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The National Adaptation Programme Report: Analytical Annex

Economics of the National Adaptation Programme

Publication: 1 July 2013

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PB13942a

Contents

1. Economics of the National Adaptation Programme

This analytical annex contains the current evidence base for adaptation decision-making. It presents the analysis that informs the National Adaptation Programme's approach to adaptation to climate change. Focus areas and programme actions in the main report are based on latest evidence and analysis.

Understanding of adaptation, both in government and beyond, is an evolving process. Research will continue to ensure adaptation is cost effective, efficient and equitable (both privately and publically).

A formal impact assessment is not required because the National Adaptation Programme is not of a regulatory nature. It is important, however, to lay out the evidence and analysis that underpins the National Adaptation Programme. This document sets out the rationale for government intervention and wider societal action to ensure the UK is resilient to climate change.

It is not possible to provide an exact measurement of costs and benefits of a well-adapted UK. Adaptation needs to be embedded in a wide range of existing policies. The National Adaptation Programme report reflects a series of voluntary agreements across government and society more widely.

1.1. Summary

The National Adaptation Programme (NAP) report presents ongoing policies and voluntary agreements to ensure that the UK is resilient to the risks of climate change. To ensure the programme is well targeted, the NAP is based on a wide range of evidence and analysis.

Two major pieces of government funded research form the basis of government understanding of adaptation to climate risks. Main risks and opportunities are compiled in the Climate Change Risk Assessment (CCRA).[1] The CCRA draws together the latest advances in climate science and currently available evidence on climate change. Defra has recently published the Economics of Climate Resilience (ECR).[2] The ECR sets out an economic framework for adaptation in the UK. Many other research projects also help develop specific objectives highlighted in the main NAP report.

[1] The CCRA was published in January 2012 and is available online at: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report
[2] The ECR was published in March 2013 and is available online at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016

Effective national adaptation requires a societal effort from the private sector, government and local communities. Private actions to adapt are crucial given the projected impacts of climate change are highly localised. In the absence of factors which may lead a market to function inefficiently, a household or organisation will choose to adapt if the benefit of doing so exceeds the cost. However, there are barriers to adaptation which may prevent or delay action. It may be appropriate for government intervention to ensure markets do function efficiently.[3] *Section 2 focuses its attention on the role for government and analyses fundamental aspects of adaptation including the role of uncertainty and 'adaptive capacity'.*

Appraisal needs to account for the full costs and benefits of all adaptation options. However, many costs and benefits of adaptation are difficult to quantify. This annex outlines appropriate appraisal methods and how an analyst can deal with issues such as uncertainty, data availability and proportionality.[4] *Section 3 reviews the costs and benefits of adaptation, both locally and overall for the UK.*

Appropriate adaptation is supportive of economic growth. It avoids unnecessary damages which may disrupt economic activity such as consumption, investment, the appropriate allocation of public finance and trade. *Section 4 analyses the relationship between adaptation, productivity and economic growth.*

Finally, Section 5 makes recommendations for future evidence needs.

1.2. Policy implications

The development of evidence to inform the NAP has identified 6 policy implications.

1) **Uncertainty is not a legitimate reason to postpone decisions by government, business or society**

   Uncertainty does not mean that action should be delayed. It means that decision-making should be an iterative process and incorporate regular reassessment to consider the latest available information. Appraisal options exist that account for deep uncertainty. Risk management needs integration into policy development to account for the uncertainty of future climate change.

2) **Decisions today can create sunk costs for the future and 'lock-in' future vulnerability[5]**

[3] It should be noted that there may be instances where government intervention is unable to improve efficiency and as a result it would not be to cost effective to do so

[4] Proportionality infers that the appropriate amount of time and resource expended on an assessment should reflect the size of the expected costs and benefits.

[5] A sunk cost is a cost that once incurred and cannot be recovered. Large sunk costs make reversal very expensive and could lock the UK into path which makes us vulnerable to climate change.

Long-term investment decisions (eg development/building of national infrastructure) that lead to substantial sunk costs must be based on the best available information, analysis of scenarios and threshold points. These decisions should incorporate future flexibility/reversibility and account for wider sets of extreme scenarios and threshold points. This can prevent long-term investments becoming locked into future vulnerabilities and avoid unnecessary costs.

3) **Government policy should be developed in such a way that it does not crowd out private initiative**

   The costs and benefits of adaptation fall mainly on private individuals and organisations. Government actions must not replace private initiative, which is likely to be more efficient. However, there are barriers to adaptation which may require future government intervention.

4) **Government needs to ensure that action on climate change adaptation is cost effective**

   Policy should be based on a sound evidence base and a proportionate assessment of costs and benefits. Adaptation may increase or decrease the costs and benefits of a project; these need accounting for appropriately. This emphasises the need for analysis to follow the Green Book and supplementary guidance for the appraisal of climate change adaptation options.

5) **Adaptation can protect growth**

   Adaptation is fundamentally an economic issue.

   Adaptation protects growth and 'allocative efficiency'. Cost effective adaptation delivers a net benefit and avoids unnecessary damage costs of climate change that would hinder economic growth.

   Adaptation activities may have a range of other economic impacts in addition to their aim of avoiding damage. In some cases they may stimulate innovation and enterprise, but they may also divert resources from other beneficial uses. The benefits of adaptation need to be considered alongside the costs in order to evaluate the extent to which it is net beneficial as it is likely to vary across different sectors, local context and specific activities. The timing of those benefits also need to be considered.

6) **There remain wide gaps in the evidence base**

   Government and research institutions need to work alongside each other to develop evidence and inform policy. Future evidence needs are discussed in Section 5 of this annex.

2. What is the role for government in adaptation?

Climate models indicate that many parts of the UK[6] are likely to experience rising average temperatures, more heavy rainfall (leading to flooding), rising sea levels and faster coastal erosion, more heatwaves, droughts and extreme weather events as this century progresses.[7] Further information is available on Gov.uk pages about scientific evidence to help us understand climate change and on Government Office for Science pages.[8,9] The CCRA shows that projected climate change presents a set of opportunities and threats for the UK economy.

2.1. Private action and government intervention

Climate change impacts are not always a 'market' failure as they constitute a private cost (and in some cases a benefit) to individuals. In many cases the costs and benefits of adaptation are borne by the same individuals (or groups of individuals). If adaptation to climate change is in the private interests of individuals and organisations (ie cost effective) then in theory it should occur automatically. The value of adaptation will appropriately be reflected in market prices. Individuals and organisations will take advantage of opportunities and will act against the risk of threats through the market.

However, barriers to adaptation do exist. These barriers prevent a socially efficient level of adaptation from occurring. It could result in too little or too much adaptation taking place, leading to a misallocation of resources. Government has a role to play to ensure adaptation actions are economically efficient. It also has responsibility to ensure public goods, such as national infrastructure (eg the road network) and non-market goods (eg environmental amenities) are resilient to climate change. Barriers are discussed in more detail in Section 2.3.

Government also needs to avoid crowding out private investment into adaptation. Certain adaptation actions could provide a business opportunity, or are incentivised by self-interest, which removes the need for government to provide them. Furthermore, climate change impacts are localised. Appropriate adaptation will vary according to geographic location. If organisations and individuals have the best knowledge about their local context, then it will be more efficient for adaptation to occur privately.

[6] Impacts will vary geographically across the country
[7] UK Climate Projections (UKCP09) can be found online at: http://ukclimateprojections.defra.gov.uk/
[8] https://www.gov.uk/government/policies/taking-international-action-to-mitigate-climate-change/supporting-pages/scientific-evidence-to-help-us-understand-climate-change
[9] http://www.bis.gov.uk/go-science/climatescience

2.2. Uncertainty

Uncertainty is fundamental to climate change. This is because of the time-scales over which climate change is expected to occur and the extent to which it will impact on society. There is also uncertainty about expected weather conditions as a result of changes in climate. Uncertainty can magnify barriers to adaptation and attract government intervention that leads to a crowding out effect.

Appropriate adaptation to climate change is affected by uncertainty**.** This is linked with a) the projected paths of greenhouse gas emissions b) changes in socio-economic context c) impact of second order effects and d) adaptation response. Decision-makers face difficult trade-offs given the prevalence of these uncertainties. Table 1 below summarises some major sources of uncertainty which need to be accounted for.

Table 1: Major sources of climate change uncertainty for decision makers

Source of uncertainty	Description

Uncertainty of future climate	• **Natural Climate Variability** is caused by the chaotic nature of the climate system and external factors like changes in solar radiation
	• We have only an incomplete **knowledge of the climate system** and this means we are unable to model it perfectly, eg:
	  ◦ Uncertainty around feedback mechanisms
	  ◦ Fat-tailed distributions of climate risks
	• There is uncertainty surrounding future **greenhouse gas emissions**. In turn emissions are dependent on a number of assumptions including population, economic growth and type and quantity of energy use

Uncertainty of future climate impacts	• We currently have incomplete knowledge of what climate impacts will be, which means we are unable to model them perfectly. Moreover impacts vastly depend on the **specific location and context** • The socio-economic context can affect the **vulnerability of society** to climate impacts (such as demographics, regional development, water consumption and environmental degradation) • There is wide uncertainty and potential limitations of modelling **knock-on effects** of climate impacts on society and the economy
Uncertainty in adaptation response	• The level and type of adaptation response, particularly in relation to **reactive adaptation action**, will greatly vary according to the specific features of an organisation • There is also uncertainty and wide evidence gaps with relation to

	the level of **adaptive capacity** and the pervasiveness of barriers to adaptation

Source: table based on ECR, CCRA, Vivid Economics (2013)[10]

The presence of uncertainty risks 'maladaptation'. These are unintended side-effects of implementing adaptation actions. Uncertainty also means it is unlikely to predict the correct future scenario and fully adapt to it.[11] The risks of maladaptation and committing to adapt to a wrong scenario need careful consideration.

Uncertainty does not mean that action should be postponed. It means that decision-making must be iterative and regularly re-assess available information.[12] Risk management needs to be integrated into the development and implementation of policy. Investment decisions that are long-term (e.g. development/building of national infrastructure) or that create substantial sunk costs are necessarily based on the best available information. These decisions should incorporate future flexibility/reversibility taking into account a wider set of more extreme scenarios and threshold points.

2.3. Barriers to adaptation

The existence of barriers to adaptation mean types of adaptation and amount of effort could be suboptimal. This provides a rationale for government intervention to ensure a socially efficient level of adaptation. The ECR identifies market failures, behavioural constraints, policy failures and governance failures as the most important barriers. Throughout this report we refer to 'barriers to adaptation' as a collective term for all cases which may require government to intervene in a market.

A **market failure** exists when market prices do not lead to an efficient level of adaptation. These include informational failures, public goods and moral hazard.

> **Information failures** exist because organisations and individuals do not have perfect information on future climate impacts. This makes it hard for them to plan

[10] Vivid Economics, *The macroeconomics of climate change*, report prepared for Defra, May 2013 available online at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18639

[11] For a further discussion on the role of government in adaptation see 'Adapting to Climate Change Analysing the Role of Government', available at http://archive.defra.gov.uk/environment/climate/documents/analysing-role-government.pdf as well as the ECR project.

[12] For more information see detailed discussion see adaptation pathways by Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A and Ruta, A. (2010) 'Adaptation in the UK: a decision making process' Gratnham Research Institute on Climate Change and the Environment Policy Brief, available online at: http://www2.lse.ac.uk/GranthamInstitute/publications/Policy/docs/PB-Ranger-adaptation-UK.pdf. The ECR also sets of illustrative adaptation 'roadmaps' for each of its nine reports.

efficiently. Knowledge about national and global climate impacts could also be seen as a public good.

Public goods can be consumed and enjoyed without reducing their availability to others and their consumption cannot be prevented. They may occur in the case of infrastructure that protects from climate hazards (e.g. flood defences) or to ensure other types of infrastructure (e.g. transport networks) are resilient to future climate.

Non-market values are an important part of social welfare but are not included in market prices nor explicitly traded. Often these are public goods (e.g. clean air) but can also be private (e.g. value of time). Their omission leads to a market failure. Government may need to intervene to ensure appropriate valuation of non-market values so they can account for them in the appraisal of adaptation options.

Moral hazard exists when an organisation or household does not adapt to climate change despite it being a rational decision. The barrier is the belief that someone else will deal with the potential impacts for them (e.g. with subsidies from the government).

Policy failures occur when the framework of regulation and policy incentives creates barriers to effective adaptation. This can happen in the presence of competing policy objectives. Similar to the concept of market failure, which as discussed above is a situation that prevents an efficient market solution, this concept must not be interpreted as a failure of policy, but as a systemic characteristic which prevents an efficient policy solution.

Governance failures occur when institutional decision-making processes create barriers to effective adaptation. An example is where sectors are fragmented and many parties are involved in adaptation actions. In this case there could be a lack of coordination.

Behavioural constraints exist because humans are not always perfectly rational. Inertia and focus on the short-term could result in an inefficient level of adaptation. Maladaptation is a possible form of behavioural constraint. For example, if a long-term investment decision ignores adaptation then inefficient retrofitting may become necessary at a later stage.

2.4. Categorising adaptation

The ECR analyses climate change adaptation by sector: agriculture and forestry, built environment, infrastructure, health and wellbeing, business, local government and natural environment. The chosen approach is consistent with previous publications and provides

an economic framework for analysing adaptation actions.[13] While there are other methods for categorising and analysing adaptation, it is naturally a very cross-cutting area.[14]

Table 2 presents the NAP themes by category and identifies the rationale for action and issues faced.[15] Henceforth, we refer to these as 'policy areas'. Rationale for action is categorised according adaptation barriers identified above: (m) for market failure, (p) for 'competing policy objectives'[16], (b) for behavioural constraints and (g) for governance failure. These tables avoid specific discussion of adaptive capacity which is covered in more detail in Section 2.2.

Table 2. Climate change adaptation analysed by policy areas

Policy area	Rationale for action
Agriculture	**Existing dependencies (m):** external costs/benefits imposed on sector by another party eg value chains[17], cross-sectoral dependencies[18] **Competing policy objectives (p):** there is a trade-off between flexibility for farmers to undertake large investments such as water reservoirs and existing regulations in place **Changing farming practices (b):** resistance to embrace new technologies and fear of taking actions deemed irrelevant
Forestry	**Presence of externalities (m):** notable proportions of forest are not actively managed. Where active management, failure to account for non-market values eg ecosystem services **Lack of formal markets (p):** failure of policy to internalise ecosystem service benefits. Current level of grants in place to address this are not likely to be sufficient to increase forest land-cover where land competes with more economically productive uses eg agriculture **Short-sightedness (b):** failure of commercial managers to plant with a view to future climate change in favour of present threats eg pests and disease

[13] This includes the CCRA and the ECR.
[14] Other ways to organise adaptation incldues by the type of social activity that it affects eg households, businesses, public organisations and third sectors. Another way is to organise adaptation by types of physical impact eg rain patterns, sea level rise, overheating, etc. Alternatively it could be by the type of resource affected eg land, water, etc.
[15] These are taken broadly from the sector reports published in the ECR. See individual reports for full discussion on the barriers to adaptation.
[16]See Section 2.3 for a brief explanation of the economic term 'policy failure'. Here for clarity it is expressed as a conflicting policy objective that could represent a barrier to adaptation.
[17] The actions of some in the value chain can affect the resilience of others, eg farmers cannot grow climate resilient varieities until successful research has developed them.
[18] Agricultural activities are inherently linked with the natural environment. Therefore, the resilience of the agriculture system and its adaptation actions can impact on the natural environment, and vice versa.

Built environment and infrastructure	**Infrastructure dependencies (m):** sectors having external costs on another sector that are ignored in decision-making **Competing adaptation and mitigation objectives (p):** there is a potential trade-off between policy objectives that aim to reduce greenhouse gas emissions and those aiming to address overheating and improve indoor air quality in buildings. Future analysis could look into this, and also explore the impacts of potential future increases of uptake of air conditioning **Rental housing market not conducive to adaptation (b):** landlords do not benefit in adaptation investment and short-term tenants have little incentive to invest either **Intra-sector independency of transport infrastructure (m):** transport is a complex network and impacts to one part of the network may lead to further impact on other areas through diversions, increased accident risk and demand spikes for different modes of transport
Businesses and services	**Supply chain dependencies (m):** lack of transparency and understanding of the supply chain can lead to external effects of one company on another **Informational failures (m):** can provide too much or too little information on the risks of climate change and appropriate responses **Policy may limit supply chain diversification (p):** regulatory requirements may inhibit supply chain diversification **Choice of production strategy (g):** businesses may trade-off flexibility and resilience, eg just in time delivery likely to lower costs/ increase efficiency but can hinder short-term resilience
Health and wellbeing	**Dependencies (m):** most notably being the requirement of most emergency services to rely on public infrastructure **Vulnerable groups in society (b):** these groups can be marginalised from emergency planning processes, or do not realise they are at risk at all **Poor coordination/communication between organisations (g):** this could be, for example, the sharing of information on vulnerable groups between voluntary organisations in the local community and public services such as hospitals
Natural environment	**Reluctance of land owners (b/m):** to adopt measures (e.g. natural flood defence) proposed by external parties. Also a clear example of differences between the private and social benefits of natural environment **Difficulty to co-ordinate landowners (g):** a natural environment problem may affect multiple landowners who all need to act together in public interest

Source: adapted from ECR

2.5. Adaptive capacity

Adaptive capacity is the ability of individuals, organisations or entire sectors to adapt to climate change. This is strongly linked with resilience. Adaptive capacity is defined as:

> "The ability of a system/organisation to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), moderate potential damages, and take advantage of opportunities, or cope with the consequences"[19]

Adaptive capacity can partially be explained by the aforementioned barriers to adaptation. If barriers prevent an efficient level of adaptation from occurring then it clearly determines the level of adaptive capacity. [20]

Market failures, for example, lower adaptive capacity when there is a diversity of responsibility for an adaptation decision between multiple organisations. This highlights cases where adaptation provides a social benefit but lacks private incentives to act.

Policy failures[21], for example, can lower adaptive capacity if information provided by government overwhelms, or is insufficient to influence, those who need to implement adaptation actions.

Governance failures, for example, can lower adaptive capacity in organisations due to poor leadership. Inability to influence business partners and suppliers may pose risks under projected climate change.

Behavioural constraints, for example, will lower adaptive capacity when there is a lack of awareness of climate change or lack of willingness to accept and account for the associated risks.

However, even if all barriers are removed there will still be *residual* adaptive capacity constraints which mean certain groups are less able to undertake adaptation. This is mainly an issue of vulnerability for which government may wish to intervene on grounds of equity. For example, some households may lack the financial capacity to undertake adaptation actions even if their value is correctly priced in the market.

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[19] From ECR which in turns refers to Ballard et al (2011), CCRA – modified IPCC definition to support project focus on management of future risks

[20] It is important to note that short-term responses to adaptation are a continuous process. Human adaptation has occurred throughout history in response to changing stimuli such as climate. From this perspective one might conclude that humans are already well adapted to the current climates which they inhabit and are not starting from a point of zero adaptation.

[21] 'Policy failure' is a well established economic concept explained in Section 2.3 but no value judgment is intended on specific policies. Just as a market failure is a problem which prevents the market from operating efficiently, the economic concept of policy failure must not be interpreted as a failure of the policy to bring about a particular solution, but is rather a systemic problem which prevents an efficient policy solution to a problem.

More research is needed to develop understanding of adaptive capacity. Whilst the drivers of high and low adaptive capacity are becoming more apparent, it is not yet possible to compare and prioritise them effectively.

Appendix 1 contains some definitional material and a summary of where we believe adaptive capacity is high and low at the household, organisational and sectoral level.

3. The costs and benefits of adaptation

To inform adaptation decisions it is necessary to analyse costs and benefits at both the local and national level. Analysis of local costs and benefits of adaptation options is fundamental given the heterogeneous nature of climate change impacts. In these cases, attention will focus primarily on direct impacts borne by the local community.

Analysis at the national level is more complex. It will not be enough to add up sector and local specific costs and benefits. For it to be representative, a wider consideration of indirect and non-localised effects needs careful aggregation to ascertain societal costs and benefits of adaptation. A drought, for example, will have direct impacts at a local level, but indirectly may have wider market and non-market knock-on effects (such as on food market prices if the supply of food is affected) and this would have to be considered in the policy appraisal.

Effective adaptation needs to consider when climate change impacts have significant indirect effects which lead to knock-on consequences. Local analyses have no incentive to account for these effects if they fall outside their jurisdiction. In this situation an externality may be imposed on society whose welfare is affected but not accounted for.

3.1. Local level costs and benefits

Planning decisions, be they in the public or private sector, require a full set of costs and benefits to ensure appropriate actions are taken. Evidence on local level appraisal for adaptation options is currently sparse. Nevertheless, the varied nature of localised climate impacts and vulnerability will determine appropriate appraisal techniques for cost-benefit analysis. This could result in different conclusions for different locations even if identical options are assessed.

Acknowledging this evidence gap, the ECR develops a toolkit for the analysis of appraisal options.[22] A number of different appraisal techniques can be adopted in the context of adaptation. Here we provide a brief explanation of these techniques. More information on

[22] Cost benefit analysis is considered in the second 'phase' of the Economics of Climate Resilience. A specific analysis of natural flood management options in Pickering, North Yorkshire is included to demonstrate application of the approach.

appraisal techniques and a discussion of their advantages and disadvantages based on the ECR project can be found in Appendix 2.

Multi-Criteria Analysis (MCA): a mixed qualitative and quantitative approach which provides a ‘ranking’ of initiatives based on weighting and scoring of a set of monetary and non-monetary criteria.

Cost-Effectiveness Analysis (CEA): a quantitative approach which ranks policy options based on the ratio between a specific output/benefit and costs.

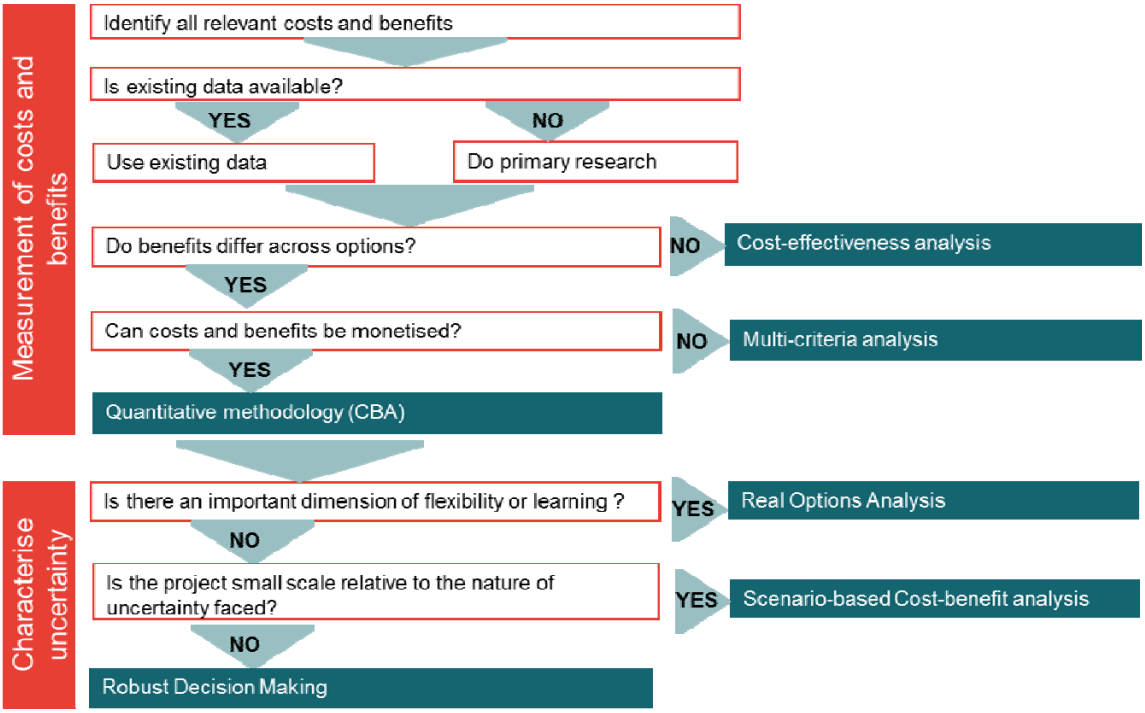
Scenario-Based Cost-Benefit Analysis (SBCBA): a quantitative approach which assesses costs and benefits across different scenarios.

Robust Decision Making (RDM): a quantitative approach which assesses the proposed initiatives across all plausible states of the world and identifies the most robust initiative across these.

Real Options Analysis (ROA): an extension of cost-benefit analysis which estimates the ‘option value’ associated with each initiative, ie the option to delay or adjust in the future. It calculates the Net Present Value (NPV) of each initiative given the particular actions that could be taken given different states of the world being realised and the probabilities of these occurring.

The choice of the most appropriate methodology depends on an assessment of the availability of data and suitability to specific local circumstances. Figure 1 provides a flow diagram illustrating the process for choosing the appropriate methodology in developing a robust cost benefit analysis.

Figure 1. Framework for gathering data and selecting appraisal methodology



Source: ECR

3.2. Overall costs and benefits of adaptation

A comprehensive analysis of the overall costs and benefits is not yet possible to achieve. Evidence remains patchy and reflects the difficulty in scaling up individual and local adaptation costs and benefits to a representative national scale. The ECR reflects our progress in understanding this complex area.

The ECR establishes situations across the policy areas where case for action is likely to exist from private adaptation and government intervention. The ECR assesses the extent of current and future adaptation anticipated in the absence of government intervention by sector.[23]

Table 3 provides indicative findings of the potential value of adaptation facing each NAP policy area.[24] These findings are based on UKCP09 central projections for climate change. They do not consider uncertainty explicitly and are compared against a baseline of no projected climate change. It is important to note that the list of impacts and illustrative

[23] Where government has responsibilities at risk of climate change, adaptation actions will need to be undertaken directly as opposed to intervening in private markets.
[24] Findings provided in Table 3 provide a summary of the 'scale of the challenge' identified in the ECR. Please see individual reports for a full discussion of these scenarios and the case for action

future impacts is not a comprehensive list of the economic consequences of climate change.

Table 3. ECR and illustrative future Impacts

Policy Area	Illustrative future impacts
Agriculture	Increased prevalence of drought could reduce **wheat** yield between 11% and 33% compared to no climate change. • Substituting towards drought resistant varieties may reduce this shortfall in yield to between 5% and 25% • Increasing irrigation can also reduce this shortfall and may even improve yield compared to no climate change. In this case the expected overall change in yield is between -14% and +48% Despite pro-active adaptation pest and disease impacts may reduce wheat yield by between 11% and 29%. Knowledge transfer and education for farmers on adaptation measures could increase yield between 19% and 80%.
Forestry	A primary difficulty is to mitigate uncertainties and exposure to pests and pathogens via diversification. Likely impacts of pests or pathogens are uncertain. Diversifying species and restocking has the potential to reduce but not fully mitigate the exposure to these. • The impact of green spruce aphid on the forest could to reduce yield by on average 3% • Species diversification and restocking could reduce the potential forest area affected by spruce in 2050 from between 26% and 22%. • Diversifying planting could reduce the potential impact of a species destroying disease on timber production by 50 million cubic metres.
Built environment and infrastructure	Climate change could lead to increased uptake and use of air cooling systems in buildings. • If the uptake of air conditioning systems continues at today's rate by 2050, so that around 1% of households in those areas have cooling (compared with 0.6% in 2010), energy demand for cooling could triple between 2010 and 2050 in London. • If in 2050 half of the households in London had air conditioning, energy demand for cooling could be around 37 times higher in 2050 compared to no climate change and current air conditioning take-up trends. Prolonged rainfall causing flooding will lead to road and rail delays and rail cancellations in the 2020s and 2050s which may have a severe impact if no adaptation occurs. • Adaptive actions include improving drainage management plans and improvement of the standard and capacity of drainage systems • Adaptive capabilities are likely to be lower in the 2020s reflecting their long-term nature of infrastructure assets • Greater certainty in benefits of adaptation for rail; substantial uncertainty on the benefits of adaptation exist for roads
Businesses and services	A 3-6 month suspension of production caused by a weather-related interruption of supply chains for a major car manufacturer could be the equivalent of output worth between £600 million and £1,100 million. • Adaptation actions could reduce this to 2-4 weeks, reducing production

	interruption by between £400 million and £1,000 million Climate change could prompt new or emerging markets. Demand for products to help society adapt could represent a benefit for certain sectors (for example chemical industries).
Health and wellbeing	The estimated costs associated with the potential mental health effects of the 2007 floods in Hull (including treatment, lost work time and reduced quality of life) was in the range of £4 million to over £600 million, depending on assumptions. The costs of temporarily closing a hospital for 10 – 60 days could be in the range of£2 million to £20 million
Natural environment	An analysis of natural flood defences in Pickering, using robust decision making, compares the implementation package of 7 natural flood defence measures against a baseline in which no measures are implemented. • Under central estimates net benefits of implementing the measures are over £3.2 million (and this is believed to be a conservative estimate). • This is robust apart from only the most extreme of sensitivity analyses.

Source: adapted from ECR

Adaptation has also been analysed from the macroeconomic perspective. Models exist which attempt to integrate climate science into an economic framework. It has been estimated in the wider European context that the value of potential damages avoided could be in the ratio of 4:1 to the cost of adaptation[25]. These macroeconomic models provide useful illustration of the potential trade-off between adaptation to climate change and mitigation of greenhouse gas emissions.

However, there is no comprehensive model of economic impact of climate change. They suffer from two main issues which limit their applicability to adaptation in the UK.[26] Firstly they are high level, focusing on global or very large regions (e.g. Europe). This inhibits interpretation of findings specific to the UK without making restrictive assumptions about the heterogeneity of climate impacts at a local level. Secondly, they ignore interactions between sectors and the second-order impacts of climate change on economic activity, such as market adjustments to climate impacts. Future economic research in adaptation needs to join up our knowledge of bottom-up (e.g. sector specific analysis) and top-down (e.g. overarching) approaches.

Conversely, projections of changes in climate variables are subject to large uncertainties which are often not being incorporated into economic models available in the literature.[27] These uncertainties are of different types, as discussed in Section 2.2. Firstly, most of the available models adopt ranges for global mean temperature that can be considered an

[25] These are called 'adaptation integrated assessment models' (AD-IAMs). Calculation based on the ratio between the cost of adaptation and the difference between gross and residual damage from table 3 pag 24 in de Bruin, K.C., Dellink, R.B. and Agrawala, S. (2009) "Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits" OECD Environment Working Papers No.6, OECD Publishing

[26] See discussion in Section 4 of this annex. For a full discussion, see the Macroeconomics of Climate Change project

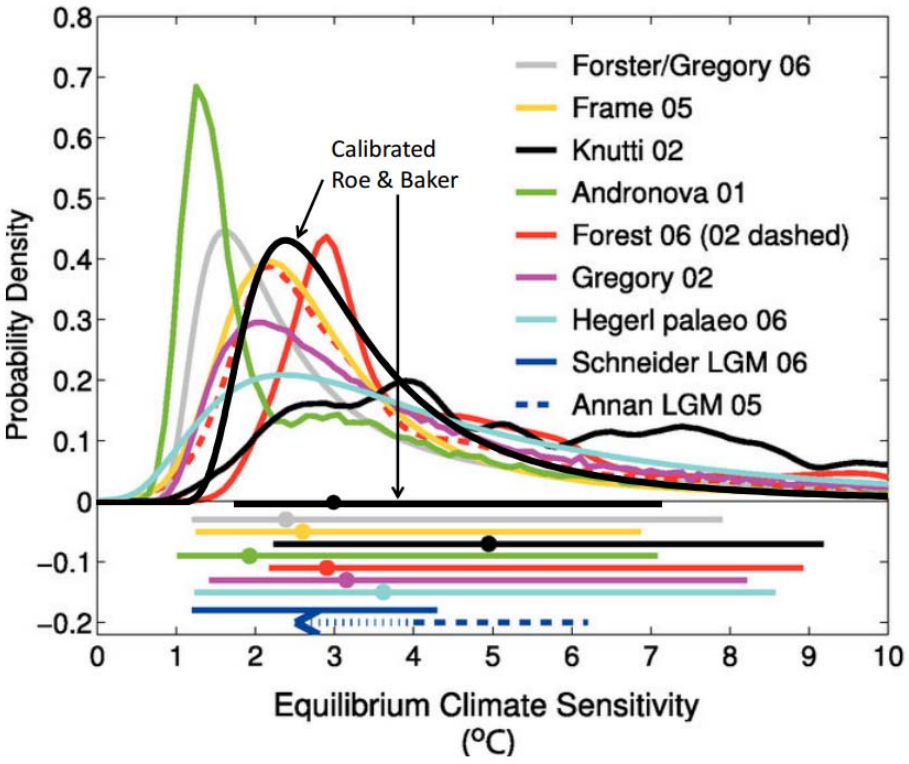
[27] For a more in depth discussion see Macroeconomics of Climate Change project

underestimate of the range of possible temperatures.[28] Secondly, they often do not take into account the potential negative consequences of extreme weather events. Finally, they do not incorporate the potential existence of 'tipping points' in the climate system that, if passed, could result in irreversible changes to how the climate system functions, and potentially larger impacts on economic and social systems.[29]

Figure 2 illustrates the consequences of some of these uncertainties, particularly those due to incomplete knowledge of the climate system. It provides 10 estimates of the probability of average global temperature changes happening. Equilibrium 'climate sensitivity', the expected global surface temperature change under a sustained doubling of atmospheric carbon dioxide, drives economic impacts. Due to uncertainties in the methods used to estimate the equilibrium climate sensitivity, it is usually expressed in terms of a range of values with an associated probability distribution. These probability distributions display 'fat upper tails'. This means that, whilst considered unlikely, it is not possible to rule out high values of temperature change which would have significant economic impacts.

[28] Ibid
[29] For further discussion see Macroeconomics of Cliamte Change project, which in turns refer to Lenton et al., 2008

Figure 2. Probability densities of the estimated range of equilibrium climate sensitivity from various studies (the equilibrium climate sensitivity is the expected global surface temperature change under a sustained doubling of atmospheric carbon dioxide)[30]



4. Growth and climate change adaptation

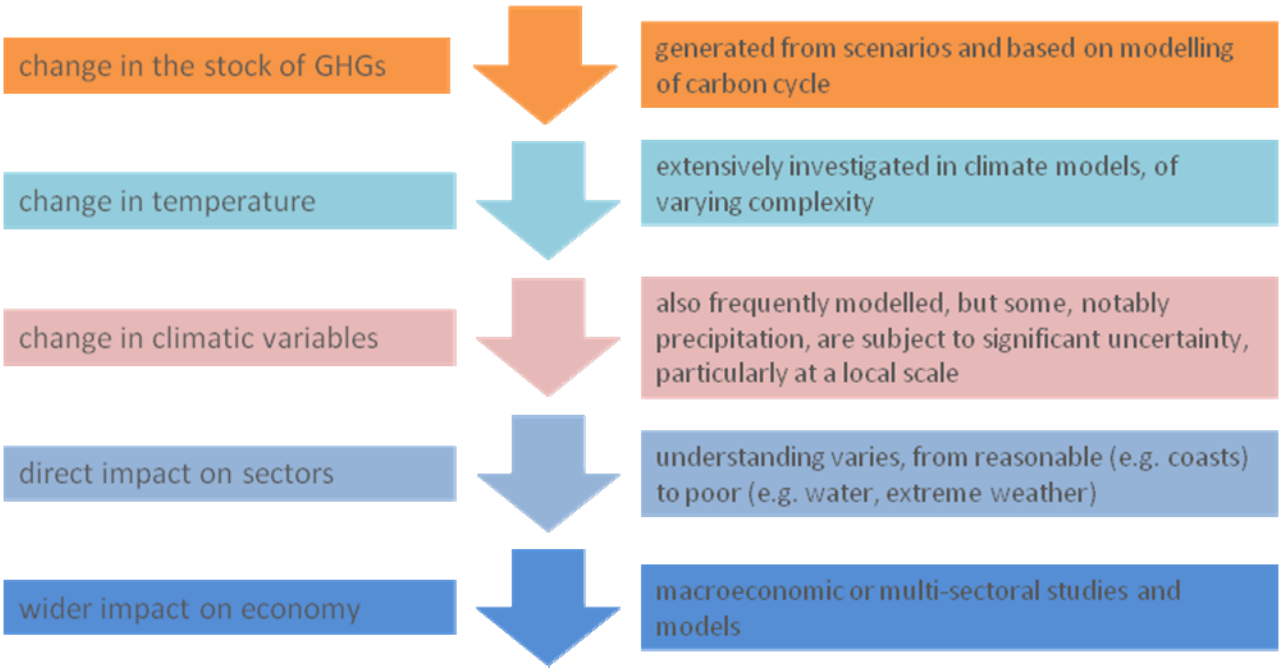
Growth and climate change are fundamentally related. This is because climate change is an input to economic activity.[31] Usually the damage to economic activity is assumed to increase proportionately more than changes in climate.[32]

Figure 3 demonstrates the impact of increasing greenhouse gas emissions and resulting climate change on economic activity. These could be direct impacts. Sectors like agriculture and water are dependent on climate and weather patterns. Changes to these systems will alter the ways in which some sectors operate. Climate change will also have

[30] Vivid Economics, *The macroeconomics of climate change*, report prepared for Defra, May 2013 which quotes EPA (2010)
[31] For a full discussion of aspects of climate change with macroeconomic relevance see Vivid Economics, *The macroeconomics of climate change*, report prepared for Defra, May 2013
[32] For example Integrated Assessment Models make assumptions about the convexity of the damage function caused by climate change. It is often assumed to be quadratic.

wider economic impacts. For example, many sectors are dependent on the availability of water. Water demand deficits are expected to increase with climate change.[33]

Figure 3 Impact of climate change on the economy



Source: adapted from Vivid Economics (2013)

Adaptation plays a role in determining economic growth. Its main function is to protect long-term growth through, for example, ensuring the allocative efficiency of current and future resources. Failure to adapt could lead to unnecessary damages and inefficiency. Adaptation may also provide opportunities.

The following sub-section outlines analysis on the relationship between adaptation and growth through avoided damage. Section 4.2 discusses the additional positive and negative impacts on growth that could arise from adaptation. Section 4.3 considers adaptation in the wider context of social welfare as opposed to growth.

4.1 Adaptation protects growth and allocative efficiency

Allocative efficiency is able to protect economic growth.[34] It means resources are being used in the most efficient way possible. This includes accounting for the opportunity cost of foregone investment elsewhere in the economy. Failure to adapt to climate change would

[33] The CCRA report on water concludes the UK on average is projected to have rising household demand for water and a decrease in public supply. The CCRA can be found online at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15747#RelatedDocuments

[34] In terms of avoiding economic costs

lead to a misallocation of resources. It would leave the UK at risk from suffering unnecessary damage costs of climate change. In such scenarios it would be cheaper to invest in adaptation than face the consequences of inaction.[35]

Resources for adaptation need to be allocated over time. Proactive adaptation can be hindered by short-term inertia. This presents risks to allocative efficiency for long-term investment decisions (for example infrastructure) which are not resilient to climate change impacts. For some measures ignoring adaptation to improve resilience may save money in the short-term but will cost more in the long-term to retrofit or fix. For others, the most economically efficient approach will be to design in the capacity to respond flexibly as the impacts of climate change become more certain.

The introduction of adaptation technologies can avoid impacts on growth through disrupted production and misallocation of resources. For example, this could be flood defences, or methods to prevent overheating in buildings. Understanding future climate change risks can incentivise businesses to invest in adaptation technology in the short-term[36]. The effectiveness of investment will be more pronounced when unused capacity is higher.[37]

The Environment Agency Thames Estuary 2100 plan is a long-term flood risk management plan for the tidal Thames which is also considering adaptation options in the short-term. It concludes that the current Thames Barrier is viable until 2070. Over the next 25 years investment will be made in actively maintaining and improving the existing system.

Adaptation can help protect long-term investments and generate competition[38].Businesses could compete on the level of their resilience to weather and climate; this would make them less likely to face disruption. Demand for their products would increase as a result. Firms can achieve this by taking ‘low regrets’ actions. ‘Low regrets’ means an adaptation action is cost effective in the present regardless of what future climate might be. For this to occur privately in markets organisations need to understand when it is more cost effective to take planned adaptation measures as opposed to reactive ones.

Low regrets actions often occur in cases where significant co-benefits are present such as natural ecosystem-based flood control.[39] The ECR conducted a cost-benefit analysis for

[35] Adaptation costs and damage costs are of course dependent on mitigation efforts in the short-term.
[36] Adaptation investment could feasibly displace investment in other areas. In these cases businesses and organisations will need to decide which type of investment is most valuable.
[37] Cost effective adaptation could also increase growth (and therefore income) relative to a counterfactual of accepting full climate damages and lead to additional future investment. However, note that cost-effective adaptation from a theoretical point of view would not necessarily lead to increased growth relative to the counterfactual at all points in time.
[38] Competition in markets reduces prices and improves quality. It drives an increase in efficiency and reduces costs. If rising efficiency leads to an increase in market share then this will provide an incentive to innovate.
[39] Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A and Ruta, A. (2010) ‘Adaptation in the UK: a decision making process’ Gratnham Research Institute on Climate Change and the Environment Policy Brief,

the implementation of natural flood defence measures in Pickering, North Yorkshire. It provides evidence of the importance of co-benefits and strong case for the implementation of a mix of adaptation measures.[40]

To protect economic growth we need to build resilience to extreme weather events and climate change. Inaction can risk making investment decisions that lock us into unnecessary damages.[41] An efficient level of adaptation will ensure expected damages only occur where it is cost effective to accept them. The UK needs to allocate its limited resources efficiently and use them where they are most valuable.

4.2 Other economic impacts of adaptation

The primary role of adaptation is protecting growth to avoid unnecessary damage costs. Like many other economic activities, adaptation is likely to have a range of positive and negative secondary effects in addition to its main intention. It could sometimes create opportunities to support growth by enhancing productivity. These could take the form of co-benefits to adaptive actions which also help to protect future growth. For example it may stimulate enterprise in business offering adaptation goods and services. It could also promote innovation from which new goods and services stem and create new markets. While we discuss these as two separate analytical concepts, in practice the same adaptation activity may help protecting growth while also supporting it by providing opportunities and spillover effects.

However, adaptation activities, whether embarked by government, businesses or other organisations, will obviously have costs. The innovation and enterprise benefits in adaptation may be offset or outweighed by the displacement of resources from other areas of the economy where they could also be productively used. The overall net effect is likely to vary. Some adaptation activities could potentially have larger net benefits through delivering co-benefits such as those illustrated below. In other cases adaptation actions might be costly. This reinforces the need to accurately evaluate the rational for action (as discussed in Section 2) and to appraise costs and benefits (see Section 3).

The largest benefits in terms of avoided damage will likely occur in the future, while costs will often be born in the short term. This highlights the importance, in the context of adaptation, to focus on ‘win-win’ and ‘no-regret’ actions: those activities that carry a range of short-term benefits and low costs.

Below some examples are presented for illustrative purposes of the type of co-benefits that action on adaptation could bring. Overall we know little about the impact of adaptation

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available online at: http://www2.lse.ac.uk/GranthamInstitute/publications/Policy/docs/PB-Ranger-adaptation-UK.pdf

[40] The ECR report on appraising flood management initiatives can be found online at http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016

[41] This is confounded by the extent of sunk costs

on economic growth. This is likely to vary across different sectors, locations and specific activities. Therefore it is highlighted as a key evidence gap in Section 5.

K-Matrix analyse a set of goods and services under the banner of adaptation and resilience for climate change (A&RCC) activities.[42] It demonstrates the potential of business enterprise in adaptation related products. Sales of these activities were worth £65.8 billion as a global industry in 2010/11. The share attributed to the UK is estimated to be £2.1 billion in the same time period. It is an emerging market which had a domestic growth rate of 3.9% for 2010/11, with forecasted growth rates to increase year-on-year and reaching 7.1% in 2017/18. On its own this does not indicate either a positive or negative effect on the economy as a whole. In an economically efficient system, the size of the adaptation sector should be driven by the optimum scale of the adaptation response, rather than adaptation policies be designed to support this sector at the expense of others. However, the expected need for adaptation makes these activities likely to become increasingly significant.

Enterprise in an emerging set of activities may encourage innovation through technological progress. The need to adapt will change over time and stimulate innovation naturally through a need to use resources in more efficient and effective ways. More broadly, a culture of innovation can be stimulated through providing appropriate incentives[43].

Such incentives are currently being tested by Defra, in collaboration with the Technology Strategy Board, to bring new climate resilience products to market. A design competition is being funded to develop innovative products and services solutions to increase infrastructure climate change adaptation. Three innovations are being funded: a stackable flood barrier; a zero energy rainwater harvester; and catchment scale modelling to improve urban drainage systems design. Another round of this competition will run from 2013.

4.3. Economic growth and social welfare

Adaptation is capable of protecting economic growth and delivering wider opportunities. However, the value of adaptation goes beyond growth and contributes to social welfare more widely. Growth is associated with traditional economic indicators. These include aggregate variables such as Gross Domestic Product (GDP), investment and rates of unemployment. Social welfare is the aggregate of all interactions of private individuals in economic markets. There exist many determinants of social welfare which are not suitably captured by economic indicators.

[42] For the report and full breakdown of A&RCC activities, see K-Matrix (2012) 'Adaptation and resilience (climate change)' report available online at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31721/12-p144-adaptation-and-resilience-climate-change-2010-11.pdf

[43] Where market failures which prevent an efficient level of innovation

Non-market goods are important contributors to an individual's welfare but are typically ignored by national indicators like GDP because they are not traded in markets and have no price. There are many examples of non-market goods. These could be environmental amenities (eg air quality or climate) or individual circumstances (e.g. personal health, marital status). To account for the full value of adaptation we need to understand how non-market goods are affected by climate change and how this impacts on our welfare.[44]

Cost effective adaptation decisions should account for whether climate change will improve or deteriorate non-market goods and what their value is. To estimate the implicit price of non-market goods it is necessary to employ techniques that derive the willingness to pay for an improvement in quality or willingness to accept compensation for a reduction. This allows the value of non-market goods to be expressed in monetary equivalents.[45] These values should be incorporated in social cost-benefit analysis when choosing between alternative adaptation actions.

It is also important to account for equity in decision-making for adaptation. Willingness to pay for improvements to non-market goods is constrained by income and positively correlated. Appropriate welfare weights should be incorporated to ensure those least able to pay for non-market goods are still able to enjoy them. Furthermore, the long time horizons associated with climate change means it is also important to consider the welfare of future generations appropriately.

5. Future evidence needs

5.1. The macroeconomics of climate change

Defra has commissioned and recently published an appraisal of existing modelling techniques that estimate the macroeconomic impacts of climate change and extreme events with and without adaptation.[46] Its purpose is to inform policymakers of the state of current modelling techniques and recommend direction for future research. The report develops a checklist of 9 criteria against which modelling techniques are assessed. Recommendations are made on how to improve these techniques. This will help inform policymakers of the advantages and limitations of employing particular macroeconomic models of climate change.

[44] By means of an example, climate change risks affecting ecosystem functionality and the quality of environmental goods we are able to consume.
[45] A review of specific techniques to value non-market goods is beyond the scope of this document. For a detailed discussion see Fujiwara, D. and Campbell, R. (2011) 'Valuation techniques for social cost-benefit analysis: stated preference, revealed preference and subjective well-being approaches' available online at: http://www.hm-treasury.gov.uk/d/green_book_valuationtechniques_250711.pdf
[46] Vivid Economics, *The macroeconomics of climate change*, report prepared for Defra, May 2013

The report highlights that current modelling of climate change does not reflect state-of-the-art macroeconomics. In particular, they are only able to account for growth exogenously. This means that economic growth is assumed to depend on external forces only, which means that climate change is assumed to have no influence on growth. Accounting for growth endogenously allows the model to determine growth based on the projected impacts of climate change. Furthermore current modelling lacks account of financial assets, public finance and sophisticated trade dimensions though these can theoretically be incorporated.

Three main recommendations and way forward for the research project are given in Table 4 below.

Table 4.Recommendations of Vivid Economics (2013)

Recommendation	Way Forward
There is some disconnect between latest advances in academic research and answers to relevant policy questions	The next step is to develop areas of policy concern and ascertain how they fit with the current academic literature. Development of well-informed policy questions by government is fundamental to stimulate academic research which will impact policy. Future modelling for adaptation needs to be based on substantial, high quality bottom-up analysis. Of particular importance is to understand better the significance of indirect macroeconomic impacts.
We need to stimulate a fundamental debate about modelling strategies	There is a trade-off against a single complex model which could explore multiple policy questions and a suite of simple models that seek to answer them individually.
There remains concern about the quality assurance of macroeconomic models if they are to inform policy	These revolve around the underlying assumptions, code and calibration data of modelling. This is crucial to ensure any models implemented can stand up to public scrutiny.

Source: Vivid Economics (2013)

5.2 Next steps

Adaptation is the central component of dealing with the impacts of climate change. It will avoid unnecessary damage costs. The focus areas and programme actions identified in

the NAP report are grounded in the current evidence we have on the risks and the economic costs of climate change.

In many cases adaptation will be an automatic and natural response. Households will alter observable behaviour such as consumption patterns. Organisations will alter factors of production according to relative prices and the availability of resources. In these cases, no intervention action is necessary and adaptation will be autonomous.

However, adaptation will also require concerted action:

Barriers to adaptation exist and could prevent an efficient level of adaptation from taking place. Households, organisations and government need to be aware of these barriers and take appropriate action to overcome them. Government should develop its thinking on when intervention can in theory improve efficiency, whether it is capable of improving efficiency and when it risks crowding out private investment.

There is a need to understand better the value of improving adaptive capacity in terms of reducing vulnerability to climate change. The varied nature of households and organisations means that certain groups will be more vulnerable to climate change and lack the capacity to adapt. Analysis could highlight the need to intervene on grounds of equity (households) or because it provides significant risk to economic growth (organisations).

Large evidence gaps still remain on the costs of inaction (or the benefits of undertaking adaptation). Further research is required to understand the costs of indirect/ second order and international impacts of climate change. Also, little is known on climate change impacts if certain thresholds or tipping points are reached.

Some costs and benefits are currently difficult to quantify and risk being omitted completely. This could lead to inappropriate selection of adaptation options or for no adaptation to be taken at all. This is particularly the case for ‘stock’ adaptation measures where the time horizons are very long, need to be planned as opposed to reactive and are subject to substantial uncertainty. Government needs to ensure that iterative and flexible appraisal options are selected for long-term investment decisions.

From the macroeconomic perspective there is a need to build a better understanding of the value of adaptation to the UK. Achieving this requires a comprehensive set of bottom-up analyses, quantification of indirect impacts and appraisal of adaptation options. From this corresponding costs and benefits can be estimated.

Further evidence is needed to understand the relationship between adaptation and growth/productivity. Adaptation actions are inextricably linked

with growth, whether through avoiding unnecessary damages or providing new opportunities to improve productivity. However, evidence is currently limited on how this will develop over time and against projected future climate change.

Appendix 1: Supplementary material on adaptive capacity

Adaptive capacity is a cross-cutting issue that is relevant to all 6 policy areas identified in this analysis. It determines the ability of households, organisations and government to undertake 'planned' adaptation.[47] The nature of adaptive capacity is also dependent on whether adaptation is better described in terms of a 'flow' or a 'stock'.

> **Flow adaptation** happens when benefits and costs occur simultaneously. It is more likely to be reactive and autonomous. Short-run responses are likely to be limited to changes in variable inputs. For example, in agriculture this could be switching between available crop varieties.
>
> **Stock adaptation** requires investment over the long-run to build up adaptation capital stick. It is likely to require planning. This includes investments that provide a stream of adaptation benefits over time. For example, sea walls protect coasts from sea level rises for a number of years. It also includes long-term investment planning such as national infrastructure which will need to be robust to future climate.

Table 5. Summary of features of high and low adaptive capacity for households and organisations

Organisations and individuals features		Description
	Higher adaptive capacity when...	
Resources	Good understanding of risks to resources	Organisations have in-house capability to respond to climate change
Processes	Flexible planning and processes embedded into decision-making	This can include flexibility of supply chains and substitutability of suppliers and how footloose and organisation is.
	Partnerships and collaboration	Are voluntary organisations/ local authorities in place to support community resilience?
	Operational planning already accounts	Clear process of risk management is in

[47] Planned adaptation is anticipatory and reflects conscious concerns about the risks of climate change. In some cases this can be directly influenced governments or collectives as a public policy initiative (ECR Synthesis Report, 2013). Examples include the Heatwave Plan for England which outlines actions to ensure health and social sectors are prepared. Alternatively, adaptation may be reactive. This is a natural response to climatic stimuli without the need for direct intervention. For example, during a heatwave people may buy air conditioning units or make more fundamental behaviour choices such as investment in clothing.

	for risks similar to those expected to increase from climate change	place
	Access to risk spreading mechanisms	Availability of insurance to offset risk
Organisation	Agents of change or champions	Community members setting up support groups
	Strong leadership and culture	Ability to influence business partners, suppliers
	Support networks	Provide support to small organisations and individuals who struggle to plan in the long-term
	Lower adaptive capacity when...	
Resources	Lack of awareness	Not aware of risks of climate change and a lack of willingness to accept the nature of a risk
	Lack of financial support and skills	Individuals of low socio-economic status and small/ medium-sized organisations
	Lack of specialised skills and training	Ability to understand and respond to climate change impacts
	Poorly targeted information	Overwhelm or provide insufficient information to individuals/organisations
Processes	Limited ability to influence policy making	Restrictions on adaptive actions that can be taken such as renting premises from landlords.
	Lack of engagement with vulnerable groups	Action needed to identify and aid to groups who are most vulnerable to climate change.
Organisation	Where diversity of responsibility exists	Multiple organisations facing different objectives – situations where adaptation provides a social benefit but lacks private incentive
	Competing demands arise from different users in the same catchment area	Multiple sectors all requiring the same factor input e.g. water needed by farming, households and industry.

Source: Adapted from ECR

Table 6. Summary of features of high and low adaptive capacity at sector level

Sectoral characteristic	Adaptive capacity
Higher adaptive capacity in sectors with...	
Low complexity	Few organisations making decisions and respond to a single regulator, such as oligopolistic/ natural monopoly markets e.g. power sector
Co-ordination between organisations	Operational planning procedures in place e.g. healthcare/ hospitals

Regulated sectors	Where regulatory requirements take due account of current and projected climate risks
Decision lifetimes are short	Short lifetimes make decisions more flexible. Allow for regular review and evolution of decisions and account for increased knowledge of climate risks over time.
Prior experience	Already experienced impacts similar to those expected from climate change e.g. extreme weather conditions.
Lower adaptive capacity in sectors with...	
High complexity	Many interacting organisations with diverse requirements, roles and responsibilities and where sector is fragmented.
Interdependency of adaptive capacity with others	Sectors where there is a reliance on the actions of others such as rental housing and social care.
Interdependency of operations	Limited ability to manage/ control risks. This could be because of a dependency on public infrastructure and provision of services
Reliance on the natural environment and management of variation in weather	Leads to short-term focus in business planning. Constraints of natural environment can inhibit ability to respond e.g. impacts of drought/ floods
Low activity levels but with long decision lifetimes	Fewer opportunities to make decisions e.g. housing, tree planting, land-use change, major infrastructure investments
Decisions to address one risk can increase vulnerability to another	Failure to consider all economic costs (and benefits) of adaptation in decision making.

Source: Adapted from ECR

Appendix 2. Advantages and disadvantages of each appraisal methodology

Methodology	Brief Description	Advantages	Disadvantages
Multi-Criteria Analysis (MCA)	Part or wholly qualitative-based approach, which provides a 'ranking' of initiatives based on monetary and non-monetary criteria	Allows appraisal to be conducted in the absence of/ limited amount of quantitative data	Limited to relative assessments of alternative policy options Outputs are appraisal-specific – i.e. cannot be generalised more widely
Cost-Effectiveness Analysis (CEA)	Quantitative approach which identifies the policy option providing a specific output/benefit at the lowest cost	Useful when a specific output/objective is needed to be met Can be used when comprehensive quantitative cost data is available for monetising costs but not benefits	Not applicable when a single initiative is being appraised, or when considering multiple initiatives providing different levels of the required benefit Implicitly ignores potentially significant co-benefits
Scenario-Based Cost-Benefit Analysis (SBCBA)	Quantitative approach which assesses costs and benefits (in monetary form) across different scenarios/states of the world	Accounts for uncertainty surrounding flood risk without being computationally or data intensive Provides numeric outputs, allowing for cardinal comparisons between initiatives Easily understood for non-technical audiences. Allows for the application of risk-based rules	Potentially difficult to gain consensus on the appropriate scenarios to use Risk of not capturing the extent of uncertainty surrounding climate change, especially under 'deep uncertainty'
Robust Decision Making (RDM)	Quantitative approach which assesses the proposed initiatives across all plausible states of the world, and identifies the most robust initiative across these	Captures deep uncertainty – leaves 'no stone unturned' Provides numeric outputs Provides a clear picture of which initiatives are optimal in different states of the world	Can be computationally and data intensive Potentially difficult to interpret for non-expert audiences Value function for deriving costs and benefits needs to be well calibrated Ranges of plausible parameter values need to be known
Real Options Analysis (ROA)	Extension of CBA which estimates the 'option value' associated with each initiative i.e. the option to delay or adjust in the future. Calculates the NPV of each initiative given the particular actions that could be taken given different states of the world being realised, and the probabilities of these occurring.	Accounts for learning about the nature or extent of flood risk going forward. – captures the value in delaying or adjusting a particular initiative Useful when comparing large irreversible options with smaller-scale flexible options.	Can be computationally or data intensive – requires the assignment of probabilities to scenarios at various future time periods

– Source: Frontier Economics