificing potential productivity for flexibility in dealing with ambiguous climatic changes. Neither of these approaches necessitates computationally-expensive detailed probabilistic projections of climate change. These approaches are discussed in the following sections.

State-of-the-art detailed and computationally-expensive climate modelling could be valuable where it is desirable to optimise a decision, rather than build in flexibility or robustness; for example, where the decision is urgent and building in flexibility from the start is overly costly (e.g. in building a major new reservoir). In such cases, it is necessary to explicitly recognise secondary uncertainties in probabilistic estimates and incorporate these into decision-making through, for example, sensitivity testing to different input probability functions or more formalised approaches (e.g. see Annex A).

[19] For example, the Central England Temperature has risen at an average rate of around 0.08°C per decade since 1900 (though faster over the past two decade) (Parker and Horton, 2005).

Box III.4: Comparison of current climate variability and climate change

This box gives an example of the size of climatic changes compared with natural climate variability for a decision-relevant climate variable: local summer precipitation. In this case, as in many other cases, the scale of manmade climate change is smaller than the scale of natural variability on short to medium-term timescales (with the timescale depending on the case). This means that in many cases adapting to current climate variability can have significant benefits both now and in the future.



The figure below compares observations of average summer precipitation in the Devon region over the period 1961 to 1984 to an ensemble-mean climate change projection out to 2030. Clearly, the variability in average summer precipitation between 1961 and 1984 (roughly ±1.5mm/day at one standard deviation), driven by natural interannual variability, is larger than the predicted trend out to 2030 (less than 0.25mm/day). If one were trying to interpret such data from a water supply perspective, one might conclude that options to reduce the vulnerability of the system to present day extremes, such as increasing water efficiency and reducing leakage, might form an effective and robust near-term adaptation strategy.

Comparison of observed (in black and grey) and ensemble-mean projected (in red) average summer daily precipitation. Projections are from the IPCC model ensemble. The bars give the observed annual quantities. The thick lines give the 10-yr moving average of the observations (black) and projections (red). The thinner lines give one standard deviation on the moving average – these are of similar scale for both observations and the IPCC model ensemble suggesting that the models represent the scale of natural climate variability quite well. Sources: observed data provided by the Environment Agency and climate change projections from the IPCC Data Distribution Centre.

III.C. What decision-method should be used in an analysis?

Rigorous decision methods can play an important role in decision-making, particularly where stakes are high and no-regrets measures are unavailable. These methods provide a formalised structure to facilitate the ranking of options given a set of decision criteria. A range of methods are available; each appropriate for differing situations of information and decision criteria.

*Figure III.4 Simplified flow diagram illustrating the linkages between decision methods and characteristics of information and decision-criteria. See Annex A for further details. (*incomplete means an incomplete set of probabilities for different outcomes; however, the decision-maker should know the range of possible outcomes, particularly the worst case scenario).*

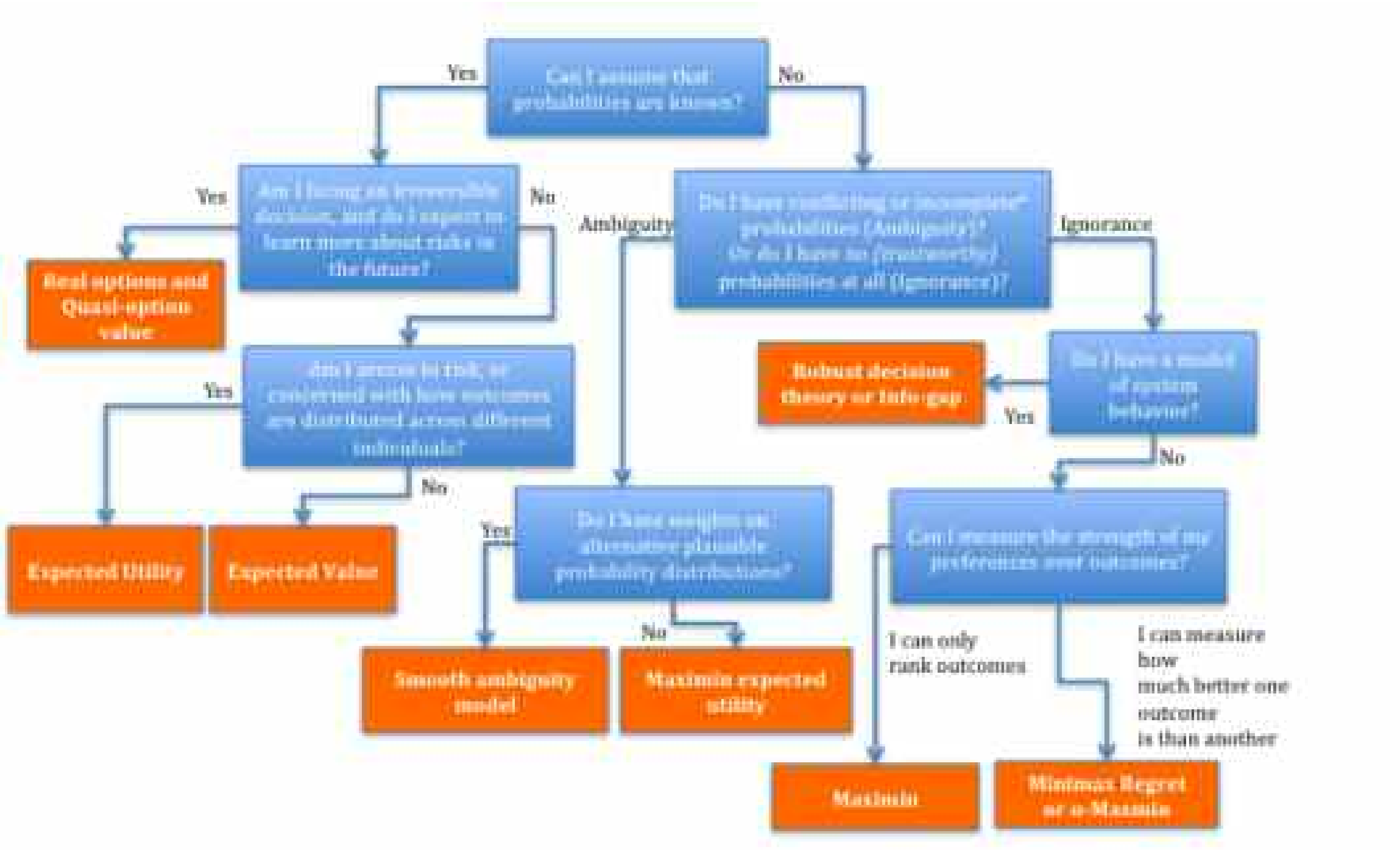


Figure III.4 illustrates the linkages between different decision methods and the characteristics of the problem across a number of dimensions, focussing on identifying the appropriate analytical tool for the type of information about future outcomes. Figure III.4 is presented as a flow chart that a decision maker could work through to by asking questions such as:

- *Can I assume that the probabilities of different future outcomes are known? These* future outcomes could include, for example, the probability of a flood of a given magnitude, the probability of different levels of regional temperature increase due to climate change, or the probability of different scenarios of future changes in water demand – whichever are relevant to the decision. Answering yes to this question implies that level of confidence in these probabilities is high.
- *Am I facing an irreversible decision and do I expect to learn more about important risks over time?* As an example, an irreversible decision might involve large-scale infrastructure that is difficult and costly to replace. Given where this question is in the flow diagram (Figure III.4), an example of a positive case would be one where the possible range of future outcomes is known and a set of trustworthy probabilities of different outcomes is available based on current understanding, but there is a belief that the knowledge of the likelihood of different outcomes will improve over time and therefore, some flexibility is desirable. A real-options analysis is one approach that could be suitable in such a case; an example is given in Section III.D.
- *Am I averse to risk, or concerned about how outcomes (i.e. impacts, costs and benefits) are distributed between different individuals?* For a case where probabilities are known and are not expected to change over the timescale of

the adaptation in light of new information a number of approaches are available. This question refers to the decision maker's attitude to risk and equity.

To give an example application – if the probabilities of different future climate projections are known and not expected to change with new information then the decision analysis might be best suited to an *expected utility analysis or expected value analysis*. Expected value approaches are used frequently in, for example, flood risk management assessment (Defra, 2009), where the probabilities of flooding are assumed to be known based on modelling and historical data. Conversely, if a decision maker has a trustworthy set of probabilities based on current knowledge but these are expected to be refined over time with new information, then a *real options* analysis would be more appropriate; this can evaluate the benefits of acquiring more information before acting. On the other hand, if the level of confidence in projections is lower, for example, I have conflicting probability estimates from different models or incomplete probability estimates (but know the worst case scenario), and can not quantify the relative confidence of these probabilities (e.g. the weights that should be applied to different model estimates) then a *maximin expected utility* analysis might be most suitable. Whereas, if I do not have any trustworthy probability estimates then *robust decision theory* is more appropriate.

Figure III.4 is simplified but provides a good first guide that can be supplemented with further information (e.g. Technical Annex A). Also, in reality factors such as technical expertise and resources will play a role in selecting the most appropriate analytical tools. Importantly, it is often **valuable to sensitivity test findings to the choice of decision method and its assumptions**.

Figure III.4 highlights that **the appropriate decision method is dependent on the characteristics of the projections, in particular, the level of confidence in those projections. It suggests that detailed probabilistic projections (alone) are only of value in decision-making where they are considered trustworthy and 'fit-for-purpose'.** This may not be the case in some circumstances. For example, climate change projections at decision-relevant spatial scales, for example of local precipitation changes and the characteristics of extreme events like heavy precipitation or peak wind speeds, currently have a low level of confidence; there are conflicting estimates from different models and probability distributions have structural uncertainty. The level of ambiguity in climate projections increases over time, due to divergent emissions scenarios and the increasing importance of possible missing feedback effects, such as carbon and methane feedbacks. As time goes on, it is more likely that the level of certainty be characterised as *ignorance*. **Misinterpretation of projections, in particular, not recognising the true level of uncertainty (e.g. beyond that which is quantified) could lead to maladaptation**. Some approaches to establishing the trustworthiness of projections are discussed briefly in Box III.3.

Given the ambiguity in many long-term projections, where decision-makers are required to make long-term decisions with high sunk costs a crucial choice in planning is likely to be how to make the trade-off between maintaining robustness under different plausible climate change scenarios and optimising productivity (i.e. assuming a 'best guess' distribution of outcomes). Both real options analyses and robustness-based analyses can help a decision-maker to evaluate the trade-off between optimising returns and robustness (Section II.E). For example, Annex B.1 reports that in the case of the Thames Estuary 2100 project, decision-makers identified that building a new Thames Barrier is a long-lived, irreversible decision (i.e. it has high sunk-costs, as well as long lead-times) and that we expect to learn more about the critical drivers of uncertainty (sea level rise and the effects of climate change on storm surges) over time. In this case a real options approach was applied, which allowed the decision-maker to evaluate the option value of waiting for more information. Given that multiple probability distributions of sea level rise are available, the project employed some aspects of a robustness approach, sensitivity testing recommendations to different assumptions. The study concluded that the approach with greatest expected benefits was a sequential decision-making approach, incorporating waiting and monitoring before investing in a new barrier, alongside the more immediate implementation of no-regrets options. Other decision methods are available for situations where probabilities of future outcomes are either conflicting or incomplete.

Another dimension to consider when selecting appropriate analytical tools is the form of the decision criteria to be satisfied in selecting adaptation options. For example, are criteria monetised or are there multiple criteria some of which are monetised and some are non-monetised. Quantifying the effectiveness of adaptation options in a single aggregate form (usually monetary, so that it can be compared directly with costs) can simplify the decision analysis. Each of the decision tools given in Figure III.4 is designed to work with such a single decision criterion. However, in some cases such aggregation is not desirable, for example where it is not possible to fully monetize impacts. ***Multi-criteria decision analysis*** **(MCDA) approaches may be useful when it is important to weigh up diverse decision-criteria, for example, for cases assessing the co-benefits to ecosystems, or the trade-offs with other development objectives** (Annex A3.iii).

In some cases different decision methods can be combined in ways that play to each of their strengths. For example, expected utility analysis is often used with multi-criteria decision analysis (MCDA) techniques where there is more than one decision criterion. Similarly, in the Thames Estuary 2100 project, a real options analysis was used with extensive sensitivity testing of sea level rise assumptions (i.e. incorporating some elements of robustness-based analyses), plus an MCDA to evaluate the benefits of incorporating flexibility into the plan across multiple decision criteria.

Each of the approaches in Figure III.4 assumes that the state and outcome spaces – i.e. the range of plausible futures and impacts resulting from climate change or other factors – are well specified. If the state and outcomes spaces are well-specified then the likelihood of a 'surprise' outcome that would significantly affect the decision is negligibly small. Clearly it is not possible to exclude all surprises (e.g. the 'unknown, unknowns'), but the space should cover all known and plausible scenarios. When the space is not well specified – i.e. there is a non-negligible chance of a 'big surprise' that could effect the decision – further approaches are available; for example, horizon scanning, scenario planning and also the adaptive capacity and vulnerability-based approaches discussed in Chapter III.

For a more detailed discussion of the decision methods' assumptions about the decision-maker's preferences and the completeness of their information about the future, and their pros, cons, and domains of applicability, see Annex A. Table III.2 provides a summary of all these methods and their assumptions. For public policy applications, the authors also refer the reader to the *HM Treasury Green Book* (HMT, 2003).

III.D. Case study: the Thames Estuary 2100 project

The objective of the EA's Thames Estuary 2100 (TE2100) project[20] was to provide a plan to manage flood risk in London and the Thames Estuary over the next 100 years. The Thames Estuary region is exposed to storm surge flooding from the North Sea. Today the region is well protected but the impacts of an unmitigated storm surge flood would be disastrous in terms of lives lost, property damaged and economic disruption. Major floods occurred in 1928, the last time central London was inundated, and in 1953, when there was extensive damage and loss of life in the eastern part of the Estuary. After 1953, flood defences in this part of the Estuary were raised and strengthened, and the Thames Barrier was opened in the 1980s to protect central London against at least a 1-in-1000 year return period storm surge. The system was originally designed to last to 2030. The TE2100 project aimed to examine whether and when the system might need to be modified and to provide a forward plan to 2100. The plan needed to consider not only growing hazards due to climate change, but also the parallel pressures and uncertainties related to ongoing development within the flood plain.

The TE2100 project is included here because it provides a real example of a 'policy-first' approach and is also a ground-breaking application of a real-options analysis to examine the benefits of incorporating flexibility into a long-lived, irreversible infrastructure project to help manage climate change uncertainty. It also carried out extensive testing of options to assumptions, particularly over future sea level rise projections, and so informally incorporated elements of a robustness-based approach. In TE2100, the plan proposed focuses on maintaining flexibility to cope with the range of possible future sea level rise. The analyses demonstrated that no-regrets measures, such as extending the lifetime of existing flood management infrastructure, could be effectively used to 'buy-time' before implementing an irreversible decision (e.g. a new and expensive barrier) that would have highly-uncertain benefits given current uncertainty over sea level rise. The plan incorporates a process to wait, monitor and learn to gain more information before taking a larger and irreversible investment decision to deal with long-term increases in extreme water levels. The TE2100 project did not explicitly set out to use a 'policy-first' approach; however the process followed was similar in spirit. Table III.1, suggests how an analogous adaptation analysis might be structured using the framework laid out in Figure III.1 (Haigh and Fisher 2010, and Tim Reeder, EA, *personal communication*)[21].

[20] TE2100 was a six-year project led by the EA. The resulting plan was issued for consultation in April 2009. Documentation is available at: http://www.environment-agency.gov.uk/research/library/consultations/106100.aspx

[21] This draws on a approach laid out in a forthcoming paper by Tim Reeder

Framework		**Simplified Analytical Steps drawing on TE2100, with application to Thames Estuary in italics**
Structure the Problem	Define Adaptation Objectives and Constraints	Identify and engage stakeholders to develop and prioritise adaptation objectives. *Key decision criteria for TE 2100 included economic value of investments and environmental and social factors. A constraint was the environmental impact standards set out in the Water Framework Directive.*
	Assess Current Vulnerability	Examine the resilience of the system to present-day risk. *The first stage of TE2100 was an evaluation of flood protection levels throughout the Estuary*
	Identify Potential Future Sensitivities	Build a high-level picture of the paths through which climate and non-climate factors will affect the system over time. *TE2100 began by building a picture of how climate change could affect flood risk in the Estuary.* Identify plausible upper and lower bounds of future projections of both climate and non-climate factors. Identify the key uncertainties that would influence adaptation strategies. *For the Thames Estuary, science and modelling initially suggested a maximum potential increase in extreme water level of 2.7m in 2100. For sensitivity testing, an upper bound of 4m was used to represent a catastrophic sea level rise scenario.* Assess the sensitivity of the system across the range of plausible futures. *Key thresholds for sensitivity in the system are: (i) a limit of the present system of walls and embankments is reached;, (ii) the current Thames Barrier system as designed will fall below the target protection level (1 in 1000); (iii) the limit of the Thames barrier with modifications; and (iv) at 5m it would become difficult to continue to protect London in its current form (i.e. limit to adaptation), potentially requiring some retreat.*
	Define and Characterise Adaptation Options	Identify/design adaptation options appropriate to the range of potential future risk and eliminate any that are unfeasible or technically ineffective. *TE2100 identified a range of structural and non-structural options relevant to the range of potential changes in extreme water level (Figure III.5).* Assess response thresholds; i.e. range of increase in extreme water level that would prompt one or more responses to be deployed. *See Figure III.5.*
Appraise Solutions	Assess Individual Adaptation Options	Develop a series of detailed climate change scenarios. *TE2100 conducted modelling work in partnership with experts to build detailed sea level rise and storm surge projections representing 'central' and a number of low and high scenarios and assessed the level of scientific confidence in each.* Assess what adaptation options or sequences of options (pathways) are able to deal with which scenarios. *All adaptation pathways are able to cope with the 'central' scenario, but only path 4 copes with the worst case.* Explore costs vs. benefits of options and pathways under the different climate change scenarios, including exploring trade-offs and co-benefits relevant to the objectives and constraints. *Under the central scenario,*

		whole-life costs ranged from £1.6bn for the 'do minimum' option (maintaining existing defences) to £5.3bn for the greatest response (a new barrage). A comprehensive assessment of the economic, environmental and social benefit of options was conducted.
	Decision Analysis to Generate Implementation Plans	Apply an appropriate decision method to rank options. In TE2100, a multi-criteria decision analysis was used to rank the options against multiple adaptation objectives under the 'central' scenario. This set out the 'best' pathway given current knowledge – enhancing the existing system with a significant upgrade to the barrier in 2070. This analysis was then repeated with other scenarios to explore the robustness to uncertainties. This showed that the 'best' pathway was robust, but strengthened the case for a new barrier, suggesting a need to monitor and keep this option under review. Develop a strategy, including monitoring and evaluation. Based on the decision analysis, the strategy sets out a range of early actions and a 40-yr investment plan. No single longer term option is specified – action is focussed on keeping options open for later. A real options analysis is used to demonstrate that this is worthwhile. On current knowledge, a decision will be needed in 2050, but this is kept under review in light of new information. Review is planned every 5 – 10 years.

Table III.1. The process of the TE2100 project presented in terms of Figure III.1.

For TE2100, the choice of adaptation option was found to be highly sensitive to mean sea level and storm surge projections, which are notoriously uncertain (e.g. Lowe et al. 2009). Figure III.5 shows the potential adaptation pathways developed by TE2100 and the ranges of sea level increase over which they are relevant. To overcome the uncertainties in projections, an important advance of the TE2100 project was to focus the analysis of options on an appraisal of thresholds, lead times and decision-points (Jonathan Fisher, *personal communication*) (Figure III.6). That is, for each adaptation option identified, the project assessed: the key threshold of climate change at which that option would be required (in this case, extreme water level); the lead time needed to implement that option; and therefore, the decision-point (in terms of an indicator value, here observed extreme water level) to trigger that implementation.

Figure III.5 High-level adaptation options and pathways developed by TE2100, shown relative to threshold levels increase in extreme water level. The blue and red lines show possible 'high level options'; particular options pathways that can be followed in response to different thresholds (Haigh and Fisher, 2010).

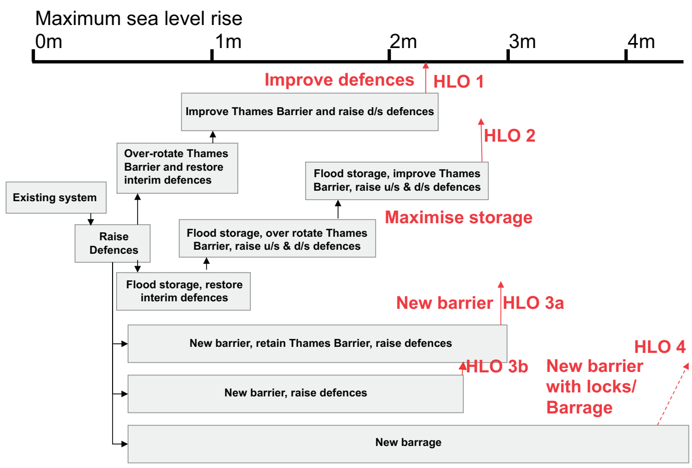
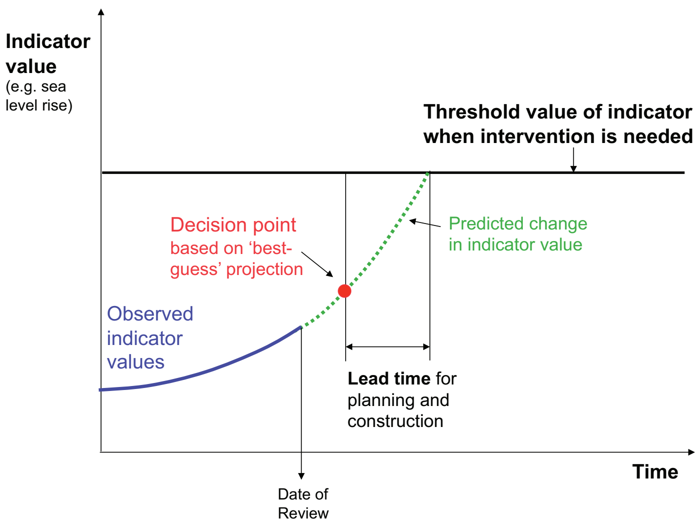


Figure III.6. Schematic diagram of the thresholds, lead times and decision points approach used in TE2100 (Haigh and Fisher, 2010).



These analyses led to the recommendation that an initial 40-yr investment plan be put in place to upgrade the existing flood management system (e.g. raise defences). Taking these cost-effective and robust interventions first meant that the decision-makers could 'buy-time' before the first critical decision point is reached. On current projections, this initial decision point is expected to come around 2050; at which point decision-makers would choose between the more irreversible options; such as upgrading the existing Thames Barrier or building a new Barrage. Delaying this choice to 2050 means that it is likely to be improved by additional information gained in the intervening decades. However, if monitoring reveals that water levels (or another indicator, such as barrier closures) are increasing faster (or slower) than predicted under current projections, decision points may be brought forwards (or put back) to ensure that decisions are made at the right time to allow an effective and cost-beneficial response. A real options analysis was used to weigh-up the trade-offs of taking an irreversible decision now versus delaying until the critical decision point is reached in around 2050. Under one scenario, this estimated a benefit in waiting of around £14bn. The plan is to be reviewed every 5 – 10 years, taking into account observed changes and any new information from, for example, climate modelling.

This example highlights the potential benefits of a real-options approach. This type of approach could be relevant in other cases where decision makers are dealing with long-lived, large and irreversible decisions that are potentially sensitive to climate uncertainties (e.g. public infrastructure, including water supply reservoirs and flood management). The 2009 supplementary Green Book guidance on Accounting for the effects of climate change states that 'a real options approach is particularly suitable for policies, programmes or projects which have three core features: uncertainty, flexibility and potential learning'. However, real options analyses do depend on trustworthy and fit-for-purpose probability distributions for future outcomes. In many adaptation examples, such data will be unavailable and over-reliance on ambiguous probabilities can lead to maladaptation. In the TE2100 case, this was overcome through an informal robustness-based analysis that sensitivity tested the options to a range of assumptions about sea level rise and made recommendations that aim to be robust to these uncertainties.

A potential challenge with real options analyses is that they can be resource intensive. However, in these cases of high sunk costs, this type of careful, substantive and clear appraisal, with a full assessment of sensitivities and uncertainties, is often necessary to justify a flexible approach[22]. The learning developed during TE2100 and other projects will be applicable to other cases and so may be able to reduce the resource requirements of future projects.

Decision method	Decision criteria	Preference assumptions	Information assumptions	Additional requirements	Reference Annex A
1. METHODS APPLICABLE WHEN PROBABILITIES ARE KNOWN					
Maximize expected value	Usually economic costs and benefits	Time discounting Risk neutral. Does not account for equity of outcomes[23]	Known probabilities over all future events. No learning.	Marginal costs and benefits, i.e. small relative to consumption.	3.i
Maximize expected utility	Consumption, broadly defined to include monetized valuations of non-monetary impacts	Time discounting. Utility function: Accounts for risk aversion and equity of outcomes.	As above.		3.ii
Multi-attribute utility theory and Multi-criteria decision analysis.	Many criteria, including non-monetary impacts.	As for expected utility, + assumptions about the interactions between criteria (e.g. independence).	Usually deterministic, i.e. applicable when accounting for multiple objectives is more important than accounting for uncertainty. If uncertainty is accounted for, requires joint probability distributions over all decision criteria.		3.iii
Quasi-option value and Real options analysis	As for expected utility or expected value.	As for expected value or expected utility.	Known probabilities, + a model of how probabilities change in response to new information.	Irreversible adaptation options (sunk costs), or costly to adjust to new information.	4

[22] This includes for example: an assessment of the net-present-value of investments under the different options and the probability of a high sea level rise scenario that would be needed to justify different adaptation pathways.

[23] See comments on equity weighting in section 3.1 of Annex A.

Decision method	Decision criteria	Preference assumptions	Information assumptions	Additional requirements	Reference Annex A
2. METHODS APPLICABLE WHEN EXACT PROBABILITIES ARE NOT KNOWN					
Maximin expected utility	As for Expected Utility	As for expected utility + Extreme ambiguity aversion (act as if the worst plausible probability distribution were correct)	Multiple plausible probability distributions.		6.i
Smooth ambiguity model	As for Expected Utility	As above, but allows for any attitude to ambiguity.	Multiple plausible probability distributions, and weights on each of these distributions		6.i
Maximin	Any	Ordinal ranking of outcomes[24]	No likelihood information		6.iii
Minimax Regret	Any	Cardinal ranking of outcomes[25]	As above		6.iii
Info-gap decision theory	Various	Does not rigorously account for preferences. Assumes satisficing[26] thresholds , i.e. acceptable levels of minimum performance/ maximum windfall.	A 'best guess' model of the decision environment, and a set of models that are 'close' to this best guess.	A method for measuring the distance between different models (an 'uncertainty model')	6.iii

Table III.2: Summary characteristics of a set of standard decision methods. For a full description see Annex A.

[24] Ordinal rankings tell us which of two outcomes is preferred, but not by how much.

[25] Cardinal rankings allow us to say how much better one outcome is than another. Differences between outcomes that are ranked cardinally are meaningful.

[26] A satisficing threshold is the value of a decision criterion at which an adaptation option is considered 'good enough'. See Annex A, section 6.3.

IV. Implications for adaptation planning: case studies

In this chapter, the *'structuring the problem'* component of the framework developed in Chapter III is applied, albeit at a high level, to four case studies to identify key risks and decision factors, and draw broad conclusions for decision-making. The aim of this exercise is to demonstrate how, by mapping relevant risks, objectives and adaptation options, a decision-maker can begin to construct near-term and long-term plans and identify important knowledge gaps. The four case studies are all UK-based and include: the food sector; inland and coastal flooding; the water sector; and ecosystems and biodiversity. These case studies were selected through an initial scoping and aim to cover most of the unique characteristics and challenges of adaptation planning.

This chapter overviews each of the case studies individually. More detailed analyses are given in Annex C (which also contains the full references for the analyses and tabulated information on the characteristics of adaptation options). From these analyses, high level conclusions are drawn, related to:

- The sensitivities of adaptation plans to climate change;
- The available adaptation options, and whether they are 'no-regrets', flexible or inflexible (for definitions, see Box III.2), and where co-benefits exist;
- The types of policies and measures that may be needed in the short-run.

The broad decision-factors are summarised in Table IV.1 and adaptation options are categorised in Table IV.2. The largest differences between the sectors come from the objectives and the adaptation options. The risk drivers and long-term uncertainties are similar, but not identical in scale or impact.

In analysing the risks and options involved in adaptation in each sector, it become clear that adaptation planning incorporates a number of cross-sectoral activities, co-benefits and trade-offs. These are discussed in more detail at the end of this Chapter.

IV.A. Flooding in the UK

Unique characteristics and challenges: flooding is a case of high levels of current exposure, highly uncertain changes in risk due to both climate and non-climate drivers, and many hard-infrastructure investments with high sunk-costs. Funding for protection and flood response has traditionally come from the taxpayer, with some complementary individual and private-sector actions.

IV.A.i. Overview of decision factors

Current vulnerability: Exposure to flooding is high in the UK; for example, the Environment Agency's 2008 *National Flood Risk Assessment* estimates a total of 5.2 million properties at risk from coastal, river and surface-water flooding in England alone. The spatial distribution of risk is heterogeneous. Localised flooding occurs frequently. Many properties are protected to some extent, but residual risks at a national level are significant; for example, the expected annual damage to property across the UK is estimated at more than £1 billion. The most recent and severe flooding was in 2007, when 55,000 properties were flooded and 13 people were killed. Flooding also leads to long-lasting effects such as stress, injury, displaced persons, damage to ecosystems, and disruption to economic activity and public services.

Potential future sensitivities: There are several drivers of potential future sensitivity related to flood risk. In the near term, the most important driver is likely to be land-use change, which tends to increase exposure to flooding and can increase the flood hazard itself through changes to drainage and runoff. In addition, there will be continued susceptibility to natural climate variability and weather. In the longer term, alongside land-use change, there could be discernable effects of climate change on inland flooding. Such trends are very difficult to predict on a local level due to the ambiguities in climate projections. Trends in coastal flooding are clearer (in direction, if not scale); for much of the UK coast, sea level rise will tend to increase flood risk (alongside coastal erosion in some areas). Flood risk will also be influenced by changes in storm surge characteristics, over which there is much uncertainty in projections at present. From climate change alone, the effects at a national level could be significant, for example, the Environment Agency estimated that by 2035, around 60% more properties could be at significant risk from flooding. This could be aggravated by further development.

The current decision context: In the UK there is no 'right' to be protected and generally no entitlement to any particular standard of protection. The UK Government has developed a rigorous framework for assessing flood risk management projects with a set of objectives defined in terms of economic value-for-money, people protected and environmental protection.

Adaptation options: A broad range of options are available to reduce and manage flood risk, including both anticipatory and reactive measures. Adaptation options can be broadly categorised as: risk information and early warning; preparedness and response; development and land-use planning; 'hard' infrastructure (e.g. flood defences, pumps and flood storage); 'soft' infrastructure (e.g. natural flood storage and restoring natural water courses); managed retreat; and property-level adaptation (including insurance). The full characteristics of these options are tabulated in Annex C.5. Many of the options are complementary and beneficial as part of an integrated strategy.

IV.A.ii. Conclusions for decision-making

The ambiguities in estimates of future flood risk and high potential sensitivities make adaptation planning in this sector a process of decision-making under deep uncertainty. However, there are some conclusions that can be drawn from this high-level analysis:

- **This is an area involving many long-lived decisions with high sunk costs that are likely to be sensitive to climate change uncertainties**; in particular, decisions related to new and upgraded hard protection infrastructure, improving property-level resilience and planning new buildings and infrastructure in flood exposed areas. **An urgent need of adaptation planning is to assess the benefits of incorporating flexibility into decisions that are already in the pipeline** to avoid locking in future vulnerability and potential maladaptation.
- **This is also an area of plentiful 'no-regrets' adaptation options, which give significant benefits in terms of reducing risk and are not sensitive to climate change uncertainties**. This includes for example:
  - **Measures to reduce current vulnerability to weather and climate;** including risk information, early warning systems, disaster preparedness, improving drainage systems, and insurance systems.
  - **Measures to manage other drivers of risk**; including risk-averse land planning (avoiding new building in high risk areas); avoid decisions that would worsen drainage (e.g. paving over green spaces in cities) and managing risks associated with coastal erosion and subsidence. These decisions may involve trade-offs with other objectives, such as targets for new housing and the need for economic development.
- **Some adaptation measures are 'low-regrets' and have significant co-benefits**; for example, natural ecosystem-based flood control.

In analysing these options, a few important knowledge gaps become clear. These particularly relate to the effects of trends in non-climate drivers, such as land-use change, and how this might interact with climate change. There are also important knowledge gaps around the economic costs and benefits of natural ecosystem-based flood management, in both urban and rural areas. There is also a lack of detailed, publically available information related to current vulnerability, in particular, detailed records of losses, standards of protection and risks of surface water flooding.

IV.B. The UK water sector

Unique characteristics and challenges: the water sector has similar characteristics to flooding, but non-climate drivers of risk are of equal or greater importance, at least in the short to medium term. Water supply is mainly provided by private sector companies under long-term licence agreements, subject to environmental and economic regulations.

IV.B.i. Overview of decision factors

Current vulnerability: levels of water stress in the UK are determined by a combination of the efficiency of water consumption, population density, industrial concentration and rainfall. Water is abstracted from rivers, groundwater and supply reservoirs, with the relative importance of each varying by region. Water management systems are designed to cope with local conditions and current climate variability. This means that, in general, the likelihood of a complete failure of supply is very low. The system can be susceptible to extended periods of drought. Water quality is also an important issue, both for water supplies, but also ecosystems. Polluted drainage from urban and agricultural areas can lead to water quality issues, creating imbalances in ecosystems. Water supply and treatment systems are often vulnerable to flooding.

Potential Future Sensitivities: Today, and in the near future, the dominant driver of increased stress on water resources is related to increased demand for water, caused by changing population densities and consumption per capita. In some cases, this could become a severe problem, requiring adaptation within the next decade. In the longer run, climate change will begin to play an increasingly prominent role. Climate change will impact available water levels across the UK; these changes will vary between regions and could be significant. The Environment Agency estimates that by 2050, average river flows might increase by 10 – 15% in the winter and fall by over 50% in late summer and early autumn (and up to 80% in some catchments). By 2025, the overall recharge of aquifers is expected to decrease, river flows fed by groundwater decrease, and there could be a general lowering of groundwater levels. A higher potential for extreme droughts would also challenge current water management systems. The effects of these changes will depend on the specifics of local water management systems. In addition, climate change itself could increase demand domestically, and more importantly, for irrigation. Water quality could also be negatively impacted by climate change.

The current decision context: Based on current regulation, the goal of adaptation is to guarantee meeting a defined level of service over a planning period, in a way that is cost-effective and compatible with environmental regulations.

Adaptation Options: the available options in a water resource zone will be specific to that zone (i.e. dependent on local hydrology and other conditions). Options are mainly anticipatory. They can be categorised as: resource-based (i.e. options to increase water output, such as desalinisation and enlarging reservoirs); user-based demand management (e.g. measures to improve efficiency of water use); distribution management (e.g. increased connectivity between regions and reducing leakage); and production management. Outside of demand management, most involve some form of hard infrastructure. Resource-based options, in particular, involve long-lived infrastructure with high sunk costs and long planning lead-times. Water quality management can involve hard infrastructure, but complementary 'soft' natural environment solutions are available. The full characteristics of these options are tabulated in Annex C.5.

IV.B.ii. Conclusions for decision-making

Like flood risk management, water supply management is an area with long-lived infrastructure and high potential future sensitivity to climate change.

There are many no-regrets options available that have been demonstrated to be reliable and beneficial in water supply management, including:

- **Managing current climate variability**: including enhancing resilience through building supply networks between regions
- **Managing other risk drivers**: including leakage reduction and demand management through, for example, education, metering, re-use and water-efficient equipment. These can be relatively fast to implement and flexible.

Note that the term 'no-regrets' in this report is used to mean that the option will provide benefits under any climate scenario. It does not necessary mean that the option should be taken, nor does it imply zero cost or zero trade-off.

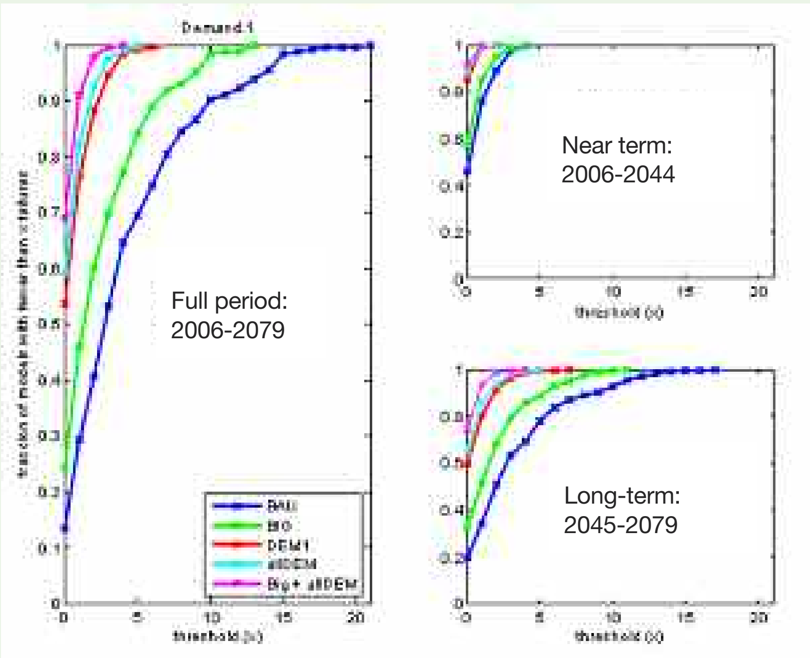
Long-lived hard-infrastructure measures, associated, for example, with new sources of supply, may be required in some cases. These options tend to have long lead-times and life-times, high sunk-costs and generally a lower level of flexibility to changing conditions, making them highly sensitive to uncertainties. Where such measures are shown to be required (as opposed to no-regrets measures) one should assess the benefits of incorporating flexibility (e.g. a reservoir with larger foundations), or waiting for more information before acting. A number of studies have evaluated soft options, like demand management, versus hard options, and found that in some cases, soft options are more desirable in the short term (e.g. Groves et al. 2008 and Box IV.1).

The ambiguity of climate change in this case could raise challenges for decision-making. However, Box IV.1 and Annex B.2, demonstrate how a simple robustness-based analysis can help in assessing the relative benefits of 'soft' demand-based measures and 'hard' resource-based measures. In this particular case, it was shown that demand-based measures provide a robust near-term solution to adaptation needs and that an option to expand a reservoir could be delayed in anticipation of better information. This is a specific finding for this case, but demonstrates the power of such an analysis in informing adaptation.

Box IV.1 Robustness in adaptation planning – an example application

This analysis aims to provide a simple illustration of decision-making using a robustness-based analysis for when the probabilities of future climate states are not known. The full analysis is given in Annex B.2. The case is a water company with the objective to meet water demand in its catchment zone until the late 21st century, at minimum cost. A large ensemble of estimates from a climate model is used to explore the range of plausible future climates. The benefits of four different adaptation options across the range of plausible futures are assessed using a water resources model for the catchment zone. The robustness of the adaptation options to climate is measured in terms of the fraction of projections that meet the performance criteria (a threshold number of failures to supply water).

The figure below illustrates the robustness of the different options as a function of the performance criteria. The four adaptation options are: increasing the storage capacity of the system by 18% during high flows (green), reducing the demand of the largest users in the resource zone by 15% (red), reducing all major demands including transfers to other zones by 15% (light blue), and a combination of the first and third options (purple). These are compared to the no adaptation case (in dark blue). The three panels illustrate three time periods: the near-term, long-term and the whole period. The analysis suggests that for this system in the near-term, demand-management options (red and light blue) are the most effective in reducing risk of failure. In the longer-term incorporating additional storage alongside demand management is advantageous, but the increase in robustness is not large over and above demand reductions. Given the high cost of additional storage, a decision-maker may choose to re-evaluate this option further down the line when uncertainties might be narrowed.



The fraction of models for which the number of yearly failures to supply demand is less than a given threshold. The left panel corresponds to failures over the full time period (2006-2079), the top right panel to failures between 2006 and 2044, and the bottom right panel to failures between 2045 and 2079.

Finally, adaptation in the water sector can involve trade-offs that are important to consider in decision-making. For example, in some regions, current levels of abstraction are causing significant damage to aquatic ecosystems at low flows, therefore any measure tending to reduce abstraction would improve the ecosystem quality. There are also potential trade-offs and co-benefits with greenhouse gas mitigation targets. Water supply is highly energy and emissions intensive. Actions that increase supply could therefore increase emissions, while it has been shown that demand-reduction would provide large savings in emissions.

IV.C. The UK food sector

Unique characteristics and challenges: the food sector is a case with many short-lived adaptation options, such as crop varieties and planting times that can be adjusted annually, and so decision-making is less sensitive to climate change uncertainties. In this sector, autonomous adaptation is likely to be dominant. It is also one of the few areas where well-planned adaptation could increase productivity above current levels in a warmer world. However, it is also unique in that it is exposed to the global impacts of climate change on agricultural productivity.

IV.C.i. Overview of decision factors

Current vulnerability: The food sector is the largest manufacturing sector in the UK, accounting for 7% of GDP, and employs almost four million people across the various stages of production, from farms to retail. The UK is a major food producer; around half of all food produced locally is exported. The UK also imports large amounts of food. In 2006, the UK exported £10.5 billion of food, and imported £24.8 billion. This interaction with global markets makes the sector susceptible to global climatic changes. During the global food crisis of 2007-2008, increases in food prices did not substantially affect general wellbeing except for the poorest people; on this measure, the resilience of the UK food sector to changes in global food markets would appear to be relatively strong at present. Nevertheless, local agricultural productivity is highly sensitive to climate, in particular climate-related shocks like drought and flooding. It is also susceptible to other types of shocks, in particular, pests and diseases.

Potential future sensitivities: In the near-term, agricultural productivity will continue to be affected by the range of climate and non-climate stresses and shocks; in the longer term more discernable effects of climate change will become apparent, both through changes in mean climate and variability. Studies suggest that the balance of the impacts of climate change is likely to be positive, but will vary between regions, possibly causing some shift in farming zones. However, there is evidence for some negative impacts, such as waterlogging, increased droughts and flooding, reduced water quality in some areas, and impacts through changes to ecosystems. These localised and complex effects are more difficult to predict. The food sector will also be affected by other long-term factors, such as changes in the regulatory environment, changing consumer preferences, the growth in biofuels and changing global patterns of production and trade; these changes are difficult to predict. There is a concern that the farming sector is less able to respond to long-term challenges than in previous decades, partly due to a reduced role of the public sector in information provision and research and development.

The current decision context: A key objective for private sector players in the food sector is short-term profitability. The government plays a role in supporting the agricultural sector, securing food availability, environmental protection, and ensure food safety and standards.

Adaptation options: A broad range of options are available to maximise near and long-term food production and enhance resilience to domestic and global shocks. Many autonomous and reactive adaptations, such as shifting varieties and cultivation areas, are already used today to respond to changing conditions. These adaptation are short-lived, they can be tuned and readjusted over only a few years, and so are less sensitive to climate change uncertainties. There is also a range of anticipatory measures that aim to enhance long-term production and resilience, including skills and information, research and development, efficient water use, sustainable farming practices, new technologies and rebuilding soil fertility. The full characteristics of these options are tabulated in Annex C.5.

IV.C.ii. Conclusions for decision-making

Adaptation in the food sector, in general, will likely be less sensitive to climate change uncertainties than other areas, for example:

- **Many of the adaptations in this sector are short-lived or reactive**, such as changing crop varieties. These actions will be mainly autonomous. An important objective of

Government action in this area may therefore be to support autonomous adaptation by removing any barriers to action, such as information barriers and disincentives for efficient adaptation (e.g. subsidy structures).

- There is also a **broad range of anticipatory, no-regrets actions available, that would have benefits under any scenario**; such as sustainable farming practices, improving water efficiency, investing in knowledge and skills, research and development of new crop varieties and technologies, monitoring, natural and semi-natural buffers to weather and rebuilding soil fertility. The short-term profitability focus of the sector suggests a potential role for public sector action in some of these areas, through for example, regulation or support of research.
- Other **no-regrets options relate to managing non-climate drivers of changes**, for example, enhancing the resilience of the food sector to global shocks through diversification and managing other systematic pressures, such as biofuels.

There are a few adaptation options that could represent 'tougher choices' in that they could increase long-term productivity but entail trade-offs and have uncertain benefits depending on the climate. These include, for example, whether the UK should aim to expand agricultural lands to enhance food security (an issue involving significant uncertainties and trade-offs) and whether to invest now in some forms of costly technologies, such as biotechnology.

Adaptation in the food sector could have significant co-benefits or trade-offs with other areas; this suggests a potential role for cross-sectoral thinking and policy. Agricultural practices and land conversion have significant impacts on flood hazard, water quality and ecosystems. For example, intensified or expanded production, if not well managed, could damage ecosystems and water quality and increase flood hazards, as well as threatening long-term sustainability through over intensive use of natural resources. Depending on the suite of adaptation measures adopted, the linkages with other sectors could be made to be positive. For example, rebuilding soil fertility and natural buffers to weather can have benefits for water quality and ecosystems.

IV.D. Ecosystems and Biodiversity

Unique characteristics and challenges: Ecosystems introduce unique questions about how people value biodiversity and in particular treat potential irreversible loss of species. This is also an area already impacted by climate change and where there has been a long-term decline as a result of multiple stresses.

It is important to note that there are two aspects of ecosystems that may require separate adaptation. The first is ecosystems for the purpose of ecosystem services, including tangible services, such as water and air quality regulation and recreation, as well as intangible services, such as aesthetic enjoyment. The second is biodiversity, the living component of ecosystems including terrestrial and aquatic organisms. Adaptation options that aim to protect or utilise ecosystem services can have benefits in terms of protecting biodiversity, but this is not always the case. In some circumstances, separate options may be required if the goal of adaptation is to protect biodiversity alone.

IV.D.i. Overview of decision factors

Current vulnerability: levels of biodiversity in the UK have declined significantly in the past as a result of long-term stresses, such as pollution and land conversion. Many of these declines have slowed since 2000 as a result of regulation and conservation. Ecosystems are also vulnerable to shocks, such as extreme weather and invasive species, and long-term stresses can reduce the resilience of ecosystems to deal with these shocks. The decline in health of ecosystems has also affected natural ecosystem services. Globally, the *Millennium Ecosystem Assessment* estimated that 60% of the ecosystem services are being degraded or used unsustainably. There are signs that climate change is already impacting ecosystems, for example, seasonal events in spring and summer, such as spawning and fruiting, are occurring earlier, and some species ranges have shifted. While the effects of climate change are apparent, it is still not possible to completely disentangle the impacts from the many other interlinked drivers (Parry et al. 2007).

Potential future sensitivities: Climate change and other drivers, such as land-use change, invasive species, land and water management practices, and pollution, will continue to impact ecosystems and biodiversity. Given past evidence, the sensitivity to these drivers could be high. Species do adapt in reaction to changing climate conditions. Many species adapt by relocating to areas with more suitable climate conditions, changing their lifecycles or preferences for habitats. Human systems can often limit adaptive capacity, for example, by removing natural migration routes. At a national level, there is no single dominant driver of risk. Irreversible loss of some species is probable without effective adaptation. For example, projections of shifts in suitable climatic conditions for a range of taxa show significant risk of local extinction of UK species.

The current decision context: Biodiversity and ecosystems are protected by a system of legislation at UK and EU level. In addition, the UK is committed to two international targets: the first (in 2001), to halt the decline in EU biodiversity by 2010; and the second (in 2002), to achieve a significant reduction in global biodiversity loss by 2010.

Adaptation options: Most available adaptation options aim to remove the barriers to autonomous adaptation by ecosystems. Such measures include: conserving existing protected areas and other high-quality habitats, reducing sources of harm not linked to climate change, developing ecologically resilient and varied landscapes and establishing ecological networks through protection, restoration and creation. The full characteristics of these options are tabulated in Annex C.5.

IV.D.ii. Conclusions for decision-making

Ecosystems and biodiversity is an area of significant present and future sensitivity to climate and other non-climatic drivers of risk. However, many of the adaptation options available are no- or low-regrets:

- Measures such as reducing non-climatic sources of harm, enhancing resilience to current weather and conserving existing protected areas and other high-quality habitats will have benefits under any climate scenario.
- Some measures can also have significant co-benefits with other sectors through the ecosystem services they provide and so might be considered win-wins, for example, natural environment solutions to flood management.

There are few adaptation options that are sensitive to climate change uncertainties. One example is assisted colonisation, where species that are not able to adapt autonomously and so may require more direct assistance (for example, more immobile species like lake-borne aquatic life may need to be relocated). There are many risks associated with such measures and their desirability should be assessed on a case-by-case basis.

A key factor in decision-making will be how people value ecosystem services and biodiversity. This is important in evaluating common trade-offs with other objectives, particularly those related to other risk drivers, such as land uses and levels of pollution. In addition, an important factor in decision-making will be how the risk of irreversible loss of ecosystems, either from the UK or globally, is valued. These have strong implications for the ways in which adaptation options are evaluated and ranked and will be a key sensitivity of an adaptation analysis. **The immediate sensitivity to climate and non-climate risks and the potential for irreversible impacts suggests the need for an urgent and thorough analysis of appropriate adaptation strategies**.

Decision-making in this area is currently limited by a lack of information covering most of the decision-factors. For example, a lack of comprehensive monitoring means it is difficult to evaluate the vulnerability of species. Also, rigorous economic analyses and empirical studies of adaptation options are not yet available.

		Flood	Water	Food	Ecosystems
Dominant Risk Drivers	Near-term (next decade)	**Land-use** change Climate variability Shocks: potential flood disasters (*uncertain*)	**Demand** **Climate variability** Shocks: extreme flood and drought (*uncertain*) Also, drivers of reductions in water quality	**Changing patterns of food** demand (price signals) **Shocks: extreme weather, pests, global price shocks** (*uncertain*) **etc.** **Demands related to mitigation**	**Land-use change** **Climate change** (*relative certain*) **Shocks: invasive species, extreme weather** (*uncertain*)
	Long-term	**Climate change** (*uncertain*) **Land-use** change (*less uncertain*)	**Climate change** **Demand** *(both uncertain; climate change potentially dominant in longer term*)	**Economic and social change** (*global, highly uncertain and but dominant in medium -term*) **Climate change** (*local and global becoming more dominant over time; global impacts are highly uncertain*)	**Climate change** (*local and to a lesser extent, global*)
Decision Appraisal		Value for money; risk to people, distribution issues, environment Government planning focus (anticipatory)	Regulatory standards (security of supply of water), cost-effectiveness Government and private actors (anticipatory)	Profitability of individual actors Distribution and Long-term food security (?) Private actors (reactive and short-term anticipatory)	**Irreversibility** **Ethical and social judgements** **Autonomous** (*reactive, but influenced by government and private actors*)
Broad Adaptation Characteristics		Broad range of options; largely anticipatory, mixture of hard and soft options, government and private actions. Potential co-benefits and trade-offs with other sectors. Barriers to implementation of some actions.	Fewer options; largely anticipatory. Mixture of hard and soft options. Regulated private actors and individuals. Potential co-benefits with other sectors.	Broad range of options. Many short-timescale anticipatory actions, Potential barriers to long-term adaptation. Many co-benefits and trade-offs.	Fewer options. Focus on autonomous, reactive adaptation, but potential to support long-term adaptation through anticipatory measures. Many co-benefits with other sectors. Potential barriers to implementation,

Table IV.1: Broad characteristics of adaptation across the four sectors

Adaptation Options		Flood	Water	Food	Ecosystems
Reactive measures		Disaster response: emergency services	Demand responses to price (distortions) Emergency water saving measures	Response to price Changing crop varieties; Reducing impacts of pests and diseases	Autonomous adaptation by ecosystems: changing locations, habitats etc.
Potential No-Regrets* (each also reduces vulnerability and increases resilience to shocks)	Managing current climate variability	Risk Information and monitoring Early warning systems Preparedness and response Insurance	Building resilience through networks between regions. Re-use and recycling Monitoring	Investing in knowledge and skills Research and technological development Monitoring Natural buffers to weather	Monitoring and research Conserve current protected areas and high-value habitats
	Managing other risk drivers	New development (location, drainage) Natural drainage systems: urban and rural areas Managing risks related to coastal erosion and subsidence	Reducing leakage User demand reduction: water saving, water efficiency etc.	Building sustainability: land-use, pollution, water quality, environmental protection Maximising efficient water use Building soil fertility	Manage other drivers: e.g. land-use change, pollution Changing crop varieties; changing production
	Short lifetime and lead-time options			Changing crop varieties; changing production locations Biotechnology	
Measures with Co-Benefits		Large-scale natural 'soft' infrastructure projects	Natural environment solutions to water quality	Natural environment solutions to soil fertility	Facilitating autonomous adaptation through maintaining varied and resilient habitats and ecological networks.
Potential for Flexibility		Property-level resilience (and some resistance) Some types of hard infrastructure Upgrading old drainage and sewerage systems	Some types of hard infrastructure for storage and supply	Investing in on-farm infrastructure Land-conversion to agriculture (potentially high-sunk costs, but relatively responsive with short-lead-times)	Conserving land for ecosystems
'Inflexible options' (long-lifetimes and lead-times, potential for high-regrets)		Some types of hard infrastructure High-spec property-level resistance measures Managed retreat	Some types of hard infrastructure for storage and supply; desalination plants		Assisted colonisation (high risk)

*Table IV.2: Categories of adaptation in terms of the management of climate change-related risks and uncertainties. *'No regrets' in this context means that the option provides benefits under any future risk scenario; cost-effectiveness should be assessed on a project-by-project basis.*

IV.E. Conclusions for Adaptation Planning

The review of the four case studies provided in Annex C demonstrates that there is no ‘one-size-fits-all’ solution to adaptation. However, a number of general conclusions can be draw and are described in this section.

IV.E.i. The decision-making process

In each of the case studies, levels of uncertainty in future conditions are high. For example, climate projections at the spatial and temporal scales relevant to decision making are often highly uncertain, dependent on models with known flaws, and highly sensitive to the unknown future emissions pathway. In addition, there are significant uncertainties related to non-climate drivers of risk, for example, trends in demand for water and consumption patterns for food, and land-use changes on flooding and ecosystems. This means that **long-term adaptation planning will often be a process of decision-making under deep** uncertainty.

IV.E.ii. Sensitivity of adaptation plans to uncertainty

A structured decision-making process (Chapter III) enables a decision-maker to establish the level of sensitivity to uncertainties and identify an appropriate decision method. **Many elements of adaptation plans, particularly in the near-term, are not highly sensitive to climate change uncertainties. In each of the case studies, a broad range of ‘no-regrets’ options are available; that is, options that will provide benefits under any climate change scenario and do not limit flexibility to cope with future climate change. These could form an important part of adaptation in the near-term.** For example, in most of the cases, the dominant driver of risk over the near-term is not likely to be climate change, but climate variability and non-climate factors: changes in land-use for flooding and ecosystems, and changes in demand for water and food. The exception is for ecosystems, where due to the susceptibility of ecosystems to even small changes in climate, there is potential for climate change to be an important driver of risk even in the near-term. For these reason, **measures to manage current climate variability and non-climate drivers of risk will be particularly important in the near-term**.

Building resilience to extreme weather events may be particularly desirable given current vulnerabilities as there is evidence that extreme events could change more rapidly than the mean (Ahmad et al. 2001) and these types of changes are more difficult to predict and monitor. In many cases, these types of measures could be implemented today with immediate benefits.

In each of the cases climate change is an important driver of risk in the long term. Uncertainties are large and grow over time. This means that decisions that are long-lived, such as infrastructure and buildings, sector-level planning and regulation, could be sensitive to climate change and other uncertainties. These types of decisions tend to be limited to public-sector and large private sector organisations (e.g. water and energy companies). **Decision methods that reflect the true extent of the uncertainty about the future and rigorously account for attitudes towards uncertainty are important tools for designing successful strategies in these cases**.

However, evidence suggests that, even in cases of long-lived decisions with high sunk-costs such as public infrastructure projects, flexible options are often available and can be shown to be desirable, either through physically incorporating flexibility or waiting and learning before acting (Section II.E). For example, even in the case of the upgrade to the Thames Barrier, a decision with high sunk-costs, long lead-times and a lifetime of 100 years, a desirable flexible approach was identified. As described in Chapter III, appropriate decision methods, such as real-options analyses and robustness-analyses, can be useful in evaluating the trade-offs between flexibility and optimality in a decision.

The case studies suggest that **only in a very few cases will a decision-maker be forced to make the difficult choice between potentially ‘high-regrets’ options today, where the benefits of options depend strongly on uncertain future climate states**. These types of measures will typically be those where building in physical flexibility from the start is extremely costly, or where the decision can not be delayed.

IV.E.iii. Early adaptations

Another important conclusion that arises from the case studies is that, **like mitigation, a delay in some forms of adaptation, could mean greater costs down the line**. For example, policy and spending decisions are made everyday that could increase future vulnerability to climate change or reduce flexibility to adapt, potentially locking-in future unnecessary costs. In addition, in some highly vulnerable areas like ecosystems, inaction could result in severe and potentially irreversible impacts even on short timescales. Three **types of action are required now**:

- **Action in areas where, for various reasons, early adaptation is essential**. This is described in more detail below.
- **Building the capacity to carry out adaptation effectively, including people and institutions, and information and skills**. The first step in building capacity must include **formalising decision-making frameworks, objectives and constraints**. This includes agreeing appropriate processes between the relevant stakeholders; e.g. who will make the decisions, what frameworks will be followed and how will stakeholders be involved? Once this is in place, a process of *structuring the problem* (Figure S.1, Chapter III) can help identify how and where capacity building is needed; for example, identifying what capabilities will be required to develop and implement strategies, including **relevant skills and institutional and regulatory structures**.
- **Developing the knowledge base for adaptation**. Identifying and filling knowledge gaps. This might include, for example, research into current vulnerability, future sensitivity and adaptation options; and building long-term monitoring systems to monitor the effectiveness of adaptation and detect any changes that might indicate the need to refine or revise plans.

The focus should be on those measures that will need to be implemented early to avoid irreversible damages and **seize opportunities for 'no-regrets' and 'flexible' options**. Based on these analyses, top adaptation priorities over the near-term (e.g. the next five years) include:

1. **Adaptation for sectors or actors with high vulnerability to weather and climate change in the near-term**. This includes identifying potential near-term thresholds in impacts and possible irreversible outcomes (e.g. species loss). For example, ecosystems have been shown to have a high sensitivity to even small changes in climate.
2. **Identify and manage any adjustments, measures, investments and policies that could increase potential vulnerability to climate change or reduce the flexibility to adapt**. This includes, for example: new long-lived projects, such as infrastructure or new housing developments; and policies that might create barriers to autonomous adaptation, such as agricultural subsidies.
3. **Broader options that are potentially desirable to implement today:**

   a) **Options that have long lead times before they can be applied**, such as research and development of new technologies (e.g. new crop varieties); restoring degraded habitats to create new ecosystem networks; and upgraded water management systems.

   b) '**No-regrets' measures**, for example:

   i) **Measures that provide benefits in managing current weather and climate variability**, insurance systems, research and development, or conservation of high-value ecosystems.

   ii) **Measures associated with managing non-climate related drivers of risk**, such as reduced leakage in water systems; enhanced planning and building controls; rebuilding soil fertility; and water quality management.

   iii) **Short-lived adaptations where climate has already changed or the system are maladapted to current climate**, such as adjusting planting times and crop varieties where necessary to suite current climate.

   iv) **Broader measures aimed at reducing vulnerability and building resilience to shocks and general stresses**, such as early warning systems, water transfer networks between regions, and capacity building (skills, knowledge and information).

   c) **Measures with significant co-benefits across sectors**, such as ecosystem solutions to flood control and water quality.

   d) **Measures and policies that promote autonomous adaptation**, for example, raising awareness and providing information, or removing broader barriers to autonomous adaptation, such as agricultural subsidies.

IV.E.iv. The importance of cross-sectoral thinking and policy in adaptation

The case studies reveal many possible trade-offs and co-benefits across areas of adaptation policy (Table IV.3). These types of trade-offs between sectors can only be resolved by utilising cross-sectoral decision making processes, which consider adaptation options and decision-criteria across

multiple sectors and development priorities. For example, planning controls that aim to prevent new developments from being built in flood exposed areas can occasionally be overruled by local authorities on grounds of other priorities, for example, the need to provide affordable housing. Similarly, restoring habitats for ecosystems may have trade-offs with other land-uses. The need for cross-sectoral decision-making processes suggests a role for public policy. Such processes are also essential in seizing opportunities to maximise the co-benefits of many adaptation options across sectors (examples in Table IV.3).

	Flood	Water	Food	Ecosystems
Impact	Flood damage to ecosystems and agricultural lands Impacts on water quality and water supply	Abstraction can damage ecosystems Security of supply to agriculture and other industries	Food production can have negative impacts on flood control, ecosystems and water quality	Ecosystem services support flood control, water quality, local climate regulation and soil fertility.
Adaptation	Some measures potential trade-offs with ecosystems and economic development Natural adaptation solutions available in many cases	Options available with trade-offs for ecosystems. Natural environment solutions to water quality	Many options available with co-benefits for ecosystems: soil fertility etc.	Ecosystem conservation can be designed to have co-benefits for flooding, water and food. Potential trade-offs with other land uses and established land management practices

Table IV.3: Cross-sectoral trade-offs and co-benefits

V. Conclusions

This report explores the challenges of adaptation planning from a decision-making perspective and laid out a framework for decision-making that can be applied by individuals and organisations across the public and private sectors. Previous work on adaptation planning is extended by providing comprehensive, up-to-date and pragmatic guidance on approaches to make decisions under deep uncertainty. The framework is applied, albeit at a high level, to four case studies, to draw more specific implications for adaptation planning.

This final chapter concludes by drawing out principles developed throughout the report to build a picture of what a well-prepared organisation can do today to manage the risks from climate change impacts and seize any opportunities. First and foremost, a well-prepared organisation will develop comprehensive adaptation plans, through a rigorous and structured decision making approach. The foundation of a good adaptation plans is a clear, relevant and agreed set of adaptation objectives that are mainstreamed within the broader set of organisational goals. Plans should identify what actions are required immediately versus longer-term actions, and where it would be appropriate to monitor, learn and review before taking actions. The comprehensiveness and quality of these plans, as well as the processes put in place to review them and evaluate their success, will be a good indicator of an organisation's preparedness for climate change.

However, planning is only the first step in adaptation. In many cases, tangible adaptation actions will be required in the short-term. Like mitigation, delays in adaptation could mean greater costs in the future. Chapter IV concluded that the most urgent actions include early adaptations that are necessary to reduce immediate impacts of climate change, avoid locking-in future vulnerability, as well as enable us to seize the opportunities provided by no-regrets adaptations and those with significant co-benefits across sectors. A well-prepared organisation will take steps to implement such measures in accordance with plans. This includes developing appropriate capacities and implementing processes to monitor and review the effectiveness of plans.

Resource constraints are an important barrier to a good decision process. For example, a complex and resource-intensive planning approach may not be feasible in some cases, due to constraints of time, skill and costs. In many cases, the decision-making process can be significantly simplified. While there is no one-size-fits-all solution to adaptation, small-scale decision-makers can be supported by provision of information and instructive examples. This report provides a set of tools and principles that can aid decision-making, but there may be a role for the public sector in continuing this research to provide more sector and actor-specific information.

A general conclusion of the report is that in some cases adaptation will be challenging and this is particularly true for public sector decision making. In many cases the most significant of these challenges will come not from climate change itself, but from agreeing and prioritising objectives, resolving trade-offs and conflicts and overcoming the political, social, economic and institutional barriers to implementation. These challenges are not unique to adaptation; they are encountered in many areas of policy, risk management and decision-making. Climate change adaptation does however present some unique challenges. Firstly, the scale, speed and extent of the potential adaptations required; this will become increasingly challenging as the world continues to warm and can only be moderated through reducing greenhouse gas emissions. A second challenge is the need to anticipate uncertain future climate changes. This report has mapped out a series of simple options and approaches to help overcome this uncertainty, including no-regrets and flexible options. The analyses suggest that 'hard choices' between options as a result of uncertainty will be relatively rare and where they are present, decision theory has provided a set of tools to help decision makers appraise a most effective response to suit their needs and preferences.

Finally, while this report has focussed on adaptation, it is important to view adaptation as one part of broader decision making, for example it is an integral part of sustainable development, land use planning, resource and risk management, and environmental sustainability. Adaptation is not an objective or process that should be considered in isolation. Considered in isolation adaptation strategies will miss important synergies and trade-offs with other areas; for example, it would be less able to effectively seize co-benefits with other policies and measures, such as ecosystem restoration and mainstreaming climate-resilience into new developments, and managing complex trade-offs across sectors, for example, between land-use development, flood risk management, agriculture and water quality. Risks, opportunities, objectives and measures should be considered within the context of the broader goals and strategies of an organisation.

VI. References

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