UK Climate Impacts Programme

Costing the impacts of climate change in the UK

Implementation report

COSTING THE IMPACTS OF CLIMATE CHANGE IN THE UK:

- Implementation Guidelines -

- Final Report -

Prepared for:

The UK Climate Impacts Programme (UKCIP)

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Executive summary: The importance of costing climate impacts and adaptation

1. Climate change is one of the most significant challenges we face over the coming century. Some climate change is now inevitable, no matter how successful we are at reducing emissions of the greenhouse gases that cause it. These changes will affect many aspects of our lives, environment, economy and society. Decision-makers need to manage the impacts of climate change – and may need to adapt – to minimise negative impacts and maximise any beneficial opportunities. In recognition of the importance of the problem, the Secretary of State for Environment, Food and Rural Affairs recently stated: “Our use of fossil fuels is changing our climate, with potentially dramatic and potentially disastrous results. Climate change is not by any means just an issue about the environment. It is a business issue.” (Rt Hon Margaret Beckett MP, Secretary of State for Environment, Food and Rural Affairs, 26 November 2003).

2. **Adaptation** to climate risks is most likely to be important for:

- managers of business areas that are currently affected, directly or indirectly, by weather or climate;
- those making decisions with long-term consequences (decades or longer) for land-use, built assets or population groups;
- infrastructure and business areas that are sensitive to changes in climate;
- contingency planning; and
- those who want to gain an ‘early-mover’ advantage on a climate change business opportunity.

At present, there is a lack of reliable information on the costs of climate impacts, which makes it difficult for decision-makers to judge the amount of resources that they should allocate to adaptation in any given case. These guidelines aim to help to fill this gap, by providing a standard methodology for costing climate impacts, and comparing these with the costs of adaptation measures. The methodology should enable decision-makers to calculate valid, order-of-magnitude estimates of the costs, to help identify priority climate risks and to select appropriate adaptation measures. The methodology can be applied across a range of sectors, and at a local, regional and national scale in the UK.

What is different about costing climate impacts?

Costing climate impacts and adaptation measures poses some specific problems:

- Climate change is already happening and is a long-term risk issue, though clearly extreme climatic events can occur at any time. Most climate impacts will intensify over the coming decades, as the climate continues to change. Since individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now, discounting needs to be applied when costing future impacts. The Treasury Green Book (HMT, 2003) recommends discount rates for different future time periods, which must be used in public sector costing studies. Costing studies in the private sector can use the 'opportunity cost of capital' approach.

- Climate impacts on one sector or region may well have knock-on effects elsewhere, and these may be significant for the choice of adaptation option. The use of the impact matrices provided in these guidelines should assist in the identification of the full range of impacts.

- In some cases, climate impacts might be significant enough that they cause changes in the prices of affected goods or services. These are called non-marginal impacts and they should be incorporated into valuations. For instance, wheat prices across Europe rose significantly in the summer of 2003, when the hot, dry weather caused harvests to fail in several European countries.

- There is uncertainty about the nature and magnitude of climate change and its impacts. There is also uncertainty about how these impacts should be valued, and about the performance of adaptation measures. It is important for decision-makers to understand and manage this uncertainty. This can include using a range of climate change scenarios to value climate impacts, and employing options selection criteria that have been developed for decision-making under uncertainty.

5. To address climate risks and uncertainties fully in the decision-making process, the costing methodology should be used within the context of the climate adaptation decision-making framework provided in another UKCIP Technical Report (Willows and Connell, 2003). In particular, the methodology is an important element of the risk assessment and options appraisal stages of the framework.

Audience for the costing methodology

6. The costing methodology is a flexible approach that can be used alongside other appraisal measures. It can be applied to costing studies in the public and private sectors. However, public sector decision-makers should primarily refer to guidelines on costings given by the Treasury Green Book, and to specialist costings guidelines from government departments, where these exist. The methodology presented here is

consistent with the Green Book.

7. Two reports have been produced:

- The 'overview of guidelines' (this report) is designed to give non-economists a sound appreciation of the methodology, without including too much technical detail. It should enable decision-makers to identify research needs and successfully commission and interpret costing studies.

- The more detailed 'implementation guidelines' are aimed at economists, who need specific guidance on how to value climate change impacts at a local, regional or national scale, disaggregated by sector.

Steps in the methodology

8. The costing methodology involves:

- identifying and measuring (quantifying) climate impacts in physical units;

- converting these physical impacts into monetary values;

- calculating the resource costs of adaptation options; and

- weighing up the costs and benefits of the adaptation options, and choosing the preferred option, taking account of risks and uncertainties.

9. To help users identify climate impacts, the implementation guidelines provide impact matrices for the following sectors:

- coastal zones

- water resources

- agriculture

- buildings and infrastructure.

These matrices cover a broad range of impacts, but impacts on other sectors can also be identified.

10. Having identified an impact, the user then needs to measure (quantify) it in physical terms, before it can be costed in terms of money. This may involve undertaking a climate impact study. Further guidance on climate impact assessment is provided in Willows and Connell (2003).

11. The impact matrices help to identify the direct ('lower-order') impacts of climate change, such as increased coastal erosion caused by sea level

rise – as well as the knock-on ('higher-order') effects, such as reduced visitor numbers to the affected coastline. Alongside each impact, the matrices highlight the appropriate economic valuation methods that can be used to convert the physical impact into monetary values.

12. The methodology is flexible enough to be applied across a range of scales from broad aggregated impacts on a region down to very refined disaggregated impacts on a particular receptor.

Techniques for valuing different types of impact

13. The valuation guidelines are grouped into two categories: conventional market-based techniques and individual guidelines tailored to specific types of receptor.

14. If the climate impact affects an asset or a marketed good or service then conventional market-based costing techniques can be applied as follows:

• Impacts on marketed goods or services can be valued according to changes in inputs or outputs, for instance using the 'change in productivity' approach.

• For impacts on man-made assets, cost-based methods, such as the 'replacement cost' and 'avertive expenditure' techniques, will be appropriate.

15. These techniques use market price data to value climate impacts. The guidelines for these techniques are therefore written to facilitate the use of primary data, as these should be readily available to the user.

16. Impacts on non-marketed goods or services are more difficult to value, and so the methodology includes individual guidelines for valuing impacts on:

- habitats and biodiversity
- human health
- recreation and amenity
- cultural objects
- leisure and working time
- non-use benefits.

17. To value impacts in these areas primary valuation studies can be conducted. These use economic techniques such as 'hedonic analysis' (which values non-marketed goods using prices for related marketed goods); 'travel cost' (which uses the total price people pay to reach a site);

or 'contingent valuation' (which asks people directly what value they place on a good or service). Using these techniques will often be expensive, but in many cases it will not be feasible or necessary to conduct primary studies. For instance, to pass a cost-benefit test, it is often only necessary to determine whether an option's benefits exceed its costs, and the exact magnitude of the exceedance is not needed.

18. Therefore, these guidelines recommend the use of 'benefit transfer', which transfers values from existing studies to the climate change context. Clearly, this approach introduces errors from the existing studies and from transferring to the new situation. The user will need to weigh up the accuracy of cost information required for decision-making against the time and money involved in doing a primary valuation study, as opposed to applying benefit transfer. The reports provide guidance to help users work out which approach to take.

19. Where the user identifies an impact that does not appear to be covered in the conventional market or non-market guidelines, the guideline on unvalued impacts shows how information on the impact may be presented and used alongside monetised data e.g. in multi-criteria analysis.

Avoiding mistakes

20. For some climate impacts, quantitative impacts data will not yet be available, so it will not be possible to put a monetary value on the impact. For other impacts, suitable economic valuation techniques will not exist. But, for a complete assessment, all the significant impacts must be incorporated into the decision-making process. Techniques such as multi-criteria analysis can be employed to help with these cases.

21. There is a danger of double-counting when costing direct, 'lower-order' impacts (such as loss of coastal land to sea level rise) by aggregating the associated knock-on 'higher-order' impacts (such as loss of recreational sites and private property). double-counting errors can also occur when adding 'use values' to 'non-use benefits', and care must be taken to avoid them.

Options appraisal

22. Once climate impacts have been valued, and the resource costs of the various adaptation options have been calculated, the decision-maker needs to bring this information together, to compare the outcomes of each adaptation option, and identify the 'best' course of action. Various decision-support tools can be used to help the decision-maker select the preferred option. These guidelines show how these decision-support techniques can be used in this context.

23. Where outcomes are expressed in monetary terms, options appraisal may be performed in the framework of cost-benefit analysis (CBA). CBA is designed to demonstrate whether the total benefits of an adaptation

option are greater than its costs.

24. However, economic value will seldom be the sole criterion for decision-making – other objectives are likely to be important too. In these cases, CBA can be used within the context of other decision-support tools, such as multi-criteria analysis, to account for these wider considerations.

25. Various selection criteria can be used to differentiate between options, depending on the quality of the decision-maker's knowledge. When knowledge of the probability of an event is poor, (as will often be the case with climate change) criteria such as 'maximin' or 'minimax regret' can be used. Other techniques, such as 'net present value', or 'expected net present value' are useful when the decision-maker has greater certainty about outcomes.

26. The decision-maker will want to know how sensitive his/her estimates are to the input data and models used in the analysis. She/he will also need to understand any key assumptions. Techniques for testing the factors that underpin the estimated outcomes include sensitivity analysis, simulation and interval analysis.

Case studies

27. This 'overview of guidelines' report includes illustrative case studies demonstrating the application of the methodology to four different issues where adaptation might be considered:

- water resources – the cost of increasingly stringent effluent standards;
- agriculture – the cost of not meeting irrigation need;
- flooding – the changing costs and impacts of flood alleviation;
- time losses – the cost of short-term disruption to transport systems.

Working towards a climate-adapted UK

28. Climate change presents a wide range of risks to decision-makers. The use of these guidelines by decision-makers in a range of sectors and regions should help in the UK's efforts to adapt appropriately to climate risks. If the guidelines are widely used, this will facilitate a national assessment of the costs of climate change to the UK.

LIST OF ACRONYMS AND ABBREVIATIONS

A	'Option' or 'course of action' in a decision problem
AC	Average cost
AISC	Average incremental social cost
AV	Averting expenditure
B/C	Benefit cost ratio
CBA	Cost-benefit analysis
CE	Choice experiment
CEA	Cost-effectiveness analysis
CGE	Computable general equilibrium (model)
CO	Conventional market-based valuation techniques
COI	Cost of illness
CV	Contingent valuation
CVM	Contingent valuation method
DETR	Department of Environment, Transport and Regions (UK)
DFID	Department for International Development
EA	Environment Agency (UK)
EMV	Expected monetary value
ET	Either 'CO' of 'IG' Valuation Guidelines
EVRI	Environmental Valuation Reference Inventory
FWR	Foundation for Water Research
GE	General equilibrium (effects)
IG	(Refer to) Individual Guideline
IPCC	The Intergovernmental Panel on Climate Change
IRR	Internal rate of return
ITCM	Individual travel cost model
I/O	Change in the input/output of a market good/service
MC	Marginal cost
MCA	Multi-criteria analysis
MSB	Marginal social benefit
MSC	Marginal social cost
NB	Net benefit
NPV	Net present value
NRA	National Rivers Authority
NT	Valuation techniques are not available to value this specific impact
NUV	Non-use value
O	'Outcome or 'consequence' in a decision problem
PE	Preventative expenditure
PDF	Probability Density Function

PTE	Present tonnes equivalent
PV	Present value
PVB	Present value benefit
PVC	Present value cost
QUALY	Quality adjusted life years
RC	Replacement (or restoration) cost
RE	River Ecosystem classification system
RU	(Refer to) the Risk and Uncertainty Guideline
S	'State-of-nature' in a decision problem
SC	Surrogate or constructed market-based valuation technique
SD	Standard deviation
SI	Sensitivity indicator
SMU	Social Marginal Utility of income
SV	Switching value
TC	Total cost
TCM	Travel cost method
TEV	Total economic value
UKCIP	The UK Climate Impacts Programme
UV	Use value
V	Coefficient of variance
VLYL	Value for a life year lost
VSL	Value of a statistical life
VPF	Value of a prevented fatality
WTA	Willingness to accept payment
WTP	Willingness to pay
ZTCM	Zonal travel cost model

TABLE OF CONTENTS

1 INTRODUCTION 1-1

1.1 Background to the Costing Guidelines 1-1
1.2 Aims and Objectives of this Report 1-2
1.2.1 Related and Complementary Guidance Manuals 1-4
1.3 Structure of the Report 1-6

2 CONTEXTUAL FRAMEWORK OF THE COSTING GUIDELINES 2-1

2.1 Introduction 2-1
2.2 Generic Decision Problem 2-1
2.2.1 Elements of a Decision Problem 2-1
2.2.2 Identifying Possible Outcomes or Consequences 2-8
2.2.3 Options appraisal 2-10
2.2.4 Issues of Uncertainty 2-17
2.3 Estimating Outcomes for the Decision Problem 2-18
2.3.1 Introduction 2-18
2.3.2 The Costing Methodology – an Overview 2-18

3 IDENTIFICATION OF CLIMATE CHANGE RISKS/IMPACTS 3-1

3.1 Introduction 3-1
3.2 Using the Impact Matrices 3-2
3.2.1 Using the Decision Tree 3-5
3.2.2 The Cost-side of the Equation 3-11
3.2.3 Potential Mistakes to Avoid When Using the Costing Methodology 3-12

4 ECONOMIC VALUATION GUIDELINES 4-1

4.1 Introduction 4-1
4.2 Valuation Methods: Changes in Inputs/Outputs 4-6
4.2.1 Context of Guideline 4-6
4.2.2 Valuation of Changes in Inputs/Outputs 4-8
4.3 Cost-based Approaches – Preventative Expenditure and Replacement Cost 4-27
4.3.1 Context of Guideline 4-27
4.3.2 Preventative Expenditures 4-27
4.3.3 Replacement Cost 4-31
4.4 Surrogate and Constructed Market-based Approaches 4-37
4.4.1 Introduction 4-37
4.4.2 Hedonic Techniques 4-37
4.4.3 Travel Cost 4-42
4.4.4 Contingent Valuation Method 4-46
4.5 Valuing Loss of Habitat and Biodiversity 4-51
4.5.1 Context of Guideline 4-51
4.5.2 The Economic Services of Natural Habitats and Biodiversity 4-51
4.5.3 The Impacts to Habitat and Biodiversity Associated with Climate Change 4-52
4.5.4 A General Procedure for Measuring the Value of a Change in Habitat and/ or Biodiversity 4-54
4.5.5 Methods of Valuing Impacts on Habitats and Biodiversity 4-55
4.5.6 A Numerical Example: Valuing the Impacts of Coastal Habitat

Loss 4-59
4.6 Valuing Impacts on Human Health 4-62
4.6.1 Context of Guideline 4-62
4.6.2 What Impacts to Human Life Expectancy and Health are Associated with Climate Change? 4-62
4.6.3 Categories of Impacts on Human Life and Health 4-63
4.6.4 A General Procedure for Measuring the Value of a Change in Health Outcome 4-64
4.6.5 Methods of Valuing Impacts on Human Health and Life Expectancy 4-64
4.6.6 A Numerical Example 4-70
4.7 Valuing Recreation And Amenity 4-72
4.7.1 Context of Guideline 4-72
4.7.2 What Recreational and Amenity Impacts are Associated with Climate Change? 4-72
4.7.3 A General Procedure for Measuring the Value of a Change in Recreational Usage....4-73
4.7.4 Methods of Valuing Impacts on Recreation....4-76
4.7.5 A General Procedure for Measuring the Amenity Value of a Change in Environmental Quality as a Result of Climate Change or Adaptation....4-82
4.7.6 Methods of Valuing Impacts on Amenity Values 4-84
4.7.7 Estimates of Amenity Premiums....4-85
4.7.8 A Numerical Example 4-87
4.8 Valuing Impacts on Cultural Objects 4-89
4.8.1 Context of Guideline 4-89
4.8.2 The Economic Services of Built Heritage 4-89
4.8.3 The Impacts to Built Heritage Associated with Climate Change 4-90
4.8.4 A General Procedure for Measuring the Value of Changes in Built Heritage....4-92
4.8.5 Methods of Valuing Impacts on Built Heritage 4-93
4.9 Valuing Impacts on Leisure and Working Time 4-96
4.9.1 Context of Guideline 4-96
4.9.2 What Time Impacts are Associated with Climate Change?....4-96
4.9.3 A General Procedure for Measuring the Value of a Change in Time Availability....4-97
4.9.4 Methods of Valuing Impacts on Time Availability....4-98
4.9.5 A Numerical Example 4-99
4.10 Valuing Impacts on Non-use Benefits....4-102
4.10.1 Context of Guideline 4-102
4.10.2 The Changes in Non-Use Values Associated with Climate Change 4-102
4.10.3 A General Procedure for Measuring the Value of a Change in Non-Use Values 4-106
4.11 The Practice of Benefit Transfer 4-109
4.11.1 Context of Guideline 4-109
4.11.2 Defining Benefit Transfer 4-109
4.11.3 Methodology of Benefit Transfer 4-110
4.11.4 How Good Are Benefit Transfers?....4-121
4.11.5 Sources of Benefit Transfer Data....4-126

5 GENERAL GUIDANCE ON ECONOMIC ANALYSIS 5-1

5.1 Introduction 5-1
5.2 General Issues in Costing Analysis: Making Adjustments for Relative Price Movements 5-2
5.2.1 Context of Guideline 5-2
5.2.2 Expressing Cost-Benefit Data in the Prices of a Common Base Year 5-2
5.2.3 The Price Basis for Future Costs 5-5
5.3 Annex: Price Indexes – Essential Mechanics 5-7
5.4 Discounting and Discount Rates 5-10
5.4.1 Context of Guideline 5-10
5.4.2 Issues in Discounting 5-10
5.4.3 The Use of Discount Rates 5-14
5.5 Treatment of Non-marginal Impacts 5-18
5.5.1 Context of Guideline 5-18
5.5.2 Methodologies for Estimating Non-marginal Impacts 5-18
5.5.3 Recommendations 5-22
5.6 Cost-effectiveness Analysis 5-24
5.6.1 Context of Guideline 5-24
5.6.2 Measuring Cost-effectiveness 5-26
5.6.3 Incremental Cost (or Supply) Curves 5-33
5.7 Options Appraisal Under Uncertainty 5-35
5.7.1 Context of Guideline 5-35
5.7.2 Making Decisions Under Conditions of Certainty....................5-35
5.7.3 Making Decisions in the Presence of Uncertainty: the knowledge is still good....................5-40
5.7.4 Making Decisions in the Presence of Uncertainty: knowledge is very poor 5-49
5.7.5 Assessing the Effect of Future Uncertainty on the Outcome Estimates 5-55
5.7.6 Assessing the effect of learning on future uncertainty: Quasi-option values 5-59
5.8 Sensitivity Analysis 5-61
5.8.1 Context of Guideline 5-61
5.8.2 Methodology 5-62
5.9 Treatment of Unvalued Impacts 5-68
5.9.1 Context of Guideline 5-68
5.9.2 Sensitivity Analysis....................5-69
5.9.3 Multi-criteria Analysis....................5-72
5.10 Treatment of Non-monetised Impacts 5-88
5.10.1 Context of Guideline 5-88
5.10.2 Sensitivity Analysis....................5-89
5.10.3 Multi-criteria Analysis....................5-92
5.11 Assessing Distributional Effects....................5-109
5.11.1 Context of Guideline 5-109
5.11.2 Treatment of Equity....................5-109
5.11.3 Stakeholder Analysis....................5-112

6 CONCEPTUAL BASIS FOR THE COSTING GUIDELINES 6-1

6.1 Introduction 6-1
6.2 Conceptual Basis for Costing Analysis 6-2

6.2.1 Introduction......6-2
6.2.2 Cost, Value and Welfare......6-2
6.2.3 Social, Private and External Cost......6-3
6.2.4 Economic (Opportunity) Cost versus Financial Cost......6-5
6.2.5 Summary of Discussion......6-6
6.2.6 Further Cost Categories......6-7
6.2.7 Average, Marginal and Total Cost......6-10
6.3 Basic Principles of Benefit Valuation......6-15
6.3.1 Introduction......6-15
6.3.2 Total Economic Value......6-15
6.3.3 Measures of Economic Benefit......6-18
6.4 Annex: Measuring Economic Benefits......6-19
7 REFERENCES......7-1

SECTION I

INTRODUCTION

This report presents part of a series of related tools, which have been developed under the UK Climate Impacts Programme (UKCIP). As part of the integrated assessment, UKCIP have developed a set of tools - climate change, and compatible socio-economic, scenarios, along with a decision-making framework. The aim is that an assessment of the vulnerability of public and private sector organisations to climate change risks will allow those organisations to plan appropriate adaptation strategies. Integration of strategies across the various sectors will be achieved by the use of the common core tools. The overall objective of this report is therefore to provide an additional tool – a methodology which public and private sector analysts might use to cost the impacts of climate change in the UK.

1 INTRODUCTION

1.1 Background to the Costing Guidelines

It is now generally accepted that the global climate is changing as a result of human activity. In 2001 the Intergovernmental Panel on Climate Change (IPCC) concluded that there is "evidence that most of the warming observed over the last 50 years is attributable to human activities". This warming has been termed **climate change**, a general phrase that is used to refer to the changes in the Earth's climate anticipated to occur as a consequence of the release and accumulation in the atmosphere of greenhouse gases resulting from human activities. As a result of climate change, changes are occurring in the whole pattern of the weather, with the extent and nature of change differing from country to country, and region to region.

Although general agreement has been reached about the fact that the global climate is changing, and despite great improvements in understanding the Earth's climate, there is still uncertainty as to the impacts that are expected to accompany climate change. Decisions as to the most appropriate action to take are therefore complex. Much of the action taken to date to lessen the effects of climate change has focused on controlling and reducing the emission of greenhouse gases (and particularly CO_2). While these actions are likely to affect the situation in the future, some climate change is now inevitable.

The changes currently taking place will have wide-ranging implications for populations, economies, and the natural and built environments, presenting society with new threats and opportunities. Climate change will alter the long-term average climate and also change the incidence of short-term extremes. Since some changes are inevitable, there is a clear need to adapt to them, and to anticipate future impacts for this generation and for future generations. There are a myriad of different adaptation strategies that could be adopted for different sectors, and at different levels; e.g.

local, regional, national and international, and policy, programme and project. For instance, two ways to adapt to lower summer rainfall are to install irrigation systems or to switch to alternative crops. Higher winter rainfall can be adapted to by improving flood management. Improved cooling systems can be used to adapt to warmer summers – the list is immense. Society, however, cannot finance all of the desirable adaptation projects. Decision-makers must therefore decide whether or not a particular risk presented by climate change should be adapted to, and if so, what adaptation option(s) should be chosen. One approach would be to choose the option that provided the highest benefit (in terms of risks avoided) over and above their costs. Identifying such strategies is difficult, not least because the benefits are sometimes not expressed in money terms.

The value of this report is that it seeks to address this problem. It does so by providing a standard methodology that can be used to estimate the cost of climate change risks, both with and without adaptation. This allows decision-makers within the public and private sectors to compare the effectiveness of different adaptation measures in limiting the effects of climate change on the welfare of society. This means that the threats and opportunities presented by climate change can be valued, and appropriate decisions made about the allocation of resources to reduce (or enhance) these threats (or opportunities).

1.2 Aims and Objectives of this Report

From the above discussion it is evident that decisions relating to climate adaptation inevitably involve prioritising among climate risks, and between the alternative options available to adapt to those risks judged to be significant. More formally, a decision-maker may face two forms of adaptation analysis – namely:

- **Assessment, Prioritisation and Ranking of Risks** - to generate valid 'order of magnitude' estimates for climate change risks of interest, so that their relative importance can be established.

- **Adaptation Options Appraisal** - to generate valid 'order of magnitude' estimates of the net benefits of options to adapt to significant climate change risks, so that the ‘best’ (or preferred) option(s) can be implemented.

Amongst the many considerations that organisations would take into account in any decision-making context, a key one is the net benefit of action, relative to the cost of doing nothing. Assuming that these ‘economic’ considerations are important to the decision-maker, it would therefore be useful to quantify them in the context of the two climate adaptation analyses listed above.[1]

Clearly, making decisions in either of these two contexts involves trade-offs between various impacts on different vulnerable receptors (e.g. flora and fauna, the man-made environment, and sub-groups of the general population) and the financial cost of investing in adaptation. In order to make such trade-offs easier for the decision-maker, it is helpful for the consequences of adaptation to be described in a single dimension, specifically, money terms, where possible. However, there is currently a clear lack of reliable cost estimates relating to the different risks that climate change presents at a regional or sector-level. This makes it difficult to prioritise between different climate change risks, and draw effective comparisons between adaptation responses and the net benefit of those responses. It is this gap that this report seeks to begin to fill, by providing a methodology with which to cost climate risks to the UK. The methodology described herein provides guidance in generating broad ('order of magnitude') estimates of the cost of climate impacts and, in the light of these estimates, the benefits of adaptation responses to those impacts judged to require urgent action. The widespread use of the costing guidelines outlined in this report should ensure consistency in cost-benefit estimates, thereby making integration of results from different studies easier - in line with the broader aims of UKCIP.

There are specific methodological issues that distinguish the costing of climate risks and adaptation options that also warrant the development of these guidelines. One is the wide range of risks that climate change is expected to present to many economic and social sectors across the UK. Decision-makers, when devising unrelated policy, programmes or projects, should take climate risks into account. This makes consistency between standard appraisal practices an important objective if the policy response is to be cost-efficient. The guidelines allow the analyst to address this issue systematically.

A second issue is that there is a pattern of uncertainty regarding the nature, scale and spread of climate risks over long time periods that make cost-benefit estimation more complex than the usual contexts in which options appraisal is conducted. This makes it imperative that a climate adaptation costing methodology is developed that is framed within the context of climate change uncertainty, and complements the UKCIP Technical Report on handling climate risk and uncertainty.[2]

Given the long time-scales that are relevant to the climate change impact

[1] As stated, economic considerations are not the sole criterion on which decisions tend to be made, particularly in the public sector. For example flexibility, political sensitivity, avoiding irreversible impacts, equity, etc. are all important 'decision factors'. Consideration of these factors when appraising options is also dealt with in these guidelines.

[2] See http://www.ukcip.org.uk/risk_uncert/risk_uncert.html

context, attention is also drawn in the report to the importance of the treatment of discounting costs and benefits. These guidelines additionally serve to present the likely physical impacts of climate change alongside the monetary valuation techniques available for these impacts and serve to steer the public sector analyst when dealing with the climate change context. The same is true for the private sector analyst, though (s)he has flexibility as to the choice of valuation technique. As a consequence, these techniques are outlined in depth within these implementation guidelines.

The costing guidelines are aimed at two user groups, each with different needs:

- ♦ Non-economists/decision-makers in either the private or the public sector – who need a document, with reduced technical content, that will: (a) introduce them to the main issues in costing climate change risks and adaptation options; (b) allow them to identify research needs and provide guidance in commissioning work in this area and; (c) allow them to interpret the results of climate change costing studies.

- ♦ Economists/specialists in either the private or the public sector – who need a document that will provide technical support when conducting climate change risk and adaptation costing studies at a local/regional scale, disaggregated by sector.

As a result, two reports have been prepared, one targeted at each user group. **This report** (‘**Implementation Guidelines**’) **is aimed at the latter user group**. The accompanying report, ‘Overview of Guidelines’, provides a synopsis of the key elements of the implementation guidelines, and is aimed at the former user group.

The implementation guidelines are designed to provide technical support to users when conducting a costing study. Specifically, these guidelines provide the user with a 'toolkit' to:

- ♦ Provide guidance on how to generate valid 'order of magnitude' estimates of the cost of climate change impacts, and the benefits of adaptation to these impacts.

- ♦ Minimise the potential for poor, inaccurate or inconsistent cost estimation.

- ♦ Provide the user with an iterative costing process with built-in flexibility to permit the depth of the analysis desired by the decision-maker to coincide with data, budget and time constraints.

1.2.1 Related and Complementary Guidance Manuals

It is worth noting that a number of relevant ‘manuals’ have been produced by various Government departments and other institutions. These manuals provide detailed guidance on one or more specific aspects of climate change impact and/or adaptation assessment. For example, the former MAFF (now Defra) have produced a series of 'guidelines' on the appraisal of flood and coastal defence projects (the 'Flood and Coastal Defence Project Appraisal Guidance' (FCDPAG) series, of which FCDPAG3 is of particularly interest since it relates to economic appraisal, (MAFF, 1999a)). The current series of guidelines can be found at http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm. The UK Treasury has also published guidelines relevant to the methodologies contained in this manual, including the revised *'The Green Book' - Appraisal and Evaluation in Central Government* (HMT, 2003), available at (http://greenbook.treasury.gov.uk/),and this is recognised within these guidelines as being the primary source of guidance for public sector economic analysts.

The Flood Hazard Research Centre at Middlesex University has also produced guidance manuals, (see e.g. Penning-Rowsell *et al.*, 1992). These documents provide guidance with respect to one key impact area each, for example, coastal developments. Similarly, the Foundation for Water Research, FWR (1996), has produced detailed guidance with respect to another key impact area: the benefits (costs) of water quality improvements (deterioration). In terms of the individual valuation methods covered in these guidelines, the DETR (now Defra) also has provided detailed guidance on, for instance, the use of multi-criteria analysis (MCA) (DETR 2001a), and the contingent valuation method (CVM). (DETR 2001b). Other related documentation published by the UK Government includes *Ancillary effects of greenhouse gas mitigation policies* by Defra[3], and *Estimating the Social Costs of Carbon*[4], that presents aggregate costs of global emissions per ton of carbon. Clearly, the costings methodology presented here does not supersede or overrule any detailed guidance provided by UK Government departments in relation to specific investment programmes. Indeed, wherever possible in these guidelines we refer to the relevant guidance already existing for analysts in government departments and executive agencies.

The reason that these guidelines have been thought important to develop is that none of the aforementioned documents provides a comprehensive guide, which is specific to climate change risk and/or adaptation assessment. However, for public sector analysts, the advice provided in these guidelines should not supersede official government guidance, where it exists on appraising specific impacts of interest.

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[3] http://www.defra.gov.uk/environment/climatechange/ewpscience/

[4] http://www.hmtreasury.gov.uk/Documents/Taxation_Work_and_Welfare/Taxation_and_the_Environment/tax_env_GESWP140.cfm

1.3 Structure of the Report

The report is divided into six main sections. Following this introduction, Section 2 outlines the contextual framework of the report. This places the costing guidelines in the context of a climate change adaptation decision, thereby defining the scope of the report. Section 3 provides an explanation of how risk (impact) assessment can be carried out using the climate change impact matrices developed for this study, and is designed to help the user link specific climate change impacts of interest to economic valuation guidelines. Information about the specific valuation guidelines and their use is provided in Section 4. Section 5 then considers the appraisal of alternative adaptation options, including standard aspects of economic analysis that should be followed when: (1) costing specific climate change risks and adaptation responses; and (2) using the estimated costs/benefits in the appraisal of alternative courses of action (or options to implement). Options appraisal under conditions of uncertainty is also considered in Section 5, since most climate change decision-making contexts inevitably involve a large element of uncertainty. A number of case studys, which illustrate the application of the costing guidelines to hypothetical climate change impacts, are presented in Section 6.

SECTION II

CONTEXTUAL STAGES OF THE COSTING GUIDELINES

2 CONTEXTUAL FRAMEWORK OF THE COSTING GUIDELINES

2.1 Introduction

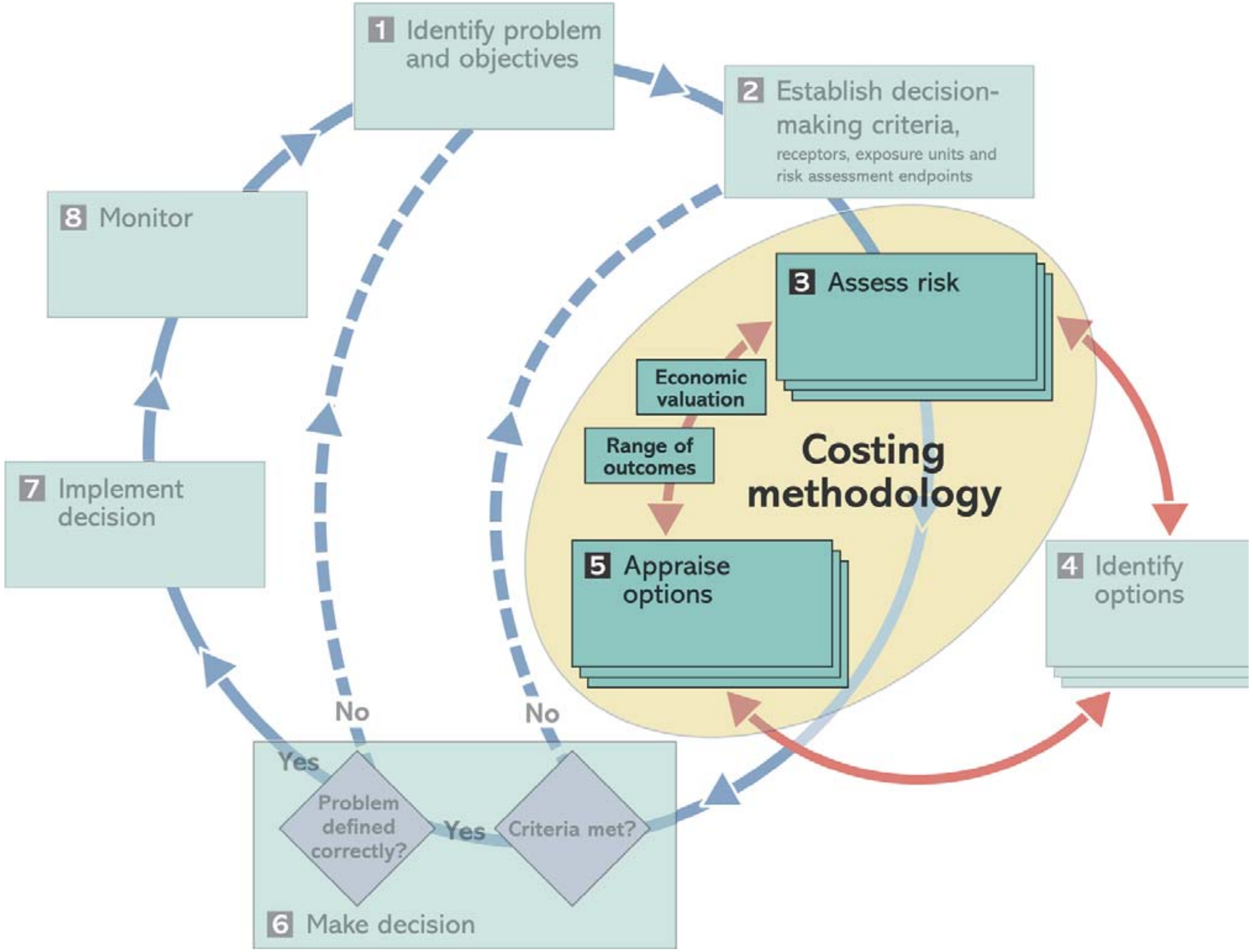
This section outlines the context, or decision-making framework, within which these costing guidelines are to be used. This framework, which is shown in Figure 2.1 below, identifies the main stages comprising 'good' decision-making in the face of climate change risk. The good practice framework in Figure 2.1 covers all stages in the decision-making process, from problem specification through to *ex-post* evaluation. The focus of this report is the economic valuation of identified climate change risks and the appraisal of options to address these risks.[5] Another UKCIP Technical Report – Willows and Connell (2003)[6] - provides this framework.

The **costing methodology** is an important element of Stages 3 and 5 within the framework – risk assessment and options appraisal. Application of the costing methodology in a climate change/adaptation decision-making context (e.g. what adaptation option should be adopted to mitigate exposure to the risks of sea level rise in a region) provides the decision-maker with a monetary measure of the outcome resulting from any course of action taken. Often, the decision-maker will have several alternative options that can be pursued, thus a range of possible outcomes may be realised. Moreover, there may be a range of outcomes arising from each option, reflecting uncertainty in the analysis. Once the range of possible outcomes has been described to the decision-maker, they are generally appraised in order to identify the option that provides the 'best' outcome subject to the broad objective(s) and decision criteria established by the decision-maker.

[5] These options range from 'doing nothing' to 'doing a little' to 'doing a lot'.

[6] Willows and Connell (Eds.), (2003)

Figure 2.1: The Costing Guidelines in the Context of a Framework to Support Good Decision-making in the Face of Climate Change Risk



Before we explore the context of the costing guidelines in further detail, it is important to acknowledge that uncertainty is inherent in climate change risk assessment. Economic valuation is also an uncertain science. Hence, combining the two within the costing methodology essentially piles uncertainty on top of uncertainty. (Figure 2.1 illustrates how the whole decision-making process operates under a veil of uncertainty.) It is therefore important when using these guidelines that uncertainty is effectively managed, and the user fully appreciates the uncertainties inherent in the range of possible outcomes. To this end, some guidance is provided on appraising outcomes in the presence of uncertainty.[7]

2.2 Generic Decision Problem

2.2.1 Elements of a Decision Problem

Any decision-making context (or decision problem), whether in the private sector or public sector, or concerning policy, programmes or projects, involves several standard elements. First, an individual (the decision-maker) must be confronted with a 'problem'. A problem may arise as a result of, for example, changes in legislation, reviews of ongoing activities, public concerns, the emergence of new evidence on climate change risks. The **decision-maker** is the person or institution that is dissatisfied with the prospect of a future event, and who possess the desire and authority to initiate actions designed to alter this event.[8] For example, a water company, concerned about the prospect of a demand-supply imbalance in the future, is potentially a decision-maker in this sense.[9] The water company may be dissatisfied with the imbalance because it compromises a broad company objective or desired 'state of affairs', e.g. the provision of a reliable water service at a reasonable cost. (The decision-maker's desire to achieve this state of affairs is the reason for the existence of the problem in the first place.)

Now, to pursue the broad objective the decision-maker must first translate the objective into operational decision-making criteria (e.g. one criterion

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[7] A more detailed treatment of dealing with the uncertainty associated with decisions in a climate change context is provided by Willows and Connell (2003).

[8] In the context of these Costing Guidelines, the decision-maker may represent: a National, Regional or Local government; a department within one of these levels of government; an environmental/economic/industry regulator; a multinational or small and medium-sized enterprise, whether privately or state-owned; or individual members of society.

[9] If the supply-demand imbalance is a judged to be a direct consequence of climate change, Willows and Connell (2003) refer to such decisions as problems of **climate adaptation**. Climate change may not necessarily be driving the need for the decision; however, the decision to address the imbalance may be sensitive to climate change risks. If these risks are not negligible, then there may be a case for building some adaptation into the decision. Willows and Connell (2003) refer to these decisions as **climate-influenced decisions**.

might involve the provision of 150 ML of raw water per day at a unit cost not exceeding 3 pence per litre). These criteria will facilitate the identification of alternative **options** to alleviate, in this example, the demand-supply imbalance, and allow the desired state of affairs to be achieved.[10] These options, together with a state of doubt as to which one is 'best', constitute the heart of the decision problem. In the case of the water company, is the demand-supply imbalance best addressed through, say, demand management or supply enhancement? (Or is it best not to address the imbalance, since one should always evaluate options versus the reference 'do nothing' option?)

Baseline Definitions Relevant to these Guidelines

The precise specification of a decision problem involves, among other things, establishing the analytical baseline from which the magnitude of climate change risks, and subsequently the effectiveness of adaptation responses, are measured. As noted earlier, these guidelines are designed to support the decision-maker with two stages in making climate adaptation decisions – namely:

- **Assessment, prioritisation and ranking of risks** (stage 3 in Figure 2.1)- to generate, where possible, valid 'order of magnitude' estimates of the cost of climate change risks, so that their relative importance can be established. (This extends economic valuation to Tier 2 risk assessment, as explained in Willows and Connell, 2003.)

- **Adaptation options appraisal** (stage5 in Figure 2.1)- to generate valid 'order of' magnitude' estimates of the net benefits of adaptation to specific climate change risks. (This extends economic valuation to Tier 3 options appraisal, as explained in Willows and Connell, 2003.)

Each of these stages has a *unique* reference scenario, which we need to define.

Prioritisation and ranking of risks

In this context we seek to estimate the economic value (*positive* or *negative*) of climate change in the absence of adaptation responses. The '**reference**' scenario (or 'baseline') appropriate to this context is defined by the situation assumed to exist in a geographical and temporal context in the absence of climate change. This particular reference scenario may also

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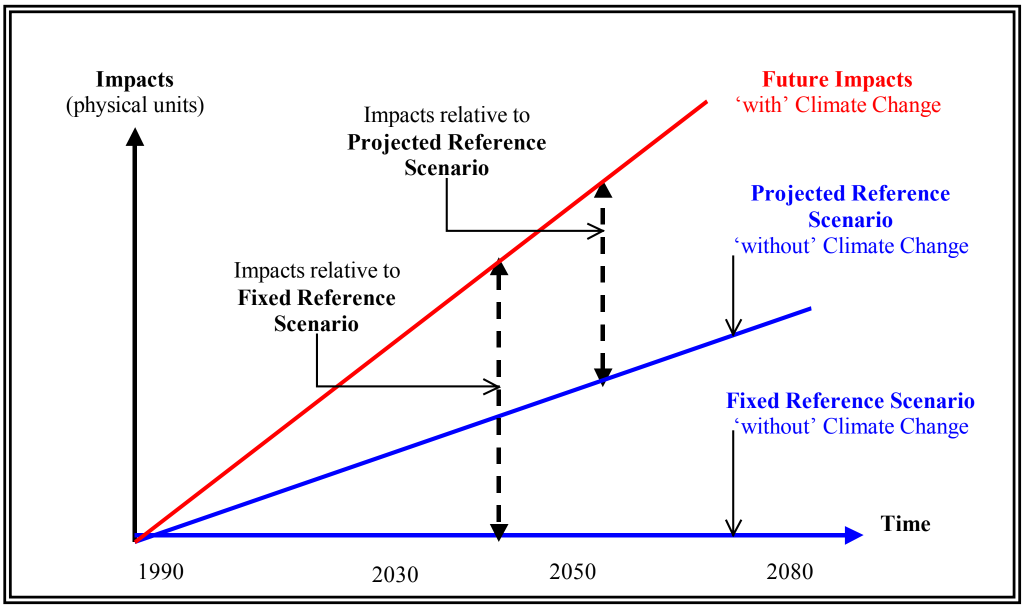
[10] The decision criteria also serve as a basis for the risk assessment and as basis for assessing the performance of the various options under consideration.

Guidance on the identification and creation of 'options' is provided both in Willows and Connell (2003) and HMT (2003), although only the former deals specifically with adaptation to climate change.

be referred to as the '**without'** climate change case. Given projected scenarios for climatic change, climate change risks are calculated as the difference between the '**with**' and '**without**' climate change case.

Figure 2.2: Illustration of Reference Scenarios Relevant to Adaptation Decision Type I: Valuing the Impact of Climate Change

Adapted from Parry and Carter (1998)



Following the presentation given in Parry and Carter (1998)[11] there are essentially two different reference scenarios, which can be used to assess climate change risks. One is a **fixed reference scenario** in which *current* (natural) climatological, environmental and socio-economic conditions are assumed to *prevail* in the study region into the future. Taking the impact of climate change on agricultural productivity for example, a fixed reference scenario would assume that current rates of productivity prevail over the whole period of study. In this case, the impact of climate change in any one time period is measured as the difference between the reference (current) rate of productivity without climate change, and the projected rate of productivity with climate change.

The fixed reference case, although frequently used in climate impact assessment studies, is an unrealistic representation of the future. Taking our example, agricultural productivity is likely to change over the study period irrespective of climate change (e.g. due to increased pressure on

[11] Parry and Carter (1998) *Climate Impact and Adaptation Assessment*, London: Earthscan Publications Limited.

agricultural land, population growth, changes in biotechnology, etc.). Realism can be introduced by constructing projections of future (natural) climatological, environmental and socio-economic conditions in the study region in the absence of climate change - i.e. we could use a **projected reference scenario** to describe the future without climate change.

The use of both a fixed and projected reference scenario to assess the impacts of climate change is illustrated in Figure 2.2[12] above. The impact of climate change in a specific year is given diagrammatically by the vertical distance between either of the two reference scenarios and the line labelled 'Future Impacts' (which in this example depicts cumulative losses in agricultural productivity as a result of climate change). In this type of adaptation decision, the costing methodology can be used to estimate the economic value (*positive* or *negative*) of climate change on an affected (exposure) unit. In general we have:

The economic value (+ve or –ve) of the climate change impact (£)[13]

equals

The estimated impact of climate change (physical units)[14]

times

The economic unit value of the impact (£ per unit)

As mentioned above, the value of this information is that it reveals to decision-makers those climate change impacts that are likely to cause the most severe damage, and therefore those risks to which most attention should be given.

Adaptation options appraisal

We assume that decision-makers can undertake some form of **adaptation strategy** in response to important climate change risks. The effect of the

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[12] In the example illustrated in Figure 2.2 productivity is assumed to be lower with climate change – hence, cumulative future impacts (foregone productivity) rise over time. Also, the impacts of climate change relative to the projected reference scenario are *less* than those relative to the fixed reference scenario, but they could just as easily be *greater* – in which case the projected reference scenario would be below the horizontal axis.

[13] The reader should be aware that climate change impacts may be sufficient in scale to alter 'prices'. We discuss this possibility and its implications for economic analysis in Section 5.

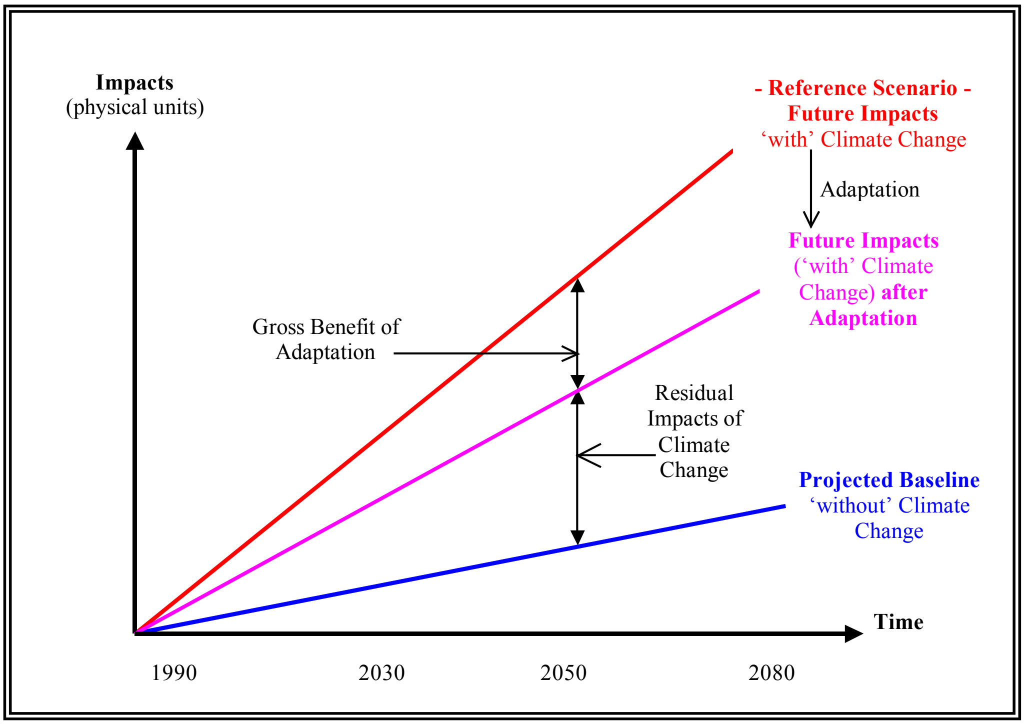
[14] Recall that the impact of climate change on the exposure unit is calculated as the difference between the '**with**' and '**without'** climate change case – that is the difference between the red and blue lines in the figures above.

adaptation response is to reduce (enhance) the future exposure of a receptor[15] to climate change risks (opportunities). We can think of the reduction (enhancement) in the risk as the 'effectiveness' of the adaptation response, or the gross benefits of adaptation. This is given by the estimated impact of climate change in the absence of adaptation minus the estimated impact with adaptation, and is illustrated in Figure 2.3. Note that in this context the reference scenario is now defined by the '**with**' climate change case, since the gross benefits of adaptation are measured *relative* to the 'Future Impacts' curve.

In this adaptation decision context, the costing methodology can be used to estimate the gross monetary benefit of an adaptation strategy – in general we have:

Figure 2.3: Illustration of the Benefits of Adaptation

Adapted from Parry and Carter (1998)



Alternatively, the gross benefit of the adaptation strategy can be computed as:

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[15] At this point it is worth making a subtle distinction between exposure units and receptors. In Willows and Connell (2003) an **exposure unit** is defined as the system considered at risk from climate change. An exposure unit is often described in terms of the geographical extent, location and distribution of the population or populations of **receptors** at risk.

Step 1

The net economic value (+ve or –ve) of the climate change risk with adaptation built into the baseline - the **residual risk** (£)

equals

The estimated climate change risk with adaptation built into the baseline (physical units)

times

The economic unit value of the risk (£ per unit)

Step 2

The gross benefit of the adaptation strategy (£)

equals

The net economic value (+ve or –ve) of the climate change risk - from CASE I (£)

minus

The net economic value (+ve or –ve) of the climate change risk with adaptation built into the baseline - the **residual risk** (£)

The value of this information to decision-makers is that, together with information on the resource costs of the adaptation strategy, we can use it to ask the following general policy question:

Is the gross benefit of the adaptation strategy *greater than* the cost of the adaptation strategy?

These costing guidelines are designed to allow the user, whether a private sector or public sector decision-maker, to answer this question This, in turn, will allow the decision-maker to:

- accept or reject a single adaptation option;

- choose one adaptation option of a number of discrete alternative options;
- choose a smaller number from a larger number of discrete alternative adaptation options;
- accept or reject a number of adaptation options;
- choose one of a number of mutually exclusive adaptation options;
- help decide whether a proposed adaptation option should be undertaken, or an existing option continued or discontinued; and
- help choose the appropriate scale and timing for an adaptation option.

Box 2.1: Relationship Between Reference Scenarios & Stages in Decision

Stage	Appropriate Reference Scenario
Assessment, prioritisation and ranking of risks	'Without' climate change case
Adaptation options appraisal	'With' climate change case

System Boundaries

The specification of a decision problem also requires the geographical boundaries of the analysis to be defined. Boundary definition will, of course, depend on the nature of the analysis been undertaken and the goals of the study 'sponsor'. Suppose, for example, that climate change is anticipated to present an adverse risk to agricultural output in one region of England, but that this will be offset by an equivalent gain in another region. From a national perspective the net cost is zero, and adaptation funded from general taxation would not be justified – at least in terms of national loses in the output of the affected produce. However, at a regional level, the relevant authority may well view the anticipated impacts as a 'real' gain or loss, and subsequently feel that a response is justified. The point is that **geographical boundaries must be defined according to user needs**; and given this boundary, it is only the **net** costs/benefits that are relevant. Users in the public sector should note that HMT (2003) defines the system boundary for all economic analyses to capture all impacts to the UK.

2.2.2 Identifying Possible Outcomes or Consequences

Having defined a decision problem in contexts applicable to these guidelines, we can now return to the method described earlier to see how it is used to analyse these problems, logically and consistently.

For any given climate adaptation decision there is likely to be a number of options that could be pursued to meet the overall decision criteria. The question that beckons is which of these options represents the preferred option(s), or the best way forward. To answer this question the decision-maker must evaluate the options against the decision criteria. This is the primary function of **options appraisal**.

However, before options appraisal can be carried out, the decision-maker needs to know, for each of the available options, what are the different outcomes or consequences that might result, and what are the uncertainties associated with these outcomes? Looking at this process in more detail, each option will interact with a variety of future factors ('states of nature'), including climate change scenarios and actions taken by other individuals or groups. These interactions will determine the outcomes of the decision problem; that is, whether the decision criteria met will be met as a result of the options considered and the prevailing states of nature. Typically, a (wide) range of outcomes will result in the context of any specific climate adaptation decision. The decision-maker is, as noted above, under pressure to choose the 'best' option. To assist the decision-maker in making their selection, the totality of possible outcomes can be presented in the form of an outcome (or consequence) array[16], an example of which is shown in Table 2.1. This outcome array summarises the '**Range of Possible Outcomes**' – see Figure 2.1

It is important to recognise when faced with an array of possible outcomes however, that *only one* specific state-of-nature will actually occur. In other words, only one future 'world' will actually be realised. Since it is generally not known which state-of-nature will occur (i.e. the future is uncertain), all must be considered.[17] The analyst must therefore plan for a range of possible scenarios (states of nature). Also, as a further consequence of uncertainty, the outcome recorded in any cell is likely to be described as range of plausible values.

At this point it is worth re-emphasising that **this report is not designed to provide guidance on the development of possible future states of nature, or the identification of adaptation options available to the decision-maker to achieve the desired state of affairs**. Other UKCIP

[16] These arrays are also known as payoff or performance matrices.

[17] In this example we only talk about three possible states of nature, but in a real climate change decision problem there may be many more possible contingencies.

Technical Reports provide guidance to these ends – e.g. Hulme et al. (2002) and Willows and Connell (2003).

Table 2.1: Example of an Outcome Array (or Payoff Matrix)

		StateofNature		
		S_1	S_2	S_3
Options	A_1	O_{11}	O_{12}	O_{13}
	A_2	O_{21}	O_{22}	O_{23}
	A_3	O_{31}	O_{32}	O_{33}

How the outcomes are described - the so-called ‘outcome descriptors’ (O_{11}, …, O_{33}) - will normally measure the degree to which the decision criteria (and therefore the broad objectives) are met. You will recall that objectives reflect the decision-maker’s desire to achieve a future state of affairs that is ‘better’ than the anticipated future state resulting from ‘inaction’.

Economic analysis is generally concerned with the increment in money associated with taking one course of action over another. Put another way, in economic analysis the decision criterion by which we judge the success of an option in achieving the decision-maker’s broad objective is based on monetary value. In this case outcome descriptors are of two types: (1) the **resource costs** associated with the option (e.g. the economic cost of all resources consumed by the adaptation strategy) and; (2) the **economic benefits** derived from the outcome (e.g. the climate change risks and associated damages avoided as a result of the adaptation response). This costing methodology aims to measure, as far as possible, the economic benefits in money terms. Since the resource costs and benefits are then expressed in the same terms – money– the difference between them (i.e. the **net benefit**) provides a valid measure of the aggregate money value of each outcome.

Reducing the outcome descriptors to a single dimension is useful in that it simplifies the identification of the ‘best’ option. To compare alternative options in terms of economic value, the decision-maker need only consider the net benefit of each option.

It is important to re-iterate at this point that there is considerable uncertainty regarding not only the impacts of climate change, but also the monetary values of those impacts (we return to this below). A second point to note is that it is not always possible to estimate the monetary values of impacts, therefore a straightforward comparison of the net benefits of options may be misleading, or not possible (important unvalued impacts would be ignored). Furthermore, decision problems may involve objectives other than economic value, such as political acceptability; these alternative objectives cannot always be described and analysed in monetary terms. It therefore may be the case that each outcome is described by a combination of a monetary descriptor and non-monetary descriptors. The comparison of outcomes in the presence of multiple descriptors (decision criteria) involves the use of multi-criteria techniques. We say more about these techniques below.

Box 2.2: The aim of the costing methodology

The primary objective of the costing methodology is to provide guidance on how outcomes, corresponding to a particular combination of a specific option (adaptation response) and a specific state-of-nature (climate change impact scenario), can be described in monetary terms. Hence, in terms of Table 2.1, the costing methodology is concerned with how outcomes (O_{11} through O_{33}) can be expressed in money, as far as possible, *given* information on options (A_1, A_2 and A_3) and states of nature (S_1, S_2 and S_3).

2.2.3 Options Appraisal

Once the climate change risks have been quantified, and where possible valued, and the resource costs of alternative adaptation options assessed, this information can be displayed in a table of the type shown in Table 2.1. The various outcomes are then compared as the decision-maker seeks a solution to the decision problem at hand. To support the decision-maker in selecting the 'best' or 'preferred' option, (or at least a good one), several options appraisal or decision-support tools can be used. When outcomes are described in money terms, options appraisal is typically performed in the framework of **cost-benefit analysis** (CBA). Note that whilst cost-benefit analysis is being suggested as a possible useful decision-making tool here in the context of adaptation options appraisal, there remains considerable debate as to the appropriateness of CBA in all adaptation contexts. See, for example, (Yohe 2003) and Tol (2003) for discussion of factors relating to uncertainty that limit the use of CBA in the climate change context, and Azar and Schneider (2002) and Tsur and Zemel (1996) for similar conclusions that may arise from the treatment of events where there are small probabilities but which might have "catastrophic impacts". Since it is not always feasible to express all relevant risks in money terms, nor is 'net benefit' the sole criterion by which the success of an option is judged, alternative decision-support tools have been developed, which are capable of dealing with unvalued outcome descriptors; namely **cost-effectiveness analysis** (CEA) and **multi-criteria analysis** (MCA). All these tools are used to support the optional appraisal component of the decision-making framework. However, government departments and executive agencies should note that the Green Book recommends the use of CBA, over CEA, with supplementary tools used for weighing up unvalued costs and benefits (HMT, 2003).

The purpose of this section is to briefly introduce the user to these options appraisal tools.

Cost-benefit Analysis

Cost-benefit analysis (CBA) is designed to show whether the total advantages (benefits) of a project or policy intervention, e.g. an adaptation option, exceed the disadvantages (costs).[18] As far as practical, all advantages and disadvantages should be valued. This essentially involves "*listing all parties affected by the option and then valuing the effect of the option on their well-being as it would be valued in money terms by them*" (Layard and Glaister, 1994).[19] The affected parties should include not only the project/policy participants and consumers, but also third parties who experience so-called **external effects**. The basic approach to CBA may be divided into three main activities or stages, as shown in Figure 2.4.

Box 2.3: Using Cost-benefit Analysis in the Context of these Guidelines

The following two points should be noted by the user when employing CBA in the context of these Guidelines:

- First, economic value will seldom be the sole criterion for selecting among options. Decision-makers may have other criteria in addition to economic value, including flexibility, equity, avoiding irreversible impacts, political sensitivity, etc. In this case the economic consequences of the various options being considered only represents one input to the decision-making process, albeit an important one. While it is possible to explicitly incorporate, for example, equity into CBA, it may be necessary to employ CBA within a broader decision-support tool such as multi-criteria analysis, in order to adequately account for multiple decision criteria.

- Second, decision-making in the context of climate change inevitably involves large uncertainties. When using CBA the user should therefore employ the option selection criteria advocated for making

[18] A review of the extent to which CBA is used in environmental policy analysis in the UK and the EU is provided in Pearce (1998) 'Cost-benefit Analysis and Environmental Policy' in *Oxford Review of Economic Policy*, 14 (4), pp. 84-100.

[19] Layard and Glaister (1994) *Cost-benefit Analysis*, 2nd edition, Cambridge: Cambridge University Press.

decisions in the presence of uncertainty (see the appropriate guideline in Section 5). To further allow for the considerable uncertainties surrounding the range of possible outcomes, the user should test the key factors that underpin the estimated outcomes, using one of the techniques suggested below.

In short, it should never be assumed that a single 'correct' measure of net benefit will result from application of these guidelines. Moreover, any measure of net benefit, no matter how reliable it is, will not necessarily provide a solution to the problem confronting the decision-maker.

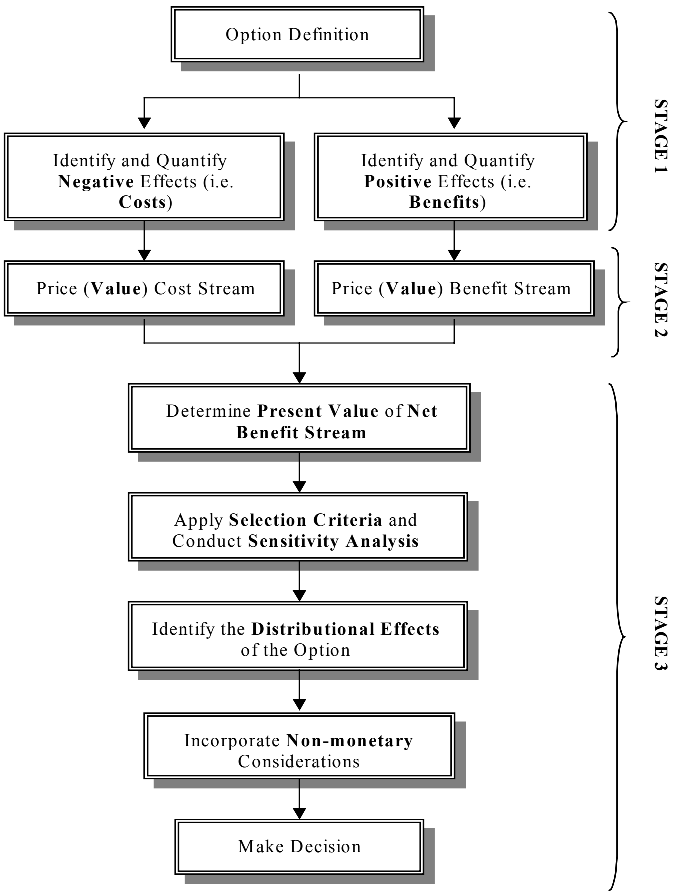
The three main stages in CBA are:

- **STAGE 1 Risk (Impact) Assessment** - The process of identifying *all* exposure units and receptors affected by the option(s) and quantifying the 'incremental' impact of the climate adaptation decision on these exposure units and receptors. By 'incremental' we mean the difference between the relevant **reference scenario** and the **policy scenario** being evaluated. In other words, we seek to measure the net impact of the decision, rather than the gross impact.

- **STAGE 2 Valuation** - The process of attaching an appropriate 'price tag' to all relevant impacts. Net impacts should, as far as practical, be expressed in monetary terms. At this stage, it may also be necessary to adjust the valuations for movements in relative prices and/or distributional considerations.

- **STAGE 3 Weighing up and Deciding** – The process of discounting (at an appropriate discount rate) to adjust for the time incidence of costs and benefits, so that the present value net benefit of the option(s) can be determined, and ultimately a decision can be made on the relative economic merits of the option. This involves the application of some form of (social) decision rule. However, before this decision rule can be applied uncertainty should be factored into the analysis (e.g. through sensitivity analysis). Moreover, before a final decision is reached, all unvalued impacts should be considered, either through sensitivity analysis or some form of weighting and scoring.

Figure 2.4: Methodological Stages for Cost-benefit Analysis



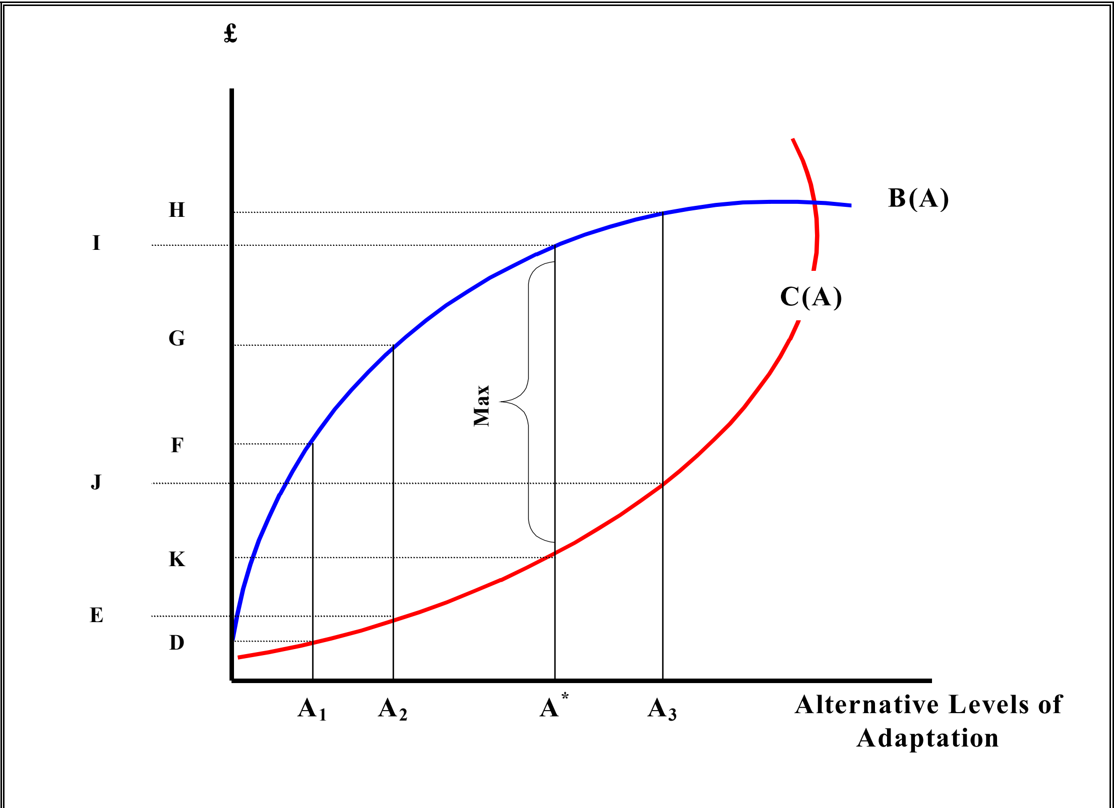
Adapted from Boyd (2000)

Box 2.4: Social Decision Rule of Cost-benefit Analysis

To illustrate the social decision rule at the foundation of CBA consider Figure 2.5. The curve denoted B(A) represents the aggregate benefits of alternative levels of adaptation (A) to climate change. C(A) is a representation of the associated aggregate costs. These curves measure social welfare from adaptation to climate change. (The shape of the curves reflects conventional assumptions – that is, benefits increase at a decreasing rate and costs increase at an increasing rate. Also, for ease of presentation the curves shown are 'well-behaved' with no discontinuities; this may not be the case in the context of climate change.) The 'optimal' or most efficient level of adaptation - given by the maximum vertical distance between B(A) and C(A) – occurs at A^*. In economics the point A^* is defined as the **Pareto-efficient** solution.

Rather than seeking the 'optimal' solution however, CBA in practice, typically considers whether a change from baseline conditions represents a desirable change. In Figure 2.5 for example, such a shift is given by moving from A_1 to A_2. The conventional social decision rule employed in CBA asks whether the *aggregate* incremental benefits (FG in Figure 2.5) exceed the *aggregate* incremental costs (DE in Figure 2.5). If the increment in benefits exceeds the increment in costs, as it does in Figure 2.5, then the policy that brings about this shift is preferable to the baseline situation. The shift from A_1 to A_2 in this case is technically known as a **Pareto improvement**.

Figure 2.5: Social Cost-benefit Criteria



Let us consider another point on the graph, A_3, to the right of A^*. We can see that the *aggregate* incremental benefit of a policy taking us from A^* to A_3 (HI in Figure 2.5) is less than its *aggregate* incremental cost (JK in Figure 2.5), meaning that the policy poses a net cost on society.[20] As a rule of thumb, it is worthwhile undertaking an adaptation measure as long as the social cost of the *next unit* of impact avoided *does not* exceed the social value of that unit of impact (of course, we are assuming that the sole decision criterion is economic value).

As mentioned in the previous section on baselines, in the context of adaptation to a specific climate change risk, the social cost-benefit criteria (or Pareto improvement hypothesis) to be tested is given by:

$$\text{Is } \left(D_j^B - D_j^{RA}\right) - \left(C_j^A\right) > 0? \qquad (2\text{-}1)$$

where

D_j^B = The baseline damage associated with climate change risk j.

D_j^{RA} = The residual damage associated with climate change risk j following the implementation of adaptation measures.

C_j^A = The cost of the adaptation response(s) to climate change risk j.

Cost-effectiveness Analysis

The main alternative economic decision-support tool to CBA is **cost-effectiveness analysis** (CEA). CEA is also used to evaluate trade-offs between benefits and resource costs, except, in contrast to CBA, the benefits are measured in units other than money. It can be used to identify ways of minimising (or maximising) some physical effect with available resources (e.g. delivering the maximum reduction in risk exposure subject to a budget constraint), as well as the least-cost method of reaching a prescribed target (e.g. the supply of a given quantity of potable water). Clearly, CEA has the relative advantage that benefits in some cases do not need to be explicitly valued. For this reason CEA has seen widespread use in the field of climate change mitigation, in which one commonly seeks to

[20] Even though the policy makes some members of society 'better-off' (the aggregate benefits are still positive: $B(A_3) > C(A_3)$), this is achieved it at the expense of other members of society.

identify the least-cost measure to reduce GHG emissions, *without* having to explicitly value the benefits of the subsequent reduction. CEA also has a role to play in the identification of least-cost adaptation responses – e.g. closing a water supply-demand imbalance at least-cost. Furthermore, the concept is applicable at all levels of decision-making – ranging from project level adaptation assessment to regional or national adaptation policies.

Issues relating to the application of CEA in the context of climate adaptation decisions are discussed in Section 5.6.

Multi-criteria Analysis

The most fundamental requirement of CBA is that both the costs and benefits are expressed in money terms. Incorporating risks, environmental or otherwise, into CBA is a two-step process. Before the risks can be valued, they must first be identified and measured. Only once the risks have been quantified can they be valued in money terms to determine their relative economic importance. The entire process is not always easy, since some risks – particularly risks to the environmental - are often dislocated in time and space, making cause and effect difficult to establish. In addition, the severity of a risk will often depend on an accumulation of problems. Furthermore, many environmental goods and services do not enter markets, which presents a difficulty for valuation, compounded by the fact that the available data are often scarce or of poor quality.

In addition to these potential problems, economic value is not the sole criterion for making climate adaptation decisions. Other decision criteria, including flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity etc., may also influence the decision-making process and the degree to which the desired state of affairs is attained.

Recognition of the above limitations of CBA has led to the development of so-called **multi-criteria analysis** (MCA) techniques. The basic idea of MCA is to define a method for integrating different broad objectives (and related decision criteria) in a quantitative analysis without assigning monetary values to *all* factors. In short, MCA provides systematic methods for comparing these decision criteria, some of which are expressed in money terms, some of which are expressed in other units.

We must stress, nevertheless, that CBA *should still be used* within the MCA method, to cost rigorously those risks that can be expressed in monetary terms. MCA cannot be used as an excuse for avoiding CBA – its purpose is not to replace valuation.

Issues relating to the application of MCA in the context of climate adaptation decisions are discussed in Section 5.9.3.

2.2.4 Issues of Uncertainty

Decision problems may be classified according to the degree of knowledge the decision-maker has about future outcomes. In theory, there are two states of knowledge, which a decision-maker can have: (1) certainty, and (2) uncertainty.

A situation of **certainty** exists if the decision-maker has complete knowledge of every element of the decision problem, (e.g. the probability of an event or state-or-nature being realised, and the magnitude of the likely consequences arising from exposure to this event or state-of-nature). In this case the decision-maker is therefore certain of the outcome associated with each option. Since each option is assumed to lead to a unique outcome, the decision problem of choosing among alternative options is reduced to one of choosing among outcomes. For example, if following the application of these costing guidelines we reduced the resource costs and associated benefits of each adaptation option to a single aggregate descriptor – net benefit – then *if* the decision-maker's sole decision criterion were maximisation of net benefit, the solution to the decision problem would be simply a matter of selecting the option with the highest net benefit. The 'best' option is the one, which leads with *certainty*, to the 'best' outcome. (Of course, solving the decision problem under certainty is not so straightforward in the presence of multiple objectives.)

Decision problems under certainty do not, however, exist in the real world. Most decision problems, especially those in the context of climate change impact and adaptation assessment, involve some degree of uncertainty about the outcomes that may result from the implementation of a given option. Uncertainty differs from certainty in that the latter involves a specified set of conditions leading to *one* outcome, while uncertainty involves a range of possible conditions which may occur, leading to the existence of *more than one* potential outcome.

Now, the decision-maker may lack certain knowledge that is important to a particular climate adaptation decision. For example, the decision-maker may not know with certainty the likelihood that a particular event will occur, or the magnitude of the consequences of exposure to that event. If we do not know the probability and/or the consequence, the decision-making context is one of 'uncertainty'. **Uncertainty** is said to exist if the decision-maker lacks knowledge as to the outcome of the decision.

All climate change related decision problems will involve uncertainty. To support the decision-maker in selecting the 'best' option in these circumstances, specialist techniques are required. These techniques are reviewed in Section 5.7.

2.3 Estimating Outcomes for the Decision Problem

2.3.1 Introduction

The purpose of the costing methodology is to populate the outcome array, shown in Table 2.1, by expressing the descriptors in monetary terms. This subsection considers the generation of these monetary descriptors.

2.3.2 The Costing Methodology – an Overview[21]

We have already shown that the costing methodology comprises two steps. Before climate change risks can be valued they must first be identified and measured. Only once they have been quantified is it possible to determine their relative economic importance by expressing them in monetary terms. The identification and measurement or quantification of risks is therefore a prerequisite for their valuation.

The two-step nature of the costing methodology is illustrated in Figure 2.6, taking coastal zones as an example (we will return to this figure below), and summarised in Figure 2.7. This two-step process is vital, as it underpins the approach to valuation prescribed in these costing guidelines.

Box 2.5: The Basic Approach to Valuation Used in These Guidelines

The cost (benefit) of a climate change risk on an exposure unit and receptor (£)

equals

The expected physical impact on the exposure unit and receptor (number of units affected)

times

The appropriate economic unit value (£ per affected unit)

[21] In the proceeding explanation of the costing methodology you may realise that the potential exists for **'double-counting'** the costs of specific climate change impacts (or, alternatively, the benefits of avoiding those impacts). When using the guidelines, care must be taken to ensure that such double-counting does not occur. We return to this in Section 3.2.3.

Figure 2.6: The General Structure of the Costing Methodology – Taking Coastal Zones as an Example

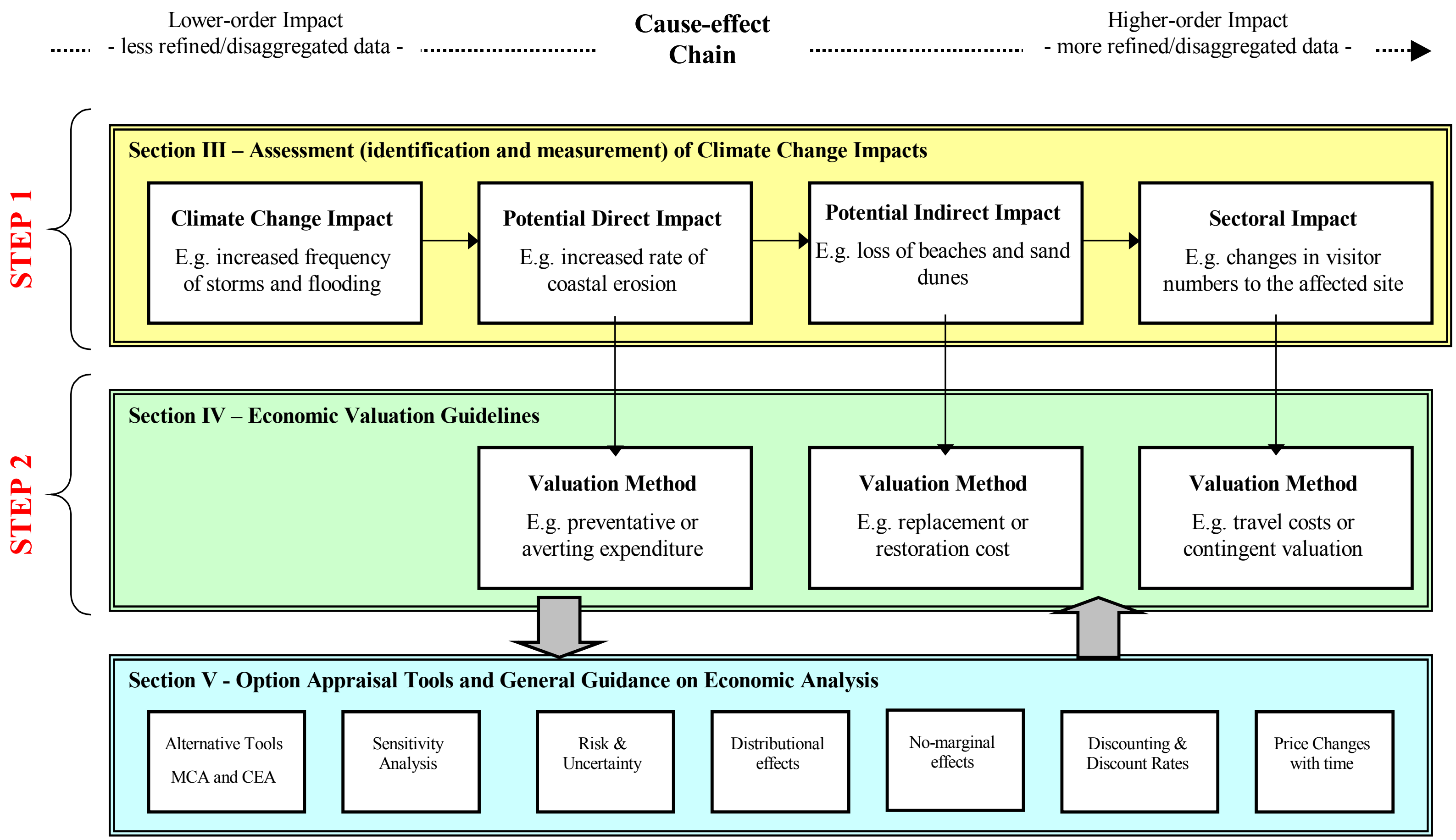
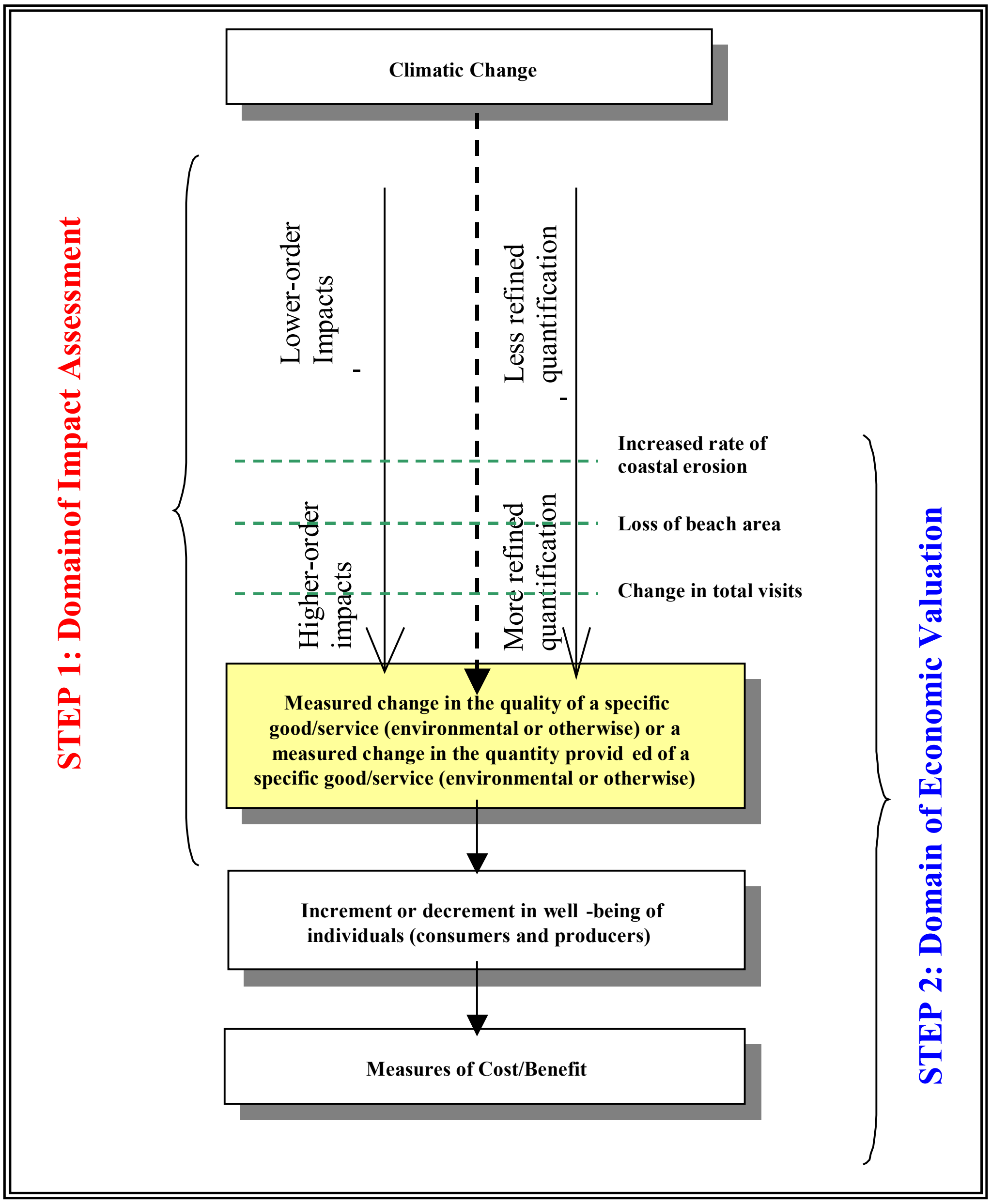


Figure 2.6 illustrates the pathway or hierarchy of cause from climate change through to specific impacts, which affect the welfare of individuals. In this report '**lower-order impacts**' refer to the direct impacts of climate change, such as flooding. '**Higher-order impacts**' result from the lower-order impacts, so that a given the lower-order impact of flooding, a higher-order impact could be loss of natural habitat, and a still higher-order impact is the loss of recreational and other values that people place on that habitat. Essentially this is represented across the top of Figure 2.6, as a 'cause-effect' chain (or impact pathway). The chain starts by linking climatic change to lower-order impacts (e.g. increased rate of coastal erosion) and moves through to specific higher-order impacts (e.g. the loss of beach area and changes in visitation rates). One problem that arises when attempting to value the impacts of climate change is that, as we move along this cause-effect chain, the extent to which *all* impacts can be quantified across *all* exposure units and receptors will vary considerably.

The implication of this for valuation studies is that, for certain 'cause-effect' chains, there may be more than one point along their length at which some form of valuation can be undertaken. For example, along a specific 'cause-effect' chain, impact data may exist in the form of crude data on the total area of coastal zone that would be lost relative to the base case, and more detailed data on changes in visitation rates to an affected recreation site. Although in an ideal world impacts would be valued using the latter (since they are able to produce a more accurate measure); that is, using detailed data relating to high order impacts, our costing methodology must be able to offer guidance on valuing lower-order impacts as well. In general this will involve using aggregate cost data to provide approximate damage cost estimates for lower-order impacts, and using data on the values individuals attach to very specific receptors, environmental or otherwise, to provide more refined damage estimates for higher-order impacts. These ideas are illustrated in Figure 2.7, which shows the pathway from climate change to the consequences for the exposure unit and receptor(s), to measures of cost and benefit. The objective is to derive detailed cost estimates for the impacts of climate change on very *specific* receptors. To this end, Step 1 must identify and quantify the climate change risk facing a receptor (e.g. the change in the quality/quantity of a *specific* good or service valued by society).

Figure 2.7: Illustration of the Linkage Between Climate Change Impact Assessment (Step One) and Economic Valuation (Step Two) – Using Impacts on Coastal Zones as an Example



For the costing methodology to be effective, valuation techniques need to be identified which can deal with a full range of impacts – as illustrated in Figure 2.6.

As the science of climate change risk/impact assessment advances, an increasing number of impacts will be quantified, and to higher levels. So while impact data may not be available for some of the higher-order impacts at present, it may become available in the future.

It is the inherent need for flexibility that has shaped the structure of these guidelines, specifically the use of the hierarchy of cause captured by the four boxes in Step 1, Figure 2.6. To summarise, the flexibility is necessary in order to accommodate:

- ♦ climate change risks/impacts that are quantified at different levels and in different ways; and

- ♦ climate change risks/impacts that are likely to be quantified in the near future.

Returning to Figure 2.1, we now consider the two elements or steps which constitute the methodology for costing climate change impacts, in turn, that is: **STEP 1**) the identification and quantification of climate change impacts; and **STEP 2**) the valuation of these impacts in accordance with standard practices in economic analysis.

STEP 1 – Climate Change Risk (Impact) Assessment and Measurement

This step is based, as we have seen, on 'cause-effect' chains (or impact pathways), which link lower-order climate change risks (e.g. increased frequency of flooding) to higher-order impacts (changes in the total number of visitors to a specific beach or recreational site). As mentioned above, it is envisaged that impact data will be available at different levels along a given cause-effect chain. The cause-effect chains are presented in the form of **impact matrices**. These matrices summarise the anticipated risks/impacts of climate change on a number of sensitive sectors.

The matrices function purely as an identifier – i.e. they link a particular impact with a valuation guideline(s). It is assumed that the reader has already undertaken a climate change risk assessment (as described in Willows and Connell, 2003) and has identified and measured impacts relevant to the decision at hand. There may well be impacts that are not shown in the matrices.

STEP 2 – Economic Valuation of Impacts

The impact matrices suggest to the reader an appropriate valuation guideline(s) for impact of interest. Each valuation guideline provides step-by-step instructions in the application of an economic valuation technique(s) to a specific 'type' of climate change impact(s). The user is free to select a valuation guideline compatible with the impact data at their disposal, the level of accuracy required, and the resources available – expertise, time and money. In the situation where the user is considering a potential impact not explicitly identified in the matrices (s)he is required to make a judgement about the appropriateness of the guideline/valuation technique to use. It is suggested that where a similar impact has been considered in the guidelines the user should follow that guidance. Where there is not, or the user is unsure of the relevance of other guidelines, (s)he will need to consult climate change impact and economic specialists.

Economic valuation techniques have varying data input requirements, and specific techniques are applicable to different order impacts. In the example shown in Figure 2.6 for instance, **preventative expenditure**[22] or **replacement cost**[23] **approaches** can be used to value the 'lower-order' impacts, whereas the **travel cost**[24] or **contingent valuation method**[25] can be used to value the 'higher-order' impacts.

Application of Steps 1 and 2 will generate monetary descriptors of the outcomes of the options considered. It is likely at this point that options appraisal tools will be employed, as shown in Figure 2.6 within the third box labelled 'Options Appraisal Tools and General Guidance on Economic Analysis'. As the box labels implies, the guidelines also provide advice on more general aspects of economic analysis – including, adjusting cost and benefit estimates for distributional impacts and relative price movements over time.

It should be noted that these guidelines adopt a bottom-up approach to costing the impacts of climate change. We believe that this approach represents the best way of providing a flexible costing methodology which can be used by non-experts to perform desk-top costing analyses and still yield approximate cost estimates at a local/regional/national scale, disaggregated by sector. At the same time, we recognise that in some cases, e.g. when impacts are large ('**non-marginal**') or the potential for indirect impacts is high, such a bottom-up approach may not yield accurate estimates.

The valuation approach adopted in these costing guidelines assumes that any climate change impact under consideration is relatively small (or '**marginal**'), and therefore the value that individuals attach to affected receptors *does not* change. Subject to this assumption, the benefit/cost of a climate change impact on a receptor is valued by multiplying the

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[22] The **preventative** (or **averting**) **expenditure** method is a valuation technique in which the time and money incurred by individuals to offset or mitigate an environmental or man-made hazard is indicative of the lower bound value the individual places on that hazard.

[23] With the **replacement cost** approach, the costs that an individual incurs in replacing or restoring (cleaning) a damaged asset are taken as a minimum estimate of the value of the inauspicious environmental condition(s) that caused the deterioration in asset quality.

[24] The **travel cost method** values site specific environmental resources (e.g. a national park) by estimating demand for access to the site. The total expenditure (time and money) on the travel required to reach the site is interpreted as the implicit, or the surrogate, price of the visit – i.e. the value of the experience afforded by the site.

[25] The **contingent valuation method** determines money measures of changes in the well-being of individuals through the use of survey questionnaires, which describe a hypothetical situation and elicit how much the respondent would be willing to pay either to obtain or to avoid the described situation.

anticipated physical impact on the receptor by the appropriate initial economic unit value. In some cases however, climate change may result in relatively large (or '**non-marginal**') impacts on a receptor, which may in turn change the current economic unit value. We are now faced with the dilemma of which 'price' to use in the costing analysis – the initial 'price' or the 'price' that prevails subsequent to the climate change impact? Moreover, depending on the nature of interrelationships between receptors, a change in the economic unit value pertaining to one receptor may disrupt price and quantity equilibria throughout the economy. A further question therefore arises - how many receptors must we consider in order to derive an accurate measure of the 'true' cost of climate change? In these cases some form of integrated modelling exercise or 'top-down' approach may be more appropriate.

SECTION III

CLIMATE CHANGE RISK (IMPACT) ASSESSMENT

3 IDENTIFICATION OF CLIMATE CHANGE RISKS/IMPACTS

3.1 Introduction

We stated in Section 2 that the links between climate change impacts and possible valuation guidelines are presented in the form of **impact matrices**. These impact matrices have been constructed, one for each of the following key (sensitive) sectors, from an extensive review of the UK climate impacts literature:

- Coastal zones sector;
- Water resources sector;
- Agricultural sector; and
- Buildings and infrastructure sector.

Note that there is not a separate matrix for the impacts of climate change on natural habitats, another key sector in the UK. This is because risks to natural habitats are inevitably included in the matrices for the other four sectors.[26] The matrices for each sector are provided below. Users should note that there maybe additional impacts not shown in these matrices and should refer to Willows and Connell (2003) for information on how to undertake a risk/impact assessment.

The matrices loosely depict the ‘cause-effect’ (or impact pathway) chain associated with a specific climate change event. So for example, starting with a climate change event such as the expected rise in sea level, the matrices trace the ‘cause-effect’ chain through the corresponding potential direct impacts; e.g. permanent loss of territory, and change in the hydrological regime, to the subsequent consequences of each of these direct impacts; e.g. loss of recreational sites, flooding of wetlands/marshes, and loss of private property, through to specific, related sector-level impacts, such as loss of cultural objects, loss of agricultural productivity, and loss of species. At various points along each ‘cause-effect’ chain, the reader is referred to different valuation guidelines, as explained in the previous section. The applicability of a valuation guideline at any particular point depends on the type and form of impact

[26] In the future it may be desirable to produce similar impact matrices for other ‘sectors’ susceptible to climate change.

data available, and the characteristics of the affected receptor, e.g. whether or not the value that individuals attach to it are observed in conventional markets.

This section explains how the impact matrices are used to identify the valuation guideline(s) that are appropriate for costing particular climate change impacts of interest to the user.

3.2 Using the Impact Matrices

As mentioned above, the impact matrices have been developed in order to accommodate two stages in climate-sensitive decision making – namely, (1) prioritisation and ranking of risks and (2) adaptation options appraisal.

In both cases the following general procedure is applicable:

1. The relevant sector matrix(ces) should be selected.

2. The climate change risk(s), direct impact(s), indirect consequence(s), and/or sector-level impact(s) relevant to the decision-making context should be identified.

3. In the column denoted 'VG' (valuation guideline), which is adjacent to each impact category, you will find one of six possible labels: each of these labels denotes a particular course of action.

   ➡ If the label 'CO' (which denotes the guideline on conventional market-based valuation techniques) is shown, then you should **go to** the decision tree shown in Figure 3.1 below, and progress along the initial 'YES' branch. Advice on the use of the decision tree is provided below.

   ➡ If the label 'IG' (which denotes individual guidelines for broad receptor categories) is shown, then you should also **go to** the decision tree, and progress along the initial 'NO' branch.

   ➡ If the label 'ET' is shown, then either of the above two routes are applicable. In this case you can use the decision tree by asking whether the impact(s) of interest "*directly affects a marketed good or service*", and then following the branch which corresponds to the answer.

   ➡ If the label 'NT' appears then valuation techniques are not available at present to value this specific impact. In this case you should read the advice given below and **go to** the Guideline on the treatment of unvalued impacts.

   ➡ If the label 'RU' (disutility resulting from climate change uncertainty) is shown, then you should **go to** the guideline on dealing with risk and uncertainty. Most impacts labelled 'RU' relate to the stress or loss of welfare that individuals experience as a result an 'uncertainty' over future events. These costs can be valued using the expected utility method outlined in the guideline on dealing with uncertainty, or you may opt for a case specific application of a constructed market valuation technique (see 'SC' immediately below).

If the label 'SC' is shown, then detailed guidance on valuing this specific impact is not provided in the report. In this instance, the nature of the impact requires the application of case specific surrogate or constructed market valuation techniques, and excludes the use of conventional market-based techniques to derive (opportunity) cost-based damage estimates. In this case you should **go to** the guideline on surrogate or constructed market valuation techniques, which provides a general description of these methods, and seek expert advice.

4. Whichever of the above courses of action you take, you can refer to Table 3.1 to locate the recommended guideline(s) within the report.

A very important component of the economic value that people derive from such resources as natural habitats, recreational sites, landscapes, objects of cultural heritage, etc., but which is completely unrelated to 'use' of that resource, is **non-use value**. Non-use values are defined as those gains/losses in welfare that arise from environmental changes *independently* of any direct or indirect use of the environment. For example, you may gain satisfaction from simply knowing that a species exists, even if you feel that you will never see this species. Non-use value is applicable to more than one of the broad receptor categories covered by the individual valuation guidelines, and often represents a significant element of the total economic value of impacts on the environment. For these reasons a separate valuation Guideline (see Section 4.10) is provided for non-use value, although this is not shown in Table 3.1. When considering an impact on a resource where non-use value is relevant, you should **go to** this Guideline.

Figure 3.1: Route Map – Going from the Impact Matrix Designations to the Valuation Guidelines

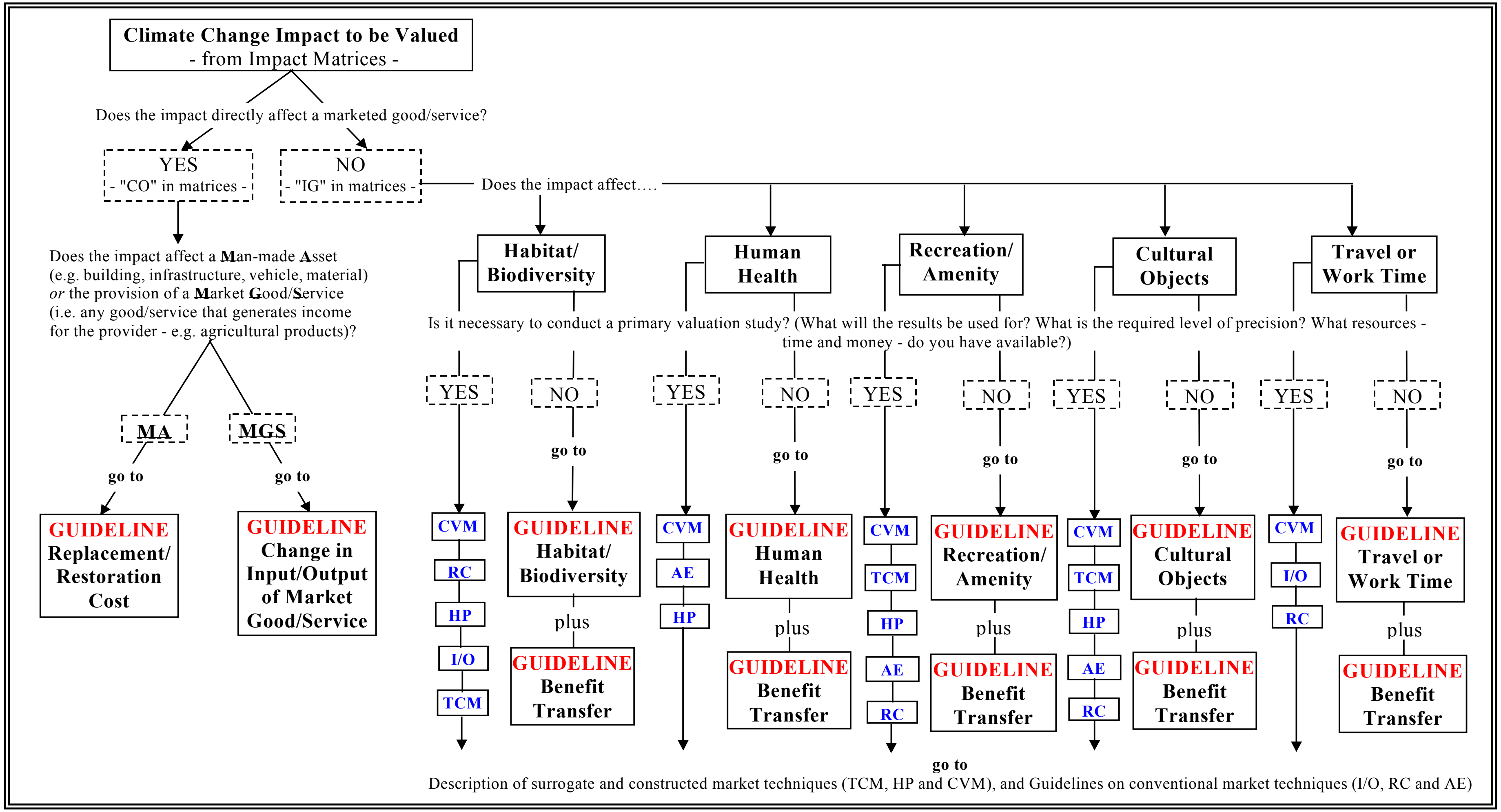


Table 3.1: Route Map - Locating the Required Guidelines

Label	Description	Go To
CO/ET	Valuation techniques based on data from conventional markets	
	GUIDELINE: Replacement (or restoration) cost	Section 4.3
	GUIDELINE: Change in input/output of market good/service	Section 4.2
IG/ET	Individual (Sectoral)Guidelines	
	Primary Valuation Studies	
	GUIDELINE: Description of valuation techniques based on data from surrogate or constructed markets	Section 4.4
	Secondary Valuation Studies Using Benefit Transfer	
	GUIDELINE: Habitat/biodiversity	Section 4.5
	GUIDELINE: Human health	Section 4.6
	GUIDELINE: Recreation and amenity	Section 4.7
	GUIDELINE: Cultural objects (built heritage)	Section 4.8
	GUIDELINE: Travel or work time	Section 4.9
	GUIDELINE: Non-use value	Section 4.10
	GUIDELINE: Benefit transfer	Section 4.11
SC	GUIDELINE: Description of valuation techniques based on data from surrogate or constructed markets	Section 4.4
RU	GUIDELINE: Dealing with risk and uncertainty	Section 5.7
NT	Valuation techniques are not available to value this specific impact; **go to** GUIDELINE: Treatment of non-monetised impacts	Section 5.9

Notes:

[1] The techniques in this category value climate change impacts using the observed market value of the affected good/service – i.e. the value ascertained in a **conventional market** system where supply and demand forces are free to work and set the value of the good/service (e.g. changes in input/output approaches, and cost-based approaches such as preventative/averting expenditure or replacement/restoration cost).

[2] The techniques in this category value climate change impacts either: (1) by observing behaviour in **surrogate markets** for the affected good/service, and *indirectly* inferring individual valuations (e.g. hedonic analysis and travel costs); or (2) by using survey questionnaires to *directly* elicit individual valuations in **hypothetical** or **constructed markets** for the affected good/service (e.g. contingent valuation).

3.2.1 Using the Decision Tree

In this section we provide guidance on using the decision tree shown in Figure 3.1. The decision tree is to be used once the valuation guideline(s) adjacent to the climate change impact(s) of interest has been identified in the impact matrix(ces). **The primary purpose of the decision tree is to take the user from the impact matrix to an appropriate valuation guideline**.

Impacts that Affect Marketed Goods/Services

The first question asked of the user in the decision tree is "*does the impact directly affect a marketed good/service*?" In the introduction to the report, marketed aspects of climate change were defined as impacts on goods and services for which a market exists. Within such markets, supply and demand forces interact to determine the value of the good/service, which is given by the observed market price. Examples of marketed goods/services include; agricultural products, industrial output, intermediate goods, raw materials, utility services, infrastructure, property, tourist services - the list is endless. The defining feature of these goods/services is that they have an observable price, which must be paid in exchange for property rights (the exclusive right to consume) to the good/service.

Impacts on marketed goods/services, as shown in Figure 3.1, can be valued using conventional market-based techniques such as:

- changes in the input/output of market goods/services approach; or
- the replacement (or restoration) cost-based approach.

Which one of these methods should be used to value the climate change impact under investigation depends on whether:

- The affected market good/service is an asset/durable good (typically man-made, although not necessarily), which is damaged or lost as a result of climate change. Examples of such goods include: buildings and other property, infrastructure, motor vehicles, etc.
- Climate change positively (or negatively) affects the provision (or production) of a market good/service. In this case the impact either in/decreases the cost of providing the affected good/service (e.g. water supply, agricultural/industrial products), or in/decreases the output and/or quality of the affected good/service (e.g. agricultural/industrial products, utility services, tourism services).

In the case of the former - i.e. when the affected good/service is an asset/durable good - then the user should **go to** the guideline on replacement/restoration cost-based approaches. If climate change affects the provision or production of a market good/service, then the user should **go to** the guideline on changes in the input/output of marketed goods/services.

It should be noted that in some cases both valuation approaches are valid. For example, consider the loss of farmland. The market price of farmland itself reflects its value to agricultural production, and therefore the loss of the land could be valued at the cost of its replacement, i.e. the cost of obtaining similar land that would allow a farmer to realise the same net income as before the impact. Alternatively, the value of the marketed agricultural output that would be lost along with the land could be measured using the change in input/output approach. The former approach yields a 'one-off' measure of loss, whilst the latter typically produces a 'recurring' annual measure of loss.[27]

Impacts which do not Directly Affect Marketed Goods/Services

If the answer to the original question ("*does the impact directly affect a marketed good/service*?") is 'No', the right-hand branch of the decision tree must be used. You will see from Figure 3.1, that in costing impacts in any of the broad receptor categories along this branch, the analyst must choose between carrying out a primary valuation study, or using existing studies which value similar impacts at another location, to approximate the value of the impact(s) being considered. The latter approach is known as **benefit transfer**. Some of the key points to consider when deciding on whether a primary study is required, or benefit transfer is acceptable, are reviewed below. Key considerations identified in the Treasury Green Book are also summarised in Box 3.1.

"*…The key question is whether the added subjectivity and uncertainty surrounding the* [benefit] *transfer are acceptable, and whether the transfer is still informative. If not, the alternatives are to forgo a quantitative CBA* [do not value the impacts] *or to conduct an original* [primary] *study…*"

Desvousges, Johnson and Banzhaf (1998)

In general, the decision as to whether a particular situation requires a primary valuation study will depend on four things: The use to which the value estimates will be put; the degree of accuracy required for this use; the degree of accuracy which can be attained using benefit transfer; and possibly of greatest importance, the relative cost of the primary study.

A primary study, which directly values the impact of interest, will inevitably provide a more accurate estimate of the 'true' costs of the impact. However, primary studies are also much more costly in terms of time and resources. The user therefore needs to decide on the acceptable balance between the level of precision required and the relative costs of primary studies. Sometimes it may be more 'economical' to use benefit transfer. In other words, in some cases the balance between accuracy and cost favours benefit transfer.

[27] A word of caution is warranted here. It is important to note that annual (or recurring) cost estimates cannot be added directly to non-recurring (or 'capitalised') cost estimates (e.g. changes in land values). Either the former must be converted into an appropriate capitalised value, or the latter converted into an equivalent annual value. Failure to do so will result in errors when aggregating across impacts.

Box 3.1: Key Considerations Governing the Decision Whether to Commission Primary Research or Use Benefit Transfer

Is the research likely to yield a more robust valuation?

Will the results of the research be applicable to a range of future appraisals?

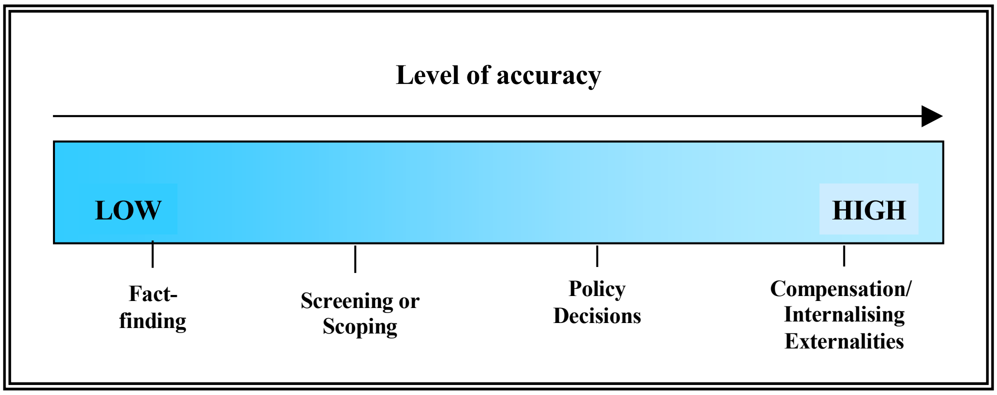
Is the accuracy of the valuation material to the decisions at hand?

What is the scale of the decision at hand? (If the decision relates to a multi-million pound investment, then clearly it is worth devoting more, as opposed to less, resources to the valuation.)

Source: HMT (2003, p. 58)

To help address these issues, Desvousges, Johnson and Banzhaf (1998) provide a 'Continuum of Decision Settings from Least to Most Required Accuracy' which is shown in Figure 3.2 below. Along this continuum they suggest that some uses of the valuation results require higher levels of accuracy than others. Situations which require the highest level of accuracy in their continuum are those where cost-benefit estimates are used to compensate the victims of (environmental) damage, or where environmental externalities are being internalised, e.g. where firms are charged for emitting pollutants at the rate equal to the marginal cost of pollution to those who suffer from it. In these situations they suggest, a **primary study** is required.

Figure 3.2: A Continuum of Decision Settings from Least to Most Required Accuracy



Source: Desvousges, Johnson and Banzhaf (1998)

Valuation studies which inform the appraisal of policies[28], such as cost-benefit tests of alternative adaptation options, are the next highest in the continuum. Since real economic commitments rest on the outcomes of these tests, valuation studies which serve as an input to such tests must meet a high standard of accuracy. It is often sufficient however, for the valuation studies to obtain a 'bounded' result. For example, to pass a cost-benefit test it is often only necessary to determine whether or not an option's benefits exceed its resource costs; that is, it is not always necessary to establish the exact magnitude of the exceedance. If the resource costs of the option are already known, it is perfectly acceptable to tolerate some uncertainty in the benefit estimates, so long as they are <u>clearly</u> larger (or smaller) than the known costs.[29] This situation is typical of many climate change decisions that users of these costing guidelines will encounter. The additional uncertainty associated with benefit transfer may thus be acceptable.

Next on the continuum, valuation studies may serve as an input to screening/scoping exercises undertaken to guide the design of an original study. Since the valuation (or transfer) results themselves will not be directly used in options appraisal, the studies need not be highly accurate. Again, this represents a context in which these guidelines are likely to be used, e.g. to identify those sectors which are likely to experience the 'largest' damages, or to identify the relatively more significant impacts. If the results of applying the costing guidelines are to be used in this way as a screening tool, then it is perfectly acceptable to use benefit transfer. Obviously, transfer studies can be used at the lowest end of the continuum – i.e. for fact finding (obtaining insights such as identifying critical linkages or markets; a purpose that only requires a relatively low level of accuracy.)

In each particular decision problem therefore the analyst will have to decide whether, given the use to which the final results will be put, it is acceptable to use benefit transfer, or if the additional costs of carrying out a primary study are justified by a need for a greater level of accuracy.

Selecting Valuation Techniques for a Primary Study – If Required

Before considering the selection of valuation techniques for a primary study, the user should note that, even though the decision has been made to conduct a primary valuation study, it is still important to consult the guideline for the individual receptor of interest, since it is likely to contain useful information on relevant valuation studies and methods.

It is all but impossible to supply hard-and-fast rules for selecting a valuation technique(s) to apply in a specific context. The choice of

[28] Note that 'Policies' include decisions made at both project and programme level.

[29] Adaptation options, in general, are costed using market prices, and can therefore be costed relatively accurately.

valuation technique for any specific costing exercise will depend on a number of criteria. Garrod and Willis (1999) have prepared a list of such criteria, which offers some guidance:

- The purpose of the study (e.g. whether opportunity cost-based estimates, or direct benefits estimates are required).

- The particular economic values required (e.g. use and/or non-use values, or a sub-set). Only contingent valuation (constructed market) studies can be used to value non-use benenfits.

- The type of values required (ex ante or ex post). For example, the replacement cost method yields ex post values, whereas the preventative expenditure method produces ex ante values.

- Whether particular assumptions are deemed acceptable or not. The reliability of the values produced by each of the valuation techniques requires that certain assumptions are met. In some situations the assumption required for, say, reliable hedonic pricing estimates may be valid, while those required for reliable travel cost estimates may not be.

- The importance attached to particular errors (e.g. statistical errors in the technique, possible cognitive psychological biases, etc.)

- The conformity of the technique with theory in particular applications (e.g. whether the model involved deals with substitution and complementary effects - important when considering site-specific recreation/amenity sites).

- The robustness of benefit estimates (e.g. in terms of statistical, content, criterion and construct validity).

- Whether the population of relevance can be identified with enough precision, and whether the cost-benefit estimates at an individual level can be easily aggregated over this population.

Table 3.2 below also provides some guidance on matching primary valuation techniques and specific impacts.[30] The table shows a selection of potential (environmental) impacts resulting from climate change, along with the main surrogate (or revealed preference) market-based and constructed (or stated preference) market-based valuation techniques that can be applied. A 'Y' indicates that the valuation technique can generally be applied to the corresponding impact. A question mark means that the

[30] Note that Table 3.2 only concerns the applicability of surrogate and constructed market-based valuation techniques to specific climate impacts (i.e. it looks only at those methods most likely to be employed as primary valuation exercises in the context of these costing guidelines). Many of the impacts listed in Table 3.2 can be valued using the implementation guidelines, in cases where a primary study is not warranted.

valuation technique may apply; an 'X' means that the valuation technique generally does not apply. As one can see from Table 3.2, constructed market-based techniques can be applied in virtually all cases, and represent the only technique capable of capturing non-use values. Also, surrogate and constructed market techniques are not generally used to value 'productivity' impacts – these impacts are typically valued using one of the conventional market-based approaches, e.g. replacement cost or change in input/output approaches.

Finally, as one can see from Table 3.2, in some cases more than one valuation technique is applicable to a specific impact. The user should note that the cost-benefit of that impact will vary depending on the primary valuation technique used. We would expect this however, due slight differences in the techniques themselves, as you will see in Section 4.4.

3.2.2 The Cost-side of the Equation

For decision problems concerned with the net benefit of adaptation, the user should be aware that application of the impact matrices and subsequent valuation guidelines allows the construction only of the 'benefit-side' of a standard cost-benefit equation. The 'cost-side' of the equation is given by the resource costs of the adaptation option(s). Analysts in some key sectors, e.g. coastal zones and water resources, have their own guidelines for costing specific engineering projects, many of which can also be used to estimate the resource cost of adaptation measures. The implementation guidelines provide some guidance on estimating the resource costs of adaptation options. It is important when costing adaptation measures that the cost concepts outlined in the implementation guidelines are adhered to, in order to ensure consistency with the impact valuation guidelines.[31]

[31] The Green Book also provides guidance on estimating 'costs' for government departments and executive agencies. The implementation guidelines are consistent with the advice provided in the Green Book.

Table 3.2: Applicability of Surrogate (Revealed Preference) and Constructed (Stated Preference) Market Techniques

Climate Change Impact	Surrogate Market			Constructed Market
	Hedonic Property	Hedonic Wage-risk	Travel Cost	Contingent Valuation
Productivity:				
Soil loss/damage	?	X	X	X
Crop loss/damage	?	X	X	X
Forest loss/damage	X	X	X	?
Habitat loss/damage	X	X	?	Y
Fisheries loss/damage	X	X	X	X
Water quality deterioration	?	?	X	Y
Property loss/damage	?	X	X	X
Resource loss/damage	?	X	?	?
Human Health:				
Mortality health outcomes	X	Y	X	Y
Morbidity health outcomes	X	Y	X	Y
Amenity:				
Recreation loss	?	X	Y	Y
Habitat loss/damage	X	X	?	Y
Visual amenity deterioration	Y	X	?	Y
Noise	Y	X	X	Y
Other:				
Non-use values	X	X	X	Y
Occupational environment	X	Y	X	Y
Damage/loss of heritage	?	X	Y	Y
Access to water	?	X	Y	Y
Sanitation services	Y	X	X	Y
Travel time savings	Y	X	X	Y

Adapted from Abelson (1996)

3.2.3 Potential Mistakes to Avoid When Using the Costing Methodology

No matter which individual valuation guideline(s) is employed to estimate the value of the climate change impact(s) of interest, there are several mistakes that the user should take care to avoid when using the final results. In this section we will draw attention to two potential sources of error. The first concerns the treatment of impacts that cannot be put into monetary terms; the second relates to the aggregation of costs associated with 'higher-order' impacts in order to obtain a value for the costs of a 'lower-order' impact. We deal with each of these potential problems in turn.

The Treatment of Unvalued Impacts

Application of the valuation guidelines depends on sufficient quantitative data being available in an appropriate form. It is likely that there will be many types of anticipated climate change impacts for which appropriate quantitative data are simply not available, and thus the suggested valuation guideline(s) cannot be applied. For example, changes in the hydrological regime and the resulting risks to natural habitat might be considered a likely consequence of coastal erosion in an area, but there may as yet be no evidence as to the extent or implications of the impacts. It is also likely, given the state of the art of economic valuation, that it will not be possible to value certain impacts even if appropriate quantitative data are available. However, these impacts are still relevant in the appraisal of alternative adaptation strategies for coastal erosion, regardless of the fact that they cannot be valued.

Thus, the lack of monetary estimates for specific climate change impacts does not mean that those impacts can be overlooked in the decision-making process.

It is important therefore, when using these costing guidelines, to have some systematic method for identifying those impacts that are relevant, but which are not valued. This will ensure that such impacts are not ignored when making the final decision(s). One approach is to construct a simple checklist, such as the one shown in Table 3.3 below. Such a checklist allows the user to identify which of the anticipated climate change impacts falling within the scope of the decision problem have been valued. This information can then be used, for example, to inform a sensitivity analysis within a cost-benefit method, or serve as input to multi-criteria analysis.

Table 3.3: Checklist for the Identification of all Impacts of Relevance: Example of Permanent Loss of Territory from Sea Level Rise.

Potential Indirect Impact	Valuation		Potential Sector-level Impact	Valuation	
	NO	YES		NO	YES
Loss of Private Property		✓	Property loss		✓
			Welfare loss	✓	
			Changes in the demand for housing in the surrounding area	✓	
Loss of agricultural land		✓	Loss of productivity		✓
Loss of non-agricultural (natural habitat) land	✓		Loss of species/ecosystems	✓	
			Migration of species/ecosystems	✓	
Flooding of Wetlands/marshes	✓		Loss of species/ecosystems	✓	
			Migration of species/ecosystems	✓	
Loss of recreational sites		✓	Reduction in demand at affected site		✓
			Shift in demand to alternative sites	✓	
Resettlement	✓		Welfare loss	✓	
			Temporary loss of productivity		✓
			Compensation		✓
			Removal Management		✓
Loss of land with cultural heritage	✓		Loss of cultural objects	✓	
Loss of building/ infrastructure (including transport)		✓	Loss of business property/ infrastructure		✓
			Loss of transport infrastructure and equipment		✓

Notes: The tick-marks shown in the table are not definitive; they pertain solely to this example. In another example the tick-marks corresponding to the same impacts may appear in different columns.

Aggregation – Avoiding Double-Counting

The second potential pitfall is that of double-counting. This may arise when attempting to cost a ‘lower-order’ climate change impact, such as the loss of territory due to sea level rise, by aggregating the associated ‘higher-order’ impacts, such as the loss of habitat, of recreational sites, the need for resettlement, etc. To avoid the problem, three points should be considered when attempting to aggregate. These are:

♦ First, that care should be taken to ensure all of the potential ‘higher-order’ impacts associated with the lower order impact have been taken into account. This relates to the discussion above, that impacts should be accounted for even if monetary values cannot be attached to them.

- Secondly, in situations where a number of direct climate change impacts will eventually be aggregated, care should be taken to ensure that the individual indirect, sector-level impacts, which comprise these direct impacts, are not repeated. For example, a permanent loss of territory might result in the loss of buildings used by the tourist industry, such as hotels. There is a danger that the loss of these buildings could be counted under both a study of the loss of private property, and a separate study to measure the effects of loss of land on the tourist industry. Double-counting is also possible if care is not exercised when measuring changes in non-use values, which are then to be added to changes in use values - particularly with respect to resources that provide recreational and amenity values. Some of the non-use values reported in the literature may also capture use values, and vice versa.

- Finally, the analyst should be aware that studies which measure the cost of climate change impacts directly, e.g. a contingent valuation study of individuals' willingness to pay to avoid sea level rise, is unlikely to yield the same result as the aggregate of studies which directly measure individuals' willingness to pay to avoid numerous indirect, sector-level, impacts of sea level rise.

Table 3.4: Matrix of Climate Change Impacts on the Coastal Zones Sector

Climate Change: Increased Frequency of Storms and Flooding							
Direct Impact	***VG***	***Potential Indirect Impact***	***VM***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased rate of coastal erosion	NT	Loss/damage of soil (soil erosion)	CO	Agriculture and forestry	Loss of productive land	CO	Farmers, households (consumers), government
					Decline in land productivity	CO	
				Habitat	Loss of species/ecosystem	IG	General public, tourists, national interest groups, government
		Loss/damage of beaches, dunes, cliffs/headlands	CO	Tourism/recreation	Decrease in tourist demand or decrease in enjoyment per visit	IG	Travel companies, hotels, local public (decrease in the demand for local products, decrease in the labour demand from travel industry)
					Increase in maintenance costs associated with coastal amenities	CO	Travel companies, hotels, local authorities
				Habitat	Loss of species	IG	General public, tourists, national interest groups, government
				Building/infrastructure (including transport)	Loss of property/infrastructure	CO	Property owners, transport operators, insurers
					Degradation of property/infrastructure	CO	
				Historical and cultural heritage	Loss of cultural objects	IG	Local public, tourists, national interest groups, government and tax payers (general public)
					Degradation of cultural object	IG	
		Negative impact on water quality	CO	Water supply (e.g. salt water intrusion)	Change in water treatment costs	CO	Water supply companies, general public (if the price of water changes), autonomous abstractors (e.g. farmers, industry, etc.)
					Change in productivity	CO	
				Tourism (e.g. increased suspended sediment)	Impact on bathing water quality	ET	General public, tourists, tourist industry, government

Climate Change: Increased Frequency of Storms and Flooding (continued)							
Direct Impact	***VM***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VM***	***Relevant Stakeholders***
Increased rate of coastal erosion (continued)	NT	Impact on hydrological regime	NT	Habitat	Loss of or change in species/ecosystem	IG	General public, tourists, national interest groups, government, regulators
				Forestry	Change in timber productivity	CO	Timber producers, consumers, national interest groups, government, regulators
				Agriculture	Loss of productive land	CO	Local farmers, consumers of farm products
					Decline in land productivity	CO	
				Building/infrastructure (including transport)	Loss of property/infrastructure	CO	Transport operators, construction companies, local public, property owners, insurers, regulators (MAFF, EA)
					Degradation of property / infrastructure	CO	
				Historical and cultural heritage	Loss of cultural objects	IG	Local public, tourists, national interest groups, government and tax payers (general public), insurers
					Degradation of cultural object	IG	
Direct Physical Impact	NT	Damage	CO	Habitat	Loss of species/ecosystems	IG	General public, tourists, national interest groups, government
					Damage to ecosystems	IG	
				Forestry	Loss of timber & associated land	CO	Timber producers, consumers, national interest groups, government, regulators
					Change in timber productivity	CO	
					Loss of recreation and amenity	IG	
				Agriculture	Loss of productive land	CO	Local farmers, consumers of farm products
					Decline in land productivity	CO	
					Loss of livestock	CO	

Climate Change: Increased Frequency of Storms and Flooding (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Direct physical impact	NT	Damage	CO	Transport infrastructure	Loss of infrastructure/equipment	CO	Transport operators, contractors, local public (users and employees in this sector)
					Damage to infrastructure/equipment	CO	
				Buildings & infrastructure	Loss of property and infrastructure	CO	Households, property owners, insurers, contractors
					Damage to property and infrastructure	CO	
				Historical and cultural heritage	Loss of cultural objects	IG	Local public, tourists, national interest groups, government and tax payers (general public), insurers
					Damage to cultural objects	IG	
				Human health	Increased risk of accidents	IG	Local public, employers, insurers, NHS, government, regulators
					Increased risk of mortality	IG	
					Increased risk of morbidity	IG	
				Sea defence	Decreased strength, increased maintenance requirements	CO	Local authorities, government, EA, MAFF, contractors
					Damage to infrastructure	CO	
				Energy sector (coastal facilities & power distribution)	Damage to wind power and wave power	CO	Power generators, and electricity consumers (prices), regulator, insurers
					Damage to thermal and nuclear stations	CO	
					Damage to offshore oil and gas facilities	CO	Oil & gas industry, insurers, consumers (including impact on exports) and local public (environmental impacts)
					Damage to refineries	CO	
					Damage to pipelines	CO	
					Damage to electricity transmission and distribution lines	CO	Power generators, and electricity consumers (disruption), regulator, insurers

1st Order Impact: Increased Frequency of Storms and Flooding (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Direct physical impact (continued)	NT	Short-term disruption	NT	Transport	Increase in the travel cost (work time)	IG	Local population, transport users (including tourists), transport operators, businesses, local authorities
					Increase in the travel cost (non-work time)	IG	
					Increased demand for alternative transport routes or modes of transport	NT	
					Externalities from increased congestion	SC	
				Households	Loss of welfare	SC	Households
				Manufacturing	Loss of productivity (or increased costs)	CO	Businesses, employees
				Agriculture	Loss of productivity (or increased costs)	CO	Farmers
		Need for temporary evacuation of the population	CO	Local public, all sectors of economy, emergency services	Increase in the costs for the government, possible losses of the private property	CO	Government, tax payers, local population
		Changes in risk/uncertainty	RU	Numerous sectors	Disutility associated with uncertainty	RU	Individuals
					Increased risk exposure/cost of compensation	RU	Insurers, all sectors
Climate Change: Sea Level Rise							
Changes in the hydrological regime	NT	Reduced efficiency of waste water infrastructure	CO	Waste water treatment companies	Need for infrastructure changes	CO	Water & sewage companies, households,
					Changes in operating conditions	CO	
				Regulators	Increased monitoring	CO	EA
		Salt water intrusion of groundwater supplies	CO	Water supply	Change in water treatment costs	CO	Water supply companies, households, regulators
					New supply sources needed	CO	

Climate Change: Sea Level Rise (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Changes in the hydrological regime (continued)	NT	Salt water intrusion of groundwater supplies	CO	Water supply	Change in productivity	CO	Autonomous abstractors
		Changes to navigation routes (morphological shifts in the coastline)	CO	Water transport/port authorities	Change in operational costs	CO	Ports, water transport companies, tourism
					Change in risk of accidents	RU	Transport companies, general public, emergency services
		Changes in the pattern of off-shore waves	NT	Numerous sectors	Changes in deposition of materials (e.g. beach movements)	CO	Local authorities, local population, tourism industry, local businesses
Permanent loss of territory	NT	Loss of property	CO	Domestic sector	Property loss	CO	Households, individuals, construction companies, landlords, local authorities, government, insurers
					Welfare loss	SC	
					Changes in the demand for porpertyin the surrounding areas	NT	
		Loss of agricultural land	CO	Agriculture	Loss of productivity	IG	Local farmers, consumers of farm products
		Loss of non-agricultural (natural habitat) land	CO	Habitat	Loss of species/ecosystems	IG	General public, tourists, national interest groups, government
					Migration of species/ecosystems	IG	
		Flooding of wetlands/marshes	CO	Habitat	Loss of species/ecosystems	IG	General public, tourists, national interest groups, government
					Migration of species/ecosystems	IG	
		Loss of recreational sites	IG	Tourism	Reduction in demand at affected site	IG	Tour operators, accommodation and related businesses, general public, tourists
					Shift in demand to alternative sites	IG	
		Resettlement	CO	All sectors	Welfare loss	SC	Producers, local population, employees, local authorities, regulators, government, insurers
					Temporary losses of productivity	CO	
					Compensation	ET	
					Removal management	CO	

Climate Change: Sea Level Rise (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Permanent loss of territory (continued)	NT	Loss of land with cultural heritage	IG	Historical and cultural heritage	Loss of cultural objects	IG	Local public, tourists, national interest groups, government and tax payers (general public), insurers
		Loss of building/infrastructure (including transport)	CO	Building/infrastructure (including transport)	Loss of business property/infra.	CO	Transport operators, construction companies, local public, property owners, insurers, regulators (MAFF, EA)
					Loss of transport infrastructure & equipment	CO	
Climate Change: Rise in the Global Mean Temperature							
Increase in the water temperature	NT	Reduced overall productivity of oceans	NT	Fisheries	Change in productivity of fishery	CO	Commercial and recreational fishermen, consumers of fish products, local population, related businesses
				Natural habitat	Changes in species/ecosystems	IG	General public, tourists, national interest groups, government
					Change in 'productivity'	IG	
		Incentive to bathe in the sea may increase	IG	Tourism, domestic sector	Increase in the tourist demand	IG	Households, individuals, tourists, travel companies
					Increase in enjoyment per visit	IG	
		Greater risk of disease for certain fish and aquaculture	NT	Fisheries, domestic sector	Change in productivity – fishery species	CO	Fishermen, consumers of fish products, local population, related businesses, NHS
					Change in productivity – non-fishery species	IG	
					Increased risk of mortality	IG	
					Increased risk of morbidity	IG	
		New 'southern' fish and aquaculture species	ET	Fisheries, domestic sector, tourism	Creation of a 'new' fisheries	CO	Fishermen, consumers of fish products, local population, related businesses
					Change in, or creation of 'new' demand for recreational angling	IG	Recreational anglers, tour operators, accommodation and related businesses, general public, tourists
					Changes in the local/regional/national diet	NT	General population, retailers, other related businesses

Climate Change: Rise in the Global Mean Temperature (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increase in the water temperature (continued)	NT	Some 'northern' species may be lost	ET	Fisheries, domestic sector, tourism	Change in productivity, or loss of 'old' fisheries	CO	Fishermen, consumers of fish products, local population, related businesses
					Change in demand for recreational angling of affected species	IG	Recreational anglers, tour operators, accommodation and related businesses, general public, tourists
					Changes in the local/regional/national diet	NT	General population, retailers, other related businesses
		Increased incidence of algal blooms	CO	Fisheries, domestic sector, tourism	Change in productivity of local fisheries	CO	Fishermen, consumers of fish products, local population, related businesses
					Change in tourist demand	IG	Tourists, accommodation and related businesses, general public
					Change in enjoyment per visit	IG	
					Change in amenity	IG	Local population, tourist, local authorities

Table 3.5: Matrix of Climate Change Impacts on the Water Resources Sector

Climate Change: Decreased Summer Rainfall							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Low flow in rivers	NT	Reduced reservoir recharge	NT	Water supply	Reduced productivity (new supply sources needed)	CO	Water suppliers, farmers, households, local population, regulatory bodies
					Poorer quality (Change in water treatment costs)	CO	
					More drought orders issued (loss of productivity or increased costs)	CO	
					More hose-pipe bans issued (welfare loss)	SC	
				Tourism and recreation	Decrease in tourist demand or decrease in enjoyment per visit	IG	Visitors, local population
					Reduced recreational opportunity /amenity	IG	
				Habitat	Damage to habitats/ecosystems	IG	Local population, national interest groups, visitors
					Loss of species	IG	Local population, national interest groups, visitors
				Energy sector (hydro-power)	Reduced power potential (loss of productivity)	CO	Hydro-power operators
		Silting up of, and collection of material in, water channels	CO	Habitat	Loss of species	IG	Local population, national interest groups, visiotrs
					Damage to habitat/ecosystems	IG	
				Regulators	Increased maintenance costs	CO	Autonomous abstractors, general public, government, regulators, water supply industry
					Increased flooding risk (**see matrix on increased risk of storm and flooding**)		
				Tourism and recreation	Decrease in demand or decrease in enjoyment per visit	IG	Tourists, recreational users of water resource
				Households	Amenity losses	IG	Property owners, general public

Climate Change: Decreased Summer Rainfall (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Low flow in rivers (continued)	NT	Silting up of, and collection of material in, water channels (continued)	CO	Water transport	Change in operational costs	CO	Transport operators, waterways authorities, emergency services
					Change in risk of accidents	IG	
				Households	Loss of amenity	IG	Local population
		Increased groundwater abstraction	CO	Water supply	Increased abstraction costs (increased depth of pumping)	CO	Water supply companies, consumers, government, regulators
					Reduced groundwater quality - increased risk of saline intrusion (increased treatment costs)	CO	
				Autonomous abstractors	Increased abstraction costs (increased depth of pumping)	CO	Autonomous abstractors
					Reduced groundwater quality - increased risk of saline intrusion (increased treatment costs)	CO	
		Reduced dilution of pollutants	NT	Human health	Increased risk of mortality	IG	Regulators, government, local population, NHS
					Increased risk of morbidity	IG	
				Habitat	Loss of species	IG	Local population, national interest groups
					Damage to habitat/ecosystems	IG	
				Tourism and recreation	Decrease in demand or decrease in enjoyment per visit	IG	Tourists, recreational users of water resource
				Households	Amenity losses	IG	Property owners, general public
				Dischargers	Increase cost of operations	CO	Waste water treatment companies
				Angling	Change in fishery class	IG	Recreational and commercial fisheries
					Loss of productivity (or increased costs)	CO	
					Increased risk of catching unhealthy fish – health risk (**see above**)		
				Water supply	Increase in water treatment costs	CO	Water suppliers, autonomous abstractors
				Agriculture, forestry, manufacturing	Decreased water quality – loss of productivity (or increased costs)	CO	Farmers, forestry companies, autonomous industrial abstractors

Climate Change: Decreased Summer Rainfall (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Low flow in rivers (continued)	NT	Reduced groundwater recharge*	NT	Water supply	Reduced productivity (new supply sources needed)	CO	Water supply companies, consumers, regulators
					Poorer quality (Change in water treatment costs)	CO	
					Increased drought orders issued (loss of productivity or increased costs)	CO	
					Increased hose-pipe bans issued (welfare loss)	SC	
				Habitat	Loss of species (related to wetland damage)	IG	Local population, national interest groups
					Damage to ecosystems/habitat (especially groundwater fed wetlands etc.)	IG	
		Fewer abstraction consents	CO	Water supply	Loss of productivity (increases in costs)	CO	Water supply companies, consumers
					New supply sources needed	CO	
				Autonomous abstractors	Loss of productivity (increases in costs)	CO	Autonomous abstractors, farmers, forestry
					New supply sources needed	CO	
		Increasingly stringent effluent standards	NT	Dischargers	Increased costs (increased water treatment costs, new technology)	CO	Industry, waste water treatment companies, EA
				Agriculture	Increased costs (increased water treatment costs, new practices or technology)	CO	Farmers, forestry industry, regulators
		Reduced oxygen availability	CO	Habitat	Change in aquatic flora/fauna	IG	Local population, national interest groups, visitors
				Angling	Change in fishery class	IG	Recreational and commercial fisheries
					Loss of productivity (or increased costs)	CO	

Note:

* Although winter rainfall is anticipated to increase, the high intensity of the rainfall events means that runoff will be very high, and less volume of water will be intercepted for the purpose of groundwater recharge, therefore the effect of decreased summer rainfall will not fully be offset.

Climate Change: Decreased Summer Rainfall (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Low flow in rivers (continued)	NT	Reduced water quality	NT	Human health	Increased risk of mortality	IG	Regulators, government, local population, NHS
					Increased risk of morbidity	IG	
				Habitat	Loss of species	IG	Local population, national interest groups, fish farmers
					Damage to habitat/ecosystems	IG	
				Angling	Change in fishery class	IG	Recreational and commercial fisheries
					Loss of productivity (or increased costs)	CO	
					Increased risk of catching unhealthy fish – health risk (**see above**)		
				Water supply	Increase in water treatment costs	CO	Water suppliers, autonomous abstractors
					New water supply sources needed	CO	
				Tourism and recreation	Decrease in demand or decrease in enjoyment per visit	IG	Tourists, recreational users of water resource
				Households	Amenity losses	IG	Property owners, general public
				Agriculture, forestry, manufacturing	Loss of productivity (or increased costs)	CO	Farmers, forestry companies, autonomous industrial abstractors
					New water supply sources needed	CO	
Increased demand for water	ET	More drought orders issued	CO	Water supply, manufacturing, agriculture	Loss of productivity (or increased costs)	CO	Water supply companies, farmers, consumers of agricultural produce, businesses, industry, regulators
		More hose-pipe bans	CO	Households	Welfare losses	SC	General public, consumer groups, regulators
		Shortened recovery period for resources	NT	Water supply	New water supply sources needed	CO	Water supply industries, government
			NT	Agriculture	Loss of productivity (or increased costs)	CO	Farmers, consumers of agricultural produce, MAFF
					Change in crop type/pattern	CO	
				Habitat	Loss of species	IG	Local population, national interest groups, visitors
					Damage to habitats/ecosystems	IG	

Climate Change: Increased Winter Rainfall							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased risk of flooding	CO	Direct (physical impact) damage	NT	Numerous sectors	(**see Coastal Zones impact matrix**)		Numerous stakeholders
		Loss/damage of soil (soil erosion)	CO	Numerous sectors	(**see Coastal Zones impact matrix**)		Numerous stakeholders
		Negative impact on water quality (increased suspended sediment, discoloration)	NT	Numerous sectors	(**see above**)		Numerous stakeholders
		Impact on the hydrological regime	NT	Numerous sectors within river catchments	(**see Coastal Zones impact matrix**)		Numerous stakeholders
		Short term disruption	NT	Numerous sectors	(**see Coastal Zones impact matrix**)		Numerous stakeholders
		Resettlement	ET	Numerous sectors	**(see Coastal Zones impact matrix)**		Numerous stakeholders
		Need for temporary evacuation of the population	CO	Numerous sectors	Increased cost for government/local authorities	CO	Government, tax payers, local authority and population, local economy, emergency services
					Welfare losses associated with inconvenience	SC	
		Changes in risk/uncertainty	RU	Numerous sectors	Disutility associated with uncertainty	RU	Individuals, insurance companies
					Increased risk exposure/cost of compensation	ET	
Increased volume of run-off	CO	Inability of existing infrastructure to cope with capacity (combined sewer outflows and storm tanks)	CO	Water industry	Increased maintenance costs	CO	Waste water companies, regulators, local authorities, local population
					Deterioration in water quality (**see above**)		
		Flooding of wetlands/marshes	CO	Habitat	Loss of species/ecosystems	IG	General public, national interest groups
					Migration of species/ecosystems	IG	
		Flushing out of agricultural chemicals	CO	Numerous sectors	Damage and/or destruction of habitats /ecosystems	IG	Local population, national interest groups, government, NHS, water suppliers, autonomous abstractors
					Deterioration in water quality (**see above**)		

Climate Change: Increase in Mean Annual Temperatures

Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increase in the water temperature	NT	Reduced overall productivity of freshwaters	NT	Commercial Fisheries and Recreational Angling	Change in fishery class	ET	Commercial and recreational fisheries, aquaculture
					Loss of productivity (or increased costs)	CO	
				Habitat	Losses of species/ecosystems	IG	General public, tourists, national interest groups, government
					Damage to habitats/ecosystems	IG	
		Increased natural biodegradation of organic pollutants (especially in waters affected by eutrophication) and discoloration	NT	Numerous sectors	Deterioration in water quality (**see above**)		Local population, farmers, visitors, national interest groups, water supply companies, regulators, other autonomous abstractors
		Greater risk of disease for certain fish and aquaculture	NT	Commercial fisheries, recreational angling, habitat	Change in fishery class	ET	Anglers, consumers of fish products, local population, related businesses, national interest groups
					Loss of productivity (or increased costs)	CO	
					Loss of/damage to species	IG	
		New 'southern' fish and aquaculture species	ET	Commercial fisheries, recreational angling, tourism, habitat	Creation of a 'new' fishery	CO	Fishermen, consumers of fish products, local population, related businesses
					Change in, or creation of 'new' demand for recreational angling	IG	Recreational anglers, tour operators, accommodation and related businesses, general public, tourists
					Existence value of 'new' species	IG	General public, national interest groups
		Some 'northern' species may be lost	ET	Commercial fisheries, recreational angling, tourism, habitat	Change in productivity, or loss of 'old' fishery	CO	Fishermen, consumers of fish products, local population, related businesses
					Change in demand for recreational angling of affected species	IG	Recreational anglers, tour operators, accommodation and related businesses, general public, tourists
					Loss of/damage to species	IG	General public, national interest groups
		Increased incidence of algal blooms	CO	Numerous sectors	Deterioration in water quality (**see above**)		Local population, farmers, visitors, national interest groups, water supply companies, regulators, other autonomous abstractors
Increased demand for water supply	ET	(**see above**)		Numerous sectors	N/A		Numerous stakeholders

Climate Change: Rise in Mean Annual Temperature							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased evaporation	NT	Reduced (low) flow in rivers	NT	Numerous sectors	(**see above**)		Numerous stakeholders
Climate Change: Increased Evapo-transpiration							
Increased uptake of water by vegetation	NT	Increased water demand from agriculture	CO	Agriculture, water supply	Loss of productivity (or increased costs)	CO	Farmers, consumers of agricultural produce, MAFF, water companies, regulators
					Change in crop type/pattern	CO	
		Changes in habitats	NT	Habitat	Losses of species/ecosystems	IG	General public, tourists, national interest groups, government
					Damage to habitats/ecosystems	IG	
		Increased water demand from households	CO	Water supply, domestic	Increased water costs	CO	Waste water companies, regulators, local authorities, general public
1st Order Impact: Increased Storminess							
Increased rate of coastal erosion	NT	Negative impact on water quality (e.g. salt water intrusion)	CO	Water supply, autonomous abstractors	Increased water treatment costs	CO	Water supply companies, general public, autonomous abstractors, regulators
					New supply sources needed	CO	

Table 3.6: Matrix of Climate Change Impacts on the Agricultural Sector

Climate Change: Increase in Mean Temperatures							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased length of growing season, decreased risk of frost & increased risk of heat stress	NT	More rapid vegetation growth	NT		Increased productivity (or decreased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
		Change in crop type/patterns	CO		Increased output of 'new' agricultural products	CO	
					Decreased output from traditional crop regimes	CO	
Livestock heat stress	NT	Lower fertility rates	CO		Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, veterinarians, MAFF
		Deterioration in overall animal health	NT		Loss of productivity (or increased costs)	CO	
Impact on arable crop management practices	NT	Reduced requirements for cereal drying	CO		Lower production costs	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
		Reduced fertiliser requirements for some crops	CO	Manufacturing, water resources, regulators, habitat	Lower production costs	CO	Farmers, consumers of farm products, food wholesalers/retailers, regulators (MAFF, EA, DETR), water industry, chemical industry, general public, ITE, ADAS
					Reduced water pollution (see **Water Resource**)		
					Decrease in fertiliser demand	CO	
		Reduced requirements for fungicide applications	CO	Manufacturing, water resources, regulators, habitat	Lower production costs	CO	
					Reduced water pollution (see **Water Resource**)		
					Decrease in fungicide demand	CO	
		Increased need for herbicides and pesticides on many crops	CO	Manufacturing, water resources, regulators, habitat	Increased production costs	CO	
					Increased water pollution (see **Water Resource**)		
					Increased demand for herbicides and pesticides	CO	

Climate Change: Increase in Mean Temperatures (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Impact on arable crop (cont.)	NT	Increased need for irrigation for crops and vegetables	CO	Water resources	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, general public, water companies, regulators
					New water supply sources needed	CO	
Warming of water temperatures	NT	Requirement of aquaculture for improved oxygenation, aeration or lower stocking densities	CO		Loss of productivity (or increased costs)	CO	Aqua-farmers, consumers of farmed fish products, wholesalers/retailers, MAFF, EA
		Requirements of aquaculture for better parasite control strategies	CO	Health	Loss of productivity (or increased costs)	CO	Aqua-farmers, consumers of farmed fish products, wholesalers/retailers, MAFF, EA
					Human health risks	IG	Consumers of farmed fish products, NHS, regulators
Milder winters	NT	Increased risk of pest and disease outbreak	NT	Health, habitat	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Human health risks	IG	Consumers of farm products, NHS, regulators
		Milder opportunities for autumn planting	NT		Increased productivity of existing products (or reduced costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Increased output of 'new' agricultural products	CO	
Climate Change: Decrease in Moisture Availability							
Decrease in water supply and quality	CO	Loss of productivity (or increased costs)	CO		N/A		Farmers, consumers of farm products, food wholesalers/retailers, MAFF
		Change in cropping type/pattern	CO		N/A		
		New water supply sources needed	CO	Water resources	N/A		Farmers, consumers of farm products, general public, water companies, regulators
		Risk of crop and livestock disease increases	CO	Health	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Human health risks	IG	Consumers of farm products, NHS, regulators

Climate Change: Decrease in Moisture Availability (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased risk of drought in summer	NT	Crop failure/yield reduction	CO		Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Change in cropping type/pattern	CO	
		Increase in irrigation demand	CO	Water resources	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, general public, water companies, regulators
					New water supply sources needed	CO	
		Increased risk of pest and disease outbreak	NT	Health	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Change in cropping type/pattern	CO	
					Human health risks	IG	Consumers of farm products, NHS, regulators
Increase d demand for water for irigation	CO	Loss of productivity (or increased costs)	CO	Water resources	N/A		Farmers, consumers of farm products, food wholesalers/retailers, MAFF
		Change in cropping type/pattern	CO				
		New water supply sources needed	CO	Water resources	N/A		Farmers, consumers of farm products, general public, water companies, regulators
Climate Change: Sea Level Rise							
Permanent loss of territory	NT	Loss of agricultural land	CO		Loss of productivity	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF

Climate Change: Changes in Precipitation Patterns							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Lower precipitation in summer	NT	Decreased water supply and quality	CO	Water resources, health	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Change in cropping type/pattern	CO	
					New water supply sources needed	CO	Farmers, consumers of farm products, general public, water companies, regulators
					Risk of crop and livestock disease increases (**see above**)		
		Increase in irrigation demand	CO	Water resources	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					New water supply sources needed	CO	Farmers, consumers of farm products, general public, water companies, regulators
Higher precipitation in winter	NT	Increased soil erosion	CO		Decline in land productivity	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Loss of productive land	CO	
		Increased risk of pest and disease outbreaks	NT	Health, habitat	Loss of productivity (or increased costs)	CO	
					Human health risks	IG	Consumers of farm products, NHS, regulators
Climate Change: Increased Frequency of Storms and Flooding							
Increased rate of coastal erosion	NT	Loss of land	CO	Water resources, habitat	Decline in land productivity	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF
					Loss of productive land	CO	
		Impact on hydrological regime	NT	Water resources, habitat	Decline in land productivity	CO	
					Loss of productive land	CO	
Direct Physical Impact	NT	Damage to land	CO		Decline in land productivity	CO	
					Loss of productive land	CO	
		Damage to livestock	CO		Loss of livestock	CO	
		Damage to buildings and infrastructure	CO	Insurance, construction industry	Loss of property/infrastructure	CO	Farmers, construction contractors, insurers
					Degradation of property/infrastructure	CO	
		Short-term disruption	NT		Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, MAFF

Table 3.7: Matrix of Climate Change Impacts on the Buildings and Infrastructure Sector

Climate Change: Increased Frequency of Storms and Flooding							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Increased rate of coastal erosion	NT	Loss/damage of beaches, dunes, cliffs/headlands	CO	Numerous sectors	Loss of property/infrastructure	CO	Property owners, transport operators, insurers, construction contractors, general public
					Degradation of property/infrastructure	CO	
Direct physical impact	NT	Damage to buildings and infrastructure	CO	Transport infrastructure	Loss of infrastructure/equipment	CO	Transport operators, construction contractors, general public (users and employees in this sector), local authorities, insurers
					Damage to infrastructure/equipment	CO	
					Short-term disruption (**see below**)		
				Residential	Loss of property and infrastructure	CO	Property owners, insurers, construction contractors, local authorities
					Damage to property and infrastructure	CO	
				Commercial, industrial and agriculture	Loss of infrastructure/equipment	CO	Business operators, farmers, construction contractors, general public (users and employees in affected sector), local authorities, insurers
					Damage to infrastructure/equipment	CO	
					Short-term disruption (**see below**)		
				Historical and cultural heritage	Loss of cultural objects	IG	General public, tourists, national interest groups, government and tax payers, insurers
					Damage to cultural objects	IG	
				Flood protection infrastructure	Decreased strength, increased maintenance and repair requirements	CO	Local authorities, government, EA, MAFF, construction contractors, general public, property owners
					Damage to infrastructure	CO	
				Utilities infrastructure	Loss of infrastructure/equipment	CO	Power generators, water, gas and electricity companies, general public, regulators, insurers, contractors
					Damage to infrastructure/equipment	CO	
					Short-term disruption (**see below**)		
				Accidents - human health	Increased risk of non-fatal accidents	IG	General public, employers, insurers, NHS, government, regulators
					Increased risk of fatal accidents	IG	

Climate Change: Increased Frequency of Storms and Flooding (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Direct physical impact (continued)	NT	Short-term disruption	NT	Transport	Increase in the travel cost (work time)	IG	Transport operators, general public (users and employees), local authorities, business operators
					Increase in the travel cost (non-work time)	IG	
					Increased demand for alternative transport routes or modes of transport	CO	
					Externalities from increased congestion	ET	
					Loss of productivity (or increased costs)	CO	
				Households	Loss of welfare	SC	General public
					Welfare cost of increased uncertainty	SC	
				Commercial, industrial and agriculture	Loss of productivity (or increased costs)	CO	Business operators, farmers, general public (users and employees in affected sector), local authorities,
				Utilities	Loss of productivity (or increased costs)	CO	Power generators, water, gas and electricity companies, general public, regulators
				Construction	Loss of productivity (or increased costs)	CO	Contractors, commissioning parties, general public
Climate Change: Sea Level Rise							
Permanent Loss of Territory	NT	Loss of buildings and infrastructure	CO	Transport	Loss of infrastructure/equipment	CO	Transport operators, construction contractors, general public (users and employees in this sector), local authorities, insurers
				Residential	Loss of property	CO	Property owners, insurers, construction contractors, local authorities
					Welfare loss	SC	
					Change in the demand for housing in surrounding areas	SC	
				Commercial, industrial and agriculture	Loss of infrastructure/equipment	CO	Business operators, farmers, construction contractors, general public (users and employees in affected sector), local authorities, insurers
				Historical and cultural heritage	Loss of cultural objects	IG	General public, tourists, national interest groups, government and tax payers, insurers
				Utilities	Loss of infrastructure/equipment	CO	Power generators, water, gas and electricity companies, general public, regulators, insurers, contractors

Climate Change: Sea Level Rise (continued)							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Permanent Loss of Territory (continued)	NT	Resettlement	ET	Numerous sectors	Welfare loss	SC	General public, business operators, government, local authorities, insurers
					Temporary loss of productivity	CO	
					Compensation (if any)	CO	
					Removal management	CO	
Change to river and coastal flooding regimes	CO	Increased flood risk to buildings and infrastructure	CO	Transport	Damage to infrastructure/equipment	CO	Transport operators, construction contractors, general public (users and employees in this sector), local authorities, insurers
					Short-term disruption (**see above**)		
				Residential	Damage to property and infrastructure	CO	Property owners, insurers, construction contractors, local authorities
				Commercial, industrial and agriculture	Damage to infrastructure/equipment	CO	Business operators, farmers, construction contractors, general public (users and employees in affected sector), local authorities, insurers
					Short-term disruption (**see above**)		
				Historical and cultural heritage	Damage to cultural objects	IG	General public, tourists, national interest groups, government and tax payers, insurers
				Flood protection infrastructure	Decreased strength, increased maintenance requirements	CO	Local authorities, government, EA, MAFF, construction contractors, general public, property owners
					Damage to infrastructure	CO	
				Utilities infrastructure	Damage to infrastructure/equipment	CO	Power generators, water, gas and electricity companies, general public, regulators, insurers, contractors
					Short-term disruption (**see above**)		
				General	Welfare cost of increased uncertainty	SC	General public

Climate Change: Increase in Mean Temperatures							
Direct Impact	***VG***	***Potential Indirect Impact***	***VG***	***Sector Affected***	***Potential Sectoral Impact***	***VG***	***Relevant Stakeholders***
Changes in the rate of deterioration of external building fabrics	NT	Changes in external maintenance regime	CO		Changes in demand patterns for buildings materials	NT	Property owners, insurers, construction contractors, material suppliers
					Increased costs	CO	
Changes in indoor temperature regime	CO	Changes in internal maintenance regime	CO		Changes in demand patterns for buildings materials	CO	Property owners, insurers, construction contractors, material suppliers, households
					Increased costs	CO	
		Increased use of air conditioning in summer	CO	Utilities	Increased energy costs	CO	Property owners, conditioning unit suppliers, power generators and electricity supply companies, gas companies, government, general public, regulators, households
					Equipment costs	CO	
					Increased energy generation/supply externalities	ET	
		Reduced winter heating requirements	CO	Utilities	Decreased energy costs	CO	
					Decreased energy generation/supply externalities	ET	
Increased drying of soil	NT	Increased ground movements	NT		Increased subsidence	ET	Transport operators, construction companies, local citizens, property owners, insurers, regulators

SECTION IV

ECONOMIC VALUATION OF CLIMATE CHANGE RISKS AND ADAPTATION:

- Valuation Guidelines -

4 ECONOMIC VALUATION GUIDELINES

4.1 Introduction

The purpose of this section is to provide guidance on the use of techniques for valuing the climate change impacts identified in Section 2. To date, these techniques have been primarily used by public sector project and policy analysts. However, there is an increasing interest in, and use by, private sector analysts in justifying action by them that may be subject to regulation.

At present, there is no standard taxonomy for classifying valuation techniques. The different classifications used may be a source of confusion where different terms are used to categorise the same techniques. Hence, to avoid any confusion, we simply split the valuation techniques into two categories:

ONE - Methods based on data from conventional markets.

The techniques in this category value climate change impacts using the market price of the affected good/service – i.e. the value ascertained in a **conventional market** system where the forces of demand and supply set the value of the good/service – and include:

- Changes in input or output approaches, and
- Cost-based approaches such as preventative/averting expenditure or replacement/restoration cost.

A separate 'step-by-step' guideline is provided for each of these sets of techniques.

TWO - Methods based on data from surrogate or constructed markets.

The techniques in this category are used to value climate change impacts either: (A) by observing behaviour in **surrogate markets** for the affected good/service, and, from these markets, *indirectly* inferring individual valuations (e.g. hedonic analysis and the travel cost method); or (B) by using survey questionnaires to *directly* elicit individual valuations in **hypothetical** or **constructed markets** for the affected good/service (e.g. the contingent valuation method). These two types of techniques are also known in the technical literature as revealed preference and stated preference techniques, respectively. Further detail on these techniques can be found in the Treasury Green Book at:

http://greenbook.treasury.gov.uk/chapter05.htm#valuing.

It should be highlighted at this point that the Green Book suggests a procedure for selecting appropriate techniques, which is summarised in Figure 4.1 below. The Green Book is the principal source of guidance for the public sector users who whish to undertake climate change impact costing work using market or non-market techniques. The guidelines presented here serve to present the likely physical impacts of climate change alongside the monetary valuation techniques available for these impacts and serve to steer the public sector analyst when dealing with the climate change context. The same is true for the private sector analyst, though (s)he has flexibility as to the choice of valuation technique. As a consequence, these techniques are outlined in this section.

Figure 4.1: Hierarchy of Valuation Techniques

Determine whether

Impacts can be measured and quantified

AND

Prices can be determined from market data

If this cannot be readily done

Use 'Willingness to Pay' for a benefit

'willingness to pay'

determined by

'revealed
preference'
or a subset
of this called
'hedonic pricing'

Inferring a price from observing consumer behaviour

If this does not provide values, determine whether:

Willingness to pay can be estimated by asking
people what they would be willing to pay for
a particular benefit

'stated
preference'

or whether

In the case of a cost: identifying the amount of compensation
consumers would demand in order to accept it

'willingness
to accept'

Source: HM Treasury Green Book

General introductory guidance is provided on the application of each of these techniques, together with reference sources for more detailed guidance. We envisage that these techniques will be used in two ways. The first is to undertake a new, primary, study, using a chosen technique. This will be necessary where the cost element identified is considered likely to be significant in determining a specific course of adaptation action, or action of any kind, and where there is no similar study from another context whose results could be transferred to this context.

There is a significant issue for the analyst regarding the time and resources that would be required to undertake a primary study. A second way in which the techniques can be used is in the 'transfer' of data from existing primary studies to the climate change-related study being undertaken. Therefore, a **benefit transfer** guideline is provided to aid the user in the transferring existing valuation data to the site of interest. These should provide ranges of unit values.

We have identified a number of specific categories/sectors for which climate change impact costing data are most likely to be needed. These include:

a) **Habitat/Biodiversity**

b) **Human Health**

c) **Recreation/Amenity**

d) **Cultural Objects**

e) **Leisure or Work Time**

f) **Non-use Value**

In these guidelines we identify appropriate valuation techniques for the particular type of impact considered. We also provide a method for estimating the total value of the impact once a unit value has been derived. We have reviewed the relevant valuation literature and present examples of unit values for environmental impacts that may be used. We would emphasise, however, that these unit values should be seen as illustrative.

In a formal appraisal, these values should simply be used as a starting point for investigating the relevant valuation literature. Values derived can then be used in conjunction with the benefit transfer guideline.

Note that this section is most interested in valuing the costs of climate change impacts and the benefits of implementing adaptation options. Guidance on estimation of the costs of adaptation options is to be found in sections 5.6 and 6.2 of this report, and in the Treasury Green Book at:

http://greenbook.treasury.gov.uk/chapter05.htm#valuing.

4.2 Valuation Methods: Changes in Inputs/Outputs

4.2.1 Context of Guideline

In many cases the environment has a direct effect on:

- the capability of an economic agent (e.g. a fishery) to produce (provide) a good (service), and/or
- the costs that the agent incurs in producing (providing) that good (service).

In economics, we say that some attribute of the environment is an argument in the production and/or cost function of some marketed good or service. For example, the amount of fish commercially harvested from a water body depends on, among other things, fish stocks. In turn, the fish stock depends on water quality and quantity. We can summarise this relationship in the following simple production function:

$$Q = f\left\{R, S(E)\right\} \tag{4.1}$$

where

Q	=	the quantity of fish commercially harvested,
f	=	the function that relates environmental quality to the quantity of fish harvested,
R	=	the amount of resources devoted to catching fish, and
$S(E)$	=	the stock of fish in the water body, which itself depends on the quality of the water body's environment (E).

Now consider the implications of a change in the quality of the water body environment as a result of climatic variation, which we denote by ΔE. Suppose that, as a result of reduced water flow and increased ambient temperature, water quality in the water body were to deteriorate. Assume further that the deterioration in water quality is sufficient to have an adverse impact on fish stocks.

There are two possible consequences of ΔE, and the subsequent decrease in fish stocks ($\downarrow S$):

- If the operator of the fishery wants to maintain current harvest rates (i.e. $\overline{Q}$ remains unchanged), then it will have to allocate more resources to catching fish ($\uparrow R$). Since fish are now less abundant in the water body, the operator will have to try harder to maintain harvest rates - e.g. buy additional fishing equipment, fish longer hours, etc.

- If the operator does not increase the amount of resources it allocates to catching fish (i.e. $\overline{R}$ remains unchanged), then we can expect the quantity of fish harvested to decrease ($\downarrow Q$).

Either way, the operator of the fishery suffers an economic loss. Under the latter scenario, (s)he loses the value of the lost output ($\downarrow Q$). In the former case, the operator's costs increase as a result of having to increase the level of fishing effort ($\uparrow R$). This provides us with two measures of the cost of the climate change-induced deterioration in environmental quality: (1) the cost of the additional resource inputs, or; (2) value of lost output.

Of course, environmental (water) quality may also improve, in which case we might expect fish stocks in the water body to increase ($\uparrow S$). The benefits of an improvement in water quality are given by either:

- the value of additional output (assuming $\overline{R}$ remains unchanged) or

- the cost savings associated with fewer resource inputs (assuming $\overline{Q}$ remains unchanged).

The impact of changes in environmental quality on the inputs to and outputs from various sectors sensitive to climate change is illustrated in Table 4.1 below. The first four rows summarise the fishery example discussed above. This example, as shown in Table 4.1, can equally be extended to forestry and agriculture. Further examples are industries that use water in production processes. These industries could benefit from an improvement in water quality in that their water treatment costs may decline (-). Conversely, deterioration in water quality may result in increased treatment costs (+). In both cases, it is unlikely that industrial output would be affected (constant).

In general, when we estimate the cost (benefit) of a deterioration (improvement) in environmental quality by valuing a decrease (increase) in output, we are employing what is referred to as the **change-in-productivity approach**, of which there are several variations (as you will see below).

The closely-related approach, where we estimate the cost (benefit) of a deterioration (improvement) in environmental quality by valuing increases (decreases) in resource costs, is the **production cost** (or **cost saving**) **technique**. Again, there are several variations to this approach.

The choice of which approach to apply depends on the impact in question and the anticipated response of affected producer – as indicated in Table 4.1, as well as data availability.

Table 4.1: Examples of the Productivity Impacts in Selected Sectors Sensitive to Climate Change

Environmental Change	Effect on Outputs	Effect on Inputs
Adverse impact on fishery – e.g. deterioration in water quality or supply	Decrease	Constant
Adverse impact on fishery – e.g. deterioration in water quality or supply	Constant	Increase
Beneficial impact on fishery – e.g. increment in water quality or supply	Increase	Constant
Beneficial impact on fishery – e.g. increment in water quality or supply	Constant	Decrease
Adverse impact on forestry – e.g. direct physical damage from storms	Decrease	Constant
Adverse impact on forestry – e.g. reduction in average water availability	Constant	Increase
Beneficial impact on forestry – e.g. expansion of forestry lands	Increase	Constant
Adverse impact on agriculture – e.g. decrement in water supply during growing season	Decrease	Constant
Adverse impact on agriculture – e.g. decrement in water supply during growing season	Constant	Increase
Beneficial impact on agriculture – e.g. expansion of growing season	Increase	Constant
Adverse impact on industrial processes – e.g. deterioration in water quality or supply	Constant	Increase
Beneficial impact on tourist industry – e.g. increase in ambient air and water temperature	Increase	Constant

4.2.2 Valuation of Changes in Inputs/Outputs

In terms of valuing changes in inputs/outputs, two situations must be distinguished from each other. These are

- **CASE 1** - changes in quantity *do not* result in changes in price; and
- **CASE 2** - changes in quantity *induce* changes in price.

They both involve assumptions concerning the size of the expected change in output/inputs.

CASE 1 – No Change in Prices

If the change in output - denoted by ΔQ - is small relative to the current total market for Q, or the change in resource inputs is small relative to the market for that variable factor of production, then we can safely assume that the output and resource input prices will remain constant after the change in Q or *R*.[32] In this case, we can simply multiply the expected change in output or inputs by market prices to derive a measure of the economic value (V) of the projected change. There are several ways of doing this.

- For changes in productivity, we can calculate a gross margin[33] for each unit of output, then multiply this by the projected change in output (see Box 4.1 for an example).
- For changes in production costs, we can calculate the unit cost of variable factors, then multiply this by the projected change in resource use (see Box 4.2 for an example).
- Alternatively, in both contexts, we can use Total (farm) Budgets (i.e. gross output minus gross input) for the '<u>with</u>' and '<u>without</u>' cases (see Box 4.3 for an example).
- In the case of productivity changes, we can also estimate changes in land values (per hectare) for the '<u>with</u>' and '<u>without</u>' climate change cases[34] (see Box 4.4 for an example).

Regardless of which approach we adopt, it is important to realise that market prices *do not* always reflect **real opportunity costs**. Distortions

[32] For instance, the fishery operator in the above example might be only one of many small producers of fish, in which case it is *unlikely* that a change in his or her output will significantly affect the total supply of fish in the market.

[33] Gross margin is simply the market value of output *less* the **variable costs** incurred in producing the output. Gross margin should not be mistaken for profit however. The profit derived from producing a commodity is generally equal to the market value of output *less* the **total cost** – i.e. variable *plus* fixed cost – of producing it. Fixed costs, in contrast to variable costs, do not vary in proportion to output, and include depreciation expense, rents, general overheads, etc.

[34] This alternative assumes that the value of a piece of land depends on the value of goods and services provided by that land.

may exist due to the presence of indirect taxes, support prices, and other subsidies; this is particularly relevant to the case of agriculture. In costing climate change impacts using market prices, we must make corrections for such distortions – for example, by deducting taxes from prices, or adding back subsidies. As mentioned, adjustments to market prices are particularly required in the agricultural sector. Examples of the type of adjustments that may be required when using these approaches in the agricultural sector are provided in MAFF (1999) and Garrod and Willis (1999).

Box 4.1: Valuing Changes in Productivity Using Data on Gross Margins

General Procedure:[35]

The economic value (V) of a decrement (increment) in productivity can be determined by first estimating the gross margin for each unit of affected output. For one unit of product k the adjusted **gross margin** (gm) is given by:

$$gm_k = P_k^0 - VC_k^0 \tag{4.2}$$

where

P_k^0 = the market price (adjusted, if necessary) for a unit of product k (the subscript '0' refers to the without climate change case), and

VC_k^0 = the **variable costs**[36] of producing a unit of product k.

Then we multiply the projected change in output by the gross margin per unit – that is:

[35] The reader should note that this general procedure is designed to be broadly applicable across many sectors. A more detailed methodology assessing the (economic) impacts on agriculture is provided in MAFF (1999).

[36] Variable costs, as the term implies, vary in proportion to output. The main variable cost components associated with, for example, crop production include fertilisers, seeds, sprays, casual labour, etc.

$$V_k = \Delta Q_k * gm_k = \left(Q_k^1 - Q_k^0\right) * gm_k \tag{4.3}$$

where

V_k = the economic value of the decrement (increment) in the output of product k,

Q_k^0 = the projected output of product k in the without climate change case, and

Q_k^1 = the projected output of product k in the with climate change case.

Numerical Example:

Suppose that as a result of climate change and the predicted decrease in summer rainfall, main crop potato yields in a defined area are anticipated to decline to 81 percent of yields under normal – i.e. without climate change – rainfall conditions.[37] The affected harvested area is 1,700 hectares (ha). Assume further that potato prices do not change as a result of the expected reduction in output and farmers do not change crop type/patterns. (If the event is likely to induce farmers (or other producers) to change cropping patterns (production processes or sequences), then you are advised to use the approach based on Total Budgets.)

Following the general procedure outlined above, we can calculate the annual economic value of the climate change-induced reduction in potato yields.

Step 1 – estimate the **gross margin** for each unit of affected output as follows:

$$gm_{\text{potatoes}} = P^0_{\text{potatoes}} - VC^0_{\text{potatoes}}$$

This requires data on the following parameters, which can be obtained from Nix (1999), if site-specific data are not available:[38]

[37] To utilise this valuation technique you must be able to quantify production/output – e.g. crop yields – with and without climate change.

[38] If fixed costs are expected to change, then the relevant fixed cost saving should also be deducted. In general, if the change in output is not substantial, then fixed costs are unlikely to change. If fixed costs are deducted, then we are working with **net margins**, and not **gross margins**.

P^0_{potatoes} = £70 per tonne (main crop) potatoes

VC^0_{potatoes} = £46 per tonne (main crop) potatoes

Hence, the adjusted gross margin per unit of main crop potatoes is:

$$gm_{\text{potatoes}} = \text{£}70/\text{t potatoes} - \text{£}46/\text{t potatoes} = \text{£}24/\text{t potatoes}$$

Step 2 – multiply the projected change in output (in tonnes) by the adjusted gross margin per unit:

$$V_{\text{potatoes}} = \Delta Q_{\text{potatoes}} * gm_{\text{potatoes}} = \left(Q^1_{\text{potatoes}} - Q^0_{\text{potatoes}}\right) * gm_{\text{potatoes}}$$

We know that the total affected area is 1,700 ha, so in order estimate total output for this area in the without climate change case we need data on average yield per ha. Again, these data are available in Nix (1999), if site-specific data are not available. We also know from the impact assessment that main crop potato yields are anticipated to decline to 81 percent of current levels. Therefore, the projected change in output (in tonnes) is given by:

Q^0_{potatoes} = $42.5 \text{ t potatoes/ha} \times 1{,}700 \text{ ha} = 72{,}250 \text{ t potatoes}$

Q^1_{potatoes} = $72{,}250 \text{ t potatoes} \times 0.81 = 58{,}523 \text{ t potatoes}$

Hence, the annual economic loss value of the climate change-induced reduction in potato yields is:

$$V_{\text{potatoes}} = \left(58{,}523 \text{ t potatoes - } 72{,}250 \text{ t potatoes}\right) \times \text{£}24/\text{t potatoes} = -\text{£}329{,}500$$

It is important to note that the above estimate is an annual (or recurring[39] (e.g. annual) value, and therefore cannot be added directly to other impacts valued, for example, through the land value approach, which yields capitalised[40] (or non-recurring values). Either the former must be converted into an appropriate capitalised value or the latter converted into an annualised valued. Failure to do so will result in errors when aggregating across impacts. Procedures for making such conversions are provided in Section 5.6.

In this example it is assumed that the affected farm enterprises *do not* adjust their input mix – e.g. increase irrigation – in response to the reduction in summer rainfall levels. If, however, it is anticipated that farmers will increase irrigation to maintain yields at pre-climate change levels, then it may be better to use the production cost approach (see Box 4.2 below for an example). Where site-specific cost data on irrigation systems are not available, again it is also provided in Nix (1999).

Recall that the market price of selected agricultural products may be distorted by subsidies, etc. For these crops, it is necessary to adjust the estimated gross margins in order to obtain a 'truer' measure of the economic value of the crop, and hence the resulting damages from lost productivity.

The general procedure presented above was illustrated with agricultural examples, but as mentioned above is equally applicable to any business that produces a good or service that may be affected by climate change. For example, a tour operator or hotel proprietor may experience changes in use/visitation rates as a result of climate change related impacts. The economic value of the impact on these parties is still computed as the predicted net change in users/visitors times the adjusted gross margin per unit.

[39] That is, the loss is only experienced for a limited period – e.g. a year. If the cause of the reduction in output were to persist, it is likely that the producer (farmer in this case) would adapt (e.g. change cropping patterns).

[40] That is, the stream of future values accruing from the land are 'capitalised' in its current price.

Box 4.2: Valuation Based on Changes in Resource Costs

General Procedure:

The economic value (V) of a decrement (increment) in production costs can be determined by multiplying the adjusted unit cost of a particular resource input (e.g. raw/potable water, agrochemicals, etc.) by the projected change in its use – that is:

$$V_i = \Delta R_i * mc_i = \left(R_i^1 - R_i^0\right) * mc_i \quad (4.4)$$

where

V_i = the economic value of the decrement (increment) in production costs associated with the use of resource input i,

mc_i = the adjusted marginal cost of resource input i,

R_i^0 = the projected use of resource input i in the without climate change case, and

R_i^1 = the projected use of resource input i in the with climate change case.

Numerical Example:

As a result of increased annual mean temperature, suppose that the annual application of fungicide (e.g. Chlorothalonil + Cyproconazole) to 1,000 ha of beans is reduced from 2 to 1 (a prediction from an impact risk assessment). The annual economic value of the climate change-induced reduction in fungicide use is computed as:

$$V_{\text{fungicide applications}} = \left(R^1_{\text{fungicide applications}} - R^0_{\text{fungicide applications}}\right) * mc_{\text{fungicide applications}}$$

where

$mc_{\text{fungicide applications}}$ = £31.25 per ha-application (Nix, 1999)

$R^0_{\text{fungicide applications}}$ = $2 \text{ apl.yr} \times 1{,}000 \text{ ha} = 2{,}000 \text{ ha - apl./yr}$

$R^1_{\text{fungicide applications}}$ = $1 \text{ apl./year} \times 1{,}000 \text{ ha} = 1{,}000 \text{ ha - apl./year}$

Hence,

$$V_{\text{fungicide}} = (1{,}000\text{ha - apl./yr} - 2{,}000\text{ha - apl./yr})*\text{£}31.25\text{ /ha - apl.} = -\text{£}3{,}125$$

Since the estimated annual cost in this example is negative, it actually represents a saving.

Again, note that this is an annual recurring value, and not a capitalised value.

Box 4.3: Valuation Based on Total Budgets

General Procedure:

Typically, a producer – e.g. a farmer – will run a multi-product/multi-input operation. In this case the producer's multi-product/multi-input production function can be written as:

$$f\left(Y_1,.....,Y_m;X_1,.....,X_n\right)=0 \qquad (4.5)$$

where Y_i is a set of feasible outputs i (e.g. cereals, crops, horticulture, livestock, etc.) and X_j is a set of production inputs j (e.g. feed, seeds, fertiliser and lime, etc.). The net margin (or net income) (which we denote by 'Z') from producing a given set of outputs can be represented by:

$$Z=\sum_{i=1}^{m}\left(Y_i \times P_{y\,i}\right)-\sum_{j=1}^{n}\left(X_j \times P_{x\,j}\right) \qquad (4.6)$$

where P_{yi} is the adjusted price of output i and P_{xj} is the adjusted price of input j.

Therefore, the cost (benefit) of an adverse (beneficial) climate change impact to producers is given by the **change in net income margin** – that is:

$$\Delta Z = Z_1 - Z_0 \qquad (4.7)$$

where the subscripts '0' and '1' refer to the without and with (climate change) case, respectively.

This approach can be used to estimate the economic cost (benefit) of a *partial* decrement (or increment) in some environmental factor affected by climate change, as well as for a *whole* decrement (or increment).[41] That is, the approach can be used to value small changes in combinations of inputs/outputs, and is not restricted to valuing the total loss/gain of those inputs/outputs. Thus, it has an advantage over the previous methods in that **it can deal with changes in the mix of inputs/outputs**, inclusive of investment expenditures. For example, if faced with a water shortage, a profit-maximising (or cost-minimising) farmer may increase irrigation, change the amount of fertiliser and other inputs, switch crops, or undertake a combination or responses. Likewise, a water supply company can select any combination of measures from a large set of total water management options in response to supply-demand imbalances in a region. Adjustments by economic agents can be readily incorporated into the 'change in income method', although the analysis is *not* easy to do accurately.

Implementation of this form of analysis requires the calculation of **Total Budgets** for the with and without cases. These budgets typically identify and value the inflows of resources and the corresponding outflows of products within a specified accounting period - usually one year - for an individual production entity. A more appropriate approach, which employs similar stages, involves modelling producer behaviour. In this case, the producer is allowed to respond to the climate change impact in a rational manner (e.g. to minimise production cost or maximise net income), and this response is modelled using, for example, linear programming methods. The output of such an exercise is still a measure of the change in net income associated with the climate change impact.

Example:

Applying the 'change in net income method' involves completing a table similar to Table 4.2 below. The example given is for agriculture, but similar tables could just as easily be constructed for any multi-product/multi-input manufacturing/business operation.

Note that the arrows in Columns 3 and 5 simply indicate that in most cases we are assessing multi-product operations – i.e. product $i+1$, product $i+2$, etc. - under the with and without climate change cases.

[41] In some cases, particularly with reference to agriculture or forestry, land may be lost for the foreseeable future as a consequence of climate change – in which case we are not just talking about an occasional loss of output from an area, or a reduction in yield. If land is lost or abandoned, then you should use the approach outlined in Box 4.4.

Table 4.2: Change in Net Income Method - Total Farm Budget: Illustrative

PART I – Gross Margin by Product				
Item	**Without Climate Change Case**		**With Climate Change Case**	
	Product *i* (£ per ha)	→ (£ per ha)	**Product *i*** (£ per ha)	→ (£ per ha)
1. Output:				
a) Projected yield (tonnes/head per hectare)		→		→
b) Projected 'adjusted' price (£ per t/head)		→		→
c) Projected output (1a * 1b) (£ per hectare)		→		→
2. Variable Costs:				
a) Total feeding stuffs		→		→
b) Total seeds		→		→
c) Total fertilisers and lime		→		→
d) Total pesticides		→		→
e) Total farm maintenance		→		→
f) Total miscellaneous expenditures		→		→
g) Total variable costs (2a to 2f)		→		→
3. Gross Margin:				
a) Gross margin per hectare (1c – 2g)		→		→
b) Total area (hectares)		→		→
c) Gross margin per product (3a * 3b) (£)		→		→
d) Total gross margin per Farm/Region	$\sum_i gm\,'\text{without}'$		$\sum_i gm\,'\text{with}'$	

PART II – Net (Profit Income) Income Margin from Farming Operations		
Item	**Without Climate Change Case**	**With Climate Change Case**
	(£)	(£)
4. Annualised Investment Expenditure[42] and Overheads:		
a) Land		
b) Machinery and equipment		
c) Buildings		
d) Livestock		
e) Irrigation systems		
f) Drainage systems		
g) Other investment expenditures		
h) Fixed costs		
j) Total for farm/region (sum of 4a to 4h)		
5. Net Income Margin from Farming:		
a) Net income for farm/region (3d – 4j)		
6. Change in Net Income Margin from Farming:	Net income margin 'without – Net income margin 'with'	

[42] See Guideline on Cost-effectiveness Analysis for definition of annualised costs (Section 5.6).

Box 4.4: Valuing Changes in Productivity Based on Land Values

General Procedure:

The use of land values to estimate the benefits of policy interventions – e.g. soil conservation or flood protection programmes – is a well-established approach.

In theory, the value of an asset, such as agricultural or forest-land, a property, or a capital facility, is given by the present value of the projected stream of net benefits accruing from the use of the asset. In other words, the flow of net benefits from all the characteristics of the asset is aggregated in the price (or present value) of that asset. So, if one of the characteristics of the asset were to change as a result of climatic change – e.g. crop yields on agricultural land – the price of the asset will be affected, other things being equal. Therefore, by observing land (or property) values under the with and without climate change cases, we can approximate the economic value (V) of the projected change on 'productivity', as follows:

$$V_j = A_j * \Delta L_j = A_j * \left(L^1_{j\rightarrow k} - L^0_j\right) \qquad (4.8)$$

where

V_j = the economic value of the decrement (increment) in value of land use type j (e.g. agricultural or forestry land),

A_j = the total affected area of land use type j (e.g. hectares of grazing land)

L^0_j = the adjusted market price of land use type j in the without climate change case, and

$L^1_{j\rightarrow k}$ = the adjusted market price of land use type j in the with climate change case.[43]

Note that it is unlikely that the necessary data will be available to value *partial* increments or decrements in land value in the with and without

[43] Even if the land is lost to agricultural production, it does not necessarily mean it has no value to society. For example, flooded agricultural land may create a valuable mudflat or freshwater wetland, which has value. The value of the land in its new use, regardless of what that may be, should also be taken into account.

cases. Rather, this approach is more amenable to valuing the complete loss of land use j - e.g. from permanent loss of territory – or a switch from land use j to land use k - e.g. from one type of agricultural use to another, or from agricultural use to use as a mudflat or salt marsh.

Numerical Example:

Consider a situation in which 100 hectares (ha) of territory is permanently lost to any use, say, coastal erosion. If the land were currently in agricultural use, then the economic value of the climate change impact can be approximated as:

$$V_{\text{agriculture}} = A_{\text{agriculture}} * \left(L^{1}_{\text{no-use}} - L^{0}_{\text{agriculture}}\right)$$

We know that 100 ha of territory is agricultural land is lost, so we need data on the adjusted market price of this land use type in the with and without climate change case. The average price paid for agricultural land, including farm buildings, in England in 1997 is £7,470 per ha. This price needs to be adjusted for the cost to the UK of agricultural support. Assume that the adjustment factor is 45%.[44] Hence, the market price needs to be multiplied by 0.45 to derive the adjusted loss per ha, which is given by £3,361. This is the value we use in the without climate change case. As the land is permanently lost, its value in the with climate change case is £zero. Our data set is thus:

$A_{\text{agriculture}}$ = 100 ha of 'general' agricultural land

$L^{0}_{\text{agricultural}}$ = £73,470361 per ha

$L^{1}_{\text{no-use}}$ = £zero

Hence, the economic value of the climate change impact is given by:

$$V_{\text{agriculture}} = 100 \text{ ha} \times \left(£0/\text{ha} - £3{,}361/\text{ha}\right) = -£336{,}150$$

Note, as emphasised above, the above damage estimate represents a capitalised value ('one-off' loss) – i.e. it is not a recurring annual cost of climate change.

As mentioned, the price used in this example is the average price paid for agricultural land, including farm buildings, in England in 1997 – obtained from the new Valuation Office Agency Transactions series issued by the

[44] This was the adjustment factor employed in MAFF (1998), however, the reader should consult Defra for the most recent factor.

former MAFF. The average price paid for land only is £5,532 per ha. The Valuation Office Agency Transactions series also provides average prices:

- By tenure - £6,557 per ha (vacant possession) and £3,690 per ha (tenanted).
- By size group - £7,217 for areas between 5 and 49.9 ha sold; £6,197 for areas between 50 and 99.9 ha sold; £5,601 for areas 100 and over ha sold; and £6,448 for all sales.
- By predominant grade of land - £7,304 for Grades 1 and 2; £7,258 for Grade 3; £3,158 for Grades 4 and 5; and £3,691 for ungraded.
- By region – ranging from £3,300 in North East England to £8,172 in South East England.

Depending on the specificity of the impact data available, it may be possible, and is desirable, to use a more specific land price.

Suppose, for example, that as a result of climate change and either increased soil erosion or desiccation, 100 ha of Grade 3 agricultural land is down-graded to Grade 4. The economic value of the climate change impact in this case is approximated as:

$$V_{\text{agriculture}} = A_{\text{agriculture}} * \left(L^1_{\text{Grade 4}} - L^0_{\text{Grade 3}}\right)$$

The required data set is:

$A_{\text{agriculture}}$ = 1,000 ha of agricultural land

$L^0_{\text{Grade 3}}$ = £7,258 per ha

$L^1_{\text{Grade 4}}$ = £3,158 per ha

Hence, the economic value of the climate change impact is equal to:

$$V_{\text{agriculture}} = 100\text{ ha} \times \left(£3{,}158/\text{ha} - £7{,}258/\text{ha}\right) = -£410{,}000$$

Again, the above damage estimate represents a 'one-off' loss.

Other agricultural and forest land price data series are available, a number of which are referenced in Nix (1999). Data on the average housing land prices are published by the former DETR;[45] data should also be available from local estate agents.

Instead of using adjusted land values (market prices) to estimate possible

[45] See, for example, DETR (1999).

climate change damages with this approach, you could equally use adjusted (annual) rental values. However, since the analysis is based on *annual* cost data in this case, it follows that the damage cost estimates produced are also (recurring) (annual) costs; as opposed to the 'one-off' (non-recurring) costs estimated using data on the market price of land. **Remember not to add capitalised (non-recurring) values to annual (recurring) values.**

Data relating to farm lets are published by the former MAFF.[46]

CASE 2 – Induced Price Changes

In some situations, the change in output may be considerable relative to the current total quantity of output available in the marketplace. This in turn may induce the price of the affected good/service to change.[47] If the change in output is large enough to affect market prices, then we must resort to the relevant supply and demand curves in order to value ΔQ.

In order to evaluate the induced change in price some information on the **price elasticity of demand** for the affected marketed good/service is needed. Then, if we can assume that the demand curve is linear over the projected change in quantity, the economic value of the change in output can be calculated using the method outlined in Box 4.5.

Box 4.5: Price Elasticity of Demand

General Procedure:

In economics, the price elasticity of demand for, say, good *X* measures the percentage change in the quantity demanded associated with a percentage change in price. Mathematically,

[46] See, for example, MAFF (1999).

[47] In the previous example, if the deterioration in water quality decimated fish populations and subsequently had a large impact on harvest rates, fish might become scarce in the local markets. In such circumstances, other things being equal, it is likely that consumers would be willing to pay increasingly higher prices for the fish – as 'old' demand exceeds 'new' supply. This would have the effect of bidding up the price of fish.

$$\xi = \frac{\left(\Delta Q / Q^0\right)}{\left(\Delta P / P^0\right)} = \left(\frac{\Delta Q}{\Delta P}\right) \times \left(\frac{P^0}{Q^0}\right) \qquad (4.9)$$

where $\Delta P = P^1 - P^0$ and $\Delta Q = Q^1 - Q^0$.

Hence, given ξ, Q^0, Q^1 and P^0, the above equation can be solved for ΔP, from which P^1 can be readily derived, since $\Delta P = P^1 - P^0$.

In general, an induced change in price is likely to bring about changes in consumer and producer surplus. An example is given below. For the particular situation depicted in this example, the change in consumer and producer surplus - i.e. the economic value of the projected ΔQ - is:

$$Value\ \Delta Q = \frac{1}{2}\left(\Delta Q \times \Delta P\right) + \left(\Delta Q \times P^0\right) \qquad (4.10)$$

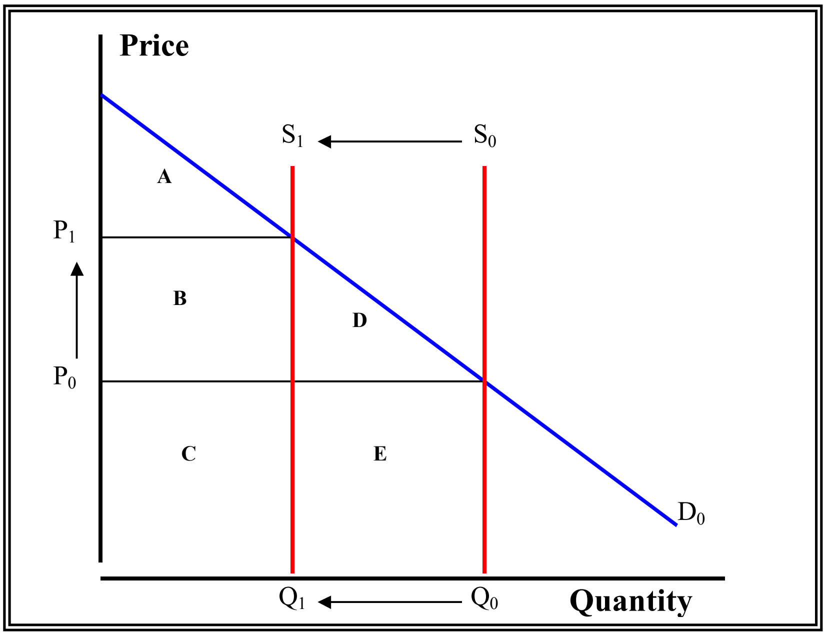
More generally, the change in consumer and producer surplus is given by

$$\frac{1}{2}\left(\Delta Q \ \times \Delta P\right) \pm \text{ change in revenue - change in cost} \qquad (4.11)$$

<u>Numerical Example:</u>

To illustrate the valuation of productivity changes when prices change consider Figure 4.2 below, which depicts the market for fish – continuing with our example. Initially, a quota of Q^0 = 100 tonnes of fish per year are supplied at an adjusted price of P^0 = £100 per tonne. Now, suppose that as a result of increased temperature and decreased water flow, and the subsequent change in water quality, fish stocks fall and the allowable catch is reduced to Q^1 = 50 tonnes per year. In the market depicted in Figure 4.2, the corresponding 'new' price of fish is P^1.

Figure 4.2: Valuing a Change in Output When Prices Change



Before the climate change-induced change in water quality consumer (CS) and producer (PS) surplus is given by

$$CS^0 = A + B + D, \text{ and}$$

$$PS^0 = C + E.$$

After the change in water quality, and the subsequent change in output and price, we have

$$CS^1 = A, \text{ and}$$

$$PS^1 = B + C.$$

The recurring (annual) cost of the deterioration in water quality in this case is therefore given by

$$[CS^1 - CS^0] + [PS^1 - PS^0]$$

$$[A - (A + B + D)] + [B + C - (C + E)]$$

$$- B - D + B - E = - D - E.$$

In short, the net loss of **consumer surplus** is equivalent to the area **D**, while the net loss of **producer surplus** accruing to fishery operator is equivalent to the area **E**. (In this example the lost PS is equivalent to the lost revenue since the supply curve is vertical.)

If some data on the price elasticity of demand for fish are available, and we can assume that the demand curve is linear over the projected change in quantity, then it is possible to derive estimates of the areas D and E. Suppose the price elasticity of demand, ξ, is –3.3. Hence,

$$\xi \quad = -3.3 = \left(\frac{50-100}{P^1-100}\right)\times\left(\frac{100}{100}\right)$$

The above equation can be solved for P^1, which is equal to £115 per tonne. The change in consumer and producer surplus - i.e. the economic value of the projected ΔQ - is therefore given as

$$\frac{1}{2}(50-100\times 115-100)+(50-100\times 100) = -375+(-5{,}000) = -5{,}375$$

The total economic cost is £5,375 per year, comprising an annual loss of **consumer surplus** equal to £375 (area **D**) and an annual loss of **producer surplus** equal to £5,000 (area **E**).

4.3 Cost-based Approaches – Preventative Expenditure and Replacement Cost

4.3.1 Context of Guideline

When the cost of a climate change impact cannot be measured directly – that is, the impact has no observable market price – we can base the valuation on supply or resource cost data.[48] Estimates of the potential costs (or savings) to households and producers for example, can be obtained by using:

- the cost of replacing the good or service provided by the affected exposure unit after the climate change impact has occurred; or

- the cost of reducing or avoiding the climate change impact on the exposure unit before it occurs.

The former are known as **replacement costs** (**restoration costs** or **corrective expenditures)**. The latter are referred to as **averting** or **preventative expenditures**.

For public sector analysts, the source of generic guidance on valuing benefits using these methods is the Treasury Green Book at: http://greenbook.treasury.gov.uk/chapter05.htm#valuing. More specific guidance of damage to property is at: http://greenbook.treasury.gov.uk/annex03.htm. Sector-specific guidance is published by individual government departments. For example, Defra produces the guidelines relevant to coastal and flood defence, to be found at:

http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm.

4.3.2 Preventative Expenditures

Description of the Technique

The use of the preventative expenditure[49] measure of willingness to pay for non-marketed aspects of the environment is based around the premise that the expenditure incurred in order to avert damage can be viewed as a

[48] That is, the valuation is from the supply side of the market rather than the demand side.

[49] The preventative expenditure technique is also known as avertive expenditure and defensive expenditure techniques in the literature (see e.g. Hanley & Spash, 1993). The terms can be used interchangeably.

surrogate demand for the current level of environmental quality.[50] Put another way, an individual's perception of the cost imposed by the environmental damage – in this case from climate change – can be assumed to be at least as much as the amount that the individual (or organisation) pays to avert the damage. This assumes that the expenditure would actually be made. Note that if the expenditure is not made there is no implicit valuation made of the damage impact averted. These techniques measure use values only and do not attempt to capture non-use values.

An example of a preventative expenditure in the present context is the expenditure that is made on a sea defence system in order to prevent future damaging impacts from sea level rise. In this case, therefore, the expenditure is taken as a proxy for the value of the environmental damage, such as infrastructure damage and ecosystem damage, averted.

Assumptions of the Technique

The previous example highlights the fact that in the context of costing climate change impacts, preventative expenditures are in fact adaptation costs, so that the adaptation cost is used as a proxy for the impact cost. The expenditure should be seen as a <u>minimum</u> estimate of the impact cost, since it does not include any measure of consumer surplus. It is also important to note also that in some cases individuals will receive benefits from the averting behaviour over and above the costs incurred. Thus, the appropriateness of using the expenditure as a proxy for the impact cost is contingent on there being no ancillary benefits associated with the expenditures, i.e. that the expenditure and the environmental quality preserved are perfect substitutes. If there are other, ancillary, benefits, the expenditure will give an over-estimate of the value of the climate change impact. The main advantages of the technique are that:

- ♦ preventative expenditures are common and are therefore likely to be a useful data source; and
- ♦ it relies on observable – as opposed to hypothetical – market behaviour.

The preventative expenditure technique is generally applicable in estimating the cost of both marketed and non-marketed climate change impacts, as long as opportunities for preventative expenditures exist. However, since what is actually being measured is the cost of adaptation to the climate change impact, the preventative expenditure technique

[50] Specifically, the preventative expenditure method uses the household production framework to value changes in environmental quality. This framework postulates that households behave like companies, combining environmental quality with market goods to produce a service such as 'cleanliness' or good health. The economist, by observing how households trade-off between the market goods and different levels of environmental quality, can infer the value of a given level of environmental quality.

cannot be used to measure the benefits of a prospective expenditure in a cost benefit analysis of an adaptation measure. This is because the method uses the cost of the measure as a proxy for the resulting benefits (the impacts avoided) – the two sides of the cost-benefit equation would be equal and therefore would cancel out.

An example of how the technique can be used is given in Box 4.6.

Box 4.6: Example of the Preventative Expenditure Approach to Valuation

General Procedure:

Step 1

Identify and quantify the climate change impact to be valued.

Step 2

Identify and estimate the expenditure incurred to avoid the climate change impact.

Step 3

If practical, indicate the value of any ancillary benefits that can be subtracted from the value estimate derived in Step 2. In practice it is more straightforward to indicate their importance in qualitative terms.

Step 4

Calculate the total cost of the impact as follows:

total cost of the climate change impact (£)

equals

the number of affected units

times

the preventative expenditure (£ per unit)

Numerical Example:

Step 1

Suppose that building subsidence is anticipated to result from increased drying of soil - 50,000 properties (units) have been identified as at risk.

Step 2

Assume that the subsidence can be avoided by a one-off expenditure of £10,000 per property in order to strengthen foundations.

Step 3

Further assume that in this case the expenditure is a perfect substitute for climate change impact avoided – hence, no ancillary benefits.

Step 4

The total cost of subsidence resulting from increased soil drying in the area at risk is therefore given by (note that this is a one-off cost):

50,000 properties * £10,000 per property = £500 million.

Thus, if it can be demonstrated that society is willing to pay this amount to avoid the damage of subsidence, then £500 million can be taken as a 'lower bound' estimate of the cost of the climate change impact. However, in the context of a cost-benefit analysis as to whether or not to undertake the strengthening of the property foundations, then £500 million cannot be taken as an estimate of benefits. Rather, this represents the cost of the adaptation measure, to which the benefits (estimated using another method) should be compared.

4.3.3 Replacement Cost

Description of Technique

The replacement cost technique assumes that the costs incurred in replacing productive environmental assets damaged through climate change can be measured, and interpreted as an estimate of the benefits that flow from the assets.

This technique is closely-related to the avertive expenditure technique. The distinction between the two techniques can be made when considering the context where the climate change impact, e.g. loss of habitat, has started. If money is spent in order to avert further losses, or impacts, then the preventative expenditure technique is appropriate. Alternatively, if the expenditure is made in order to restore the environmental asset to its original state, the replacement cost is appropriate. The distinction therefore lies in whether the change in the state of the environment being considered is from its current level to a lower level (to be avoided) or to its original level (to be restored). A further distinction is that the expenditure can be seen as an objective valuation of the impact since the impact has actually occurred, rather than a subjective valuation of the impact perceived to have been avoided. In practice, it may not be easy to distinguish which aspect of the environmental impact a particular expenditure is targeted at, and it may indeed be targeted at both.

Assumptions of Technique

Use of the replacement cost technique assumes that:

- replacement costs are calculable and that, as with the preventative expenditure approach;
- there are no ancillary benefits resulting from the expenditure unrelated to the climate change impact reversed.

The main advantage of the replacement cost approach is that it is relatively simple to use. However, it ignores behavioural responses to the impact in question. Also, the replacement cost **technique obscures the distinction between costs and benefits**. For example, if it is not known that society is willing to pay the estimated replacement cost, then the technique provides an upper estimate of the economic cost of the damage. On the other hand, if the replaced asset does not completely compensate for the environmental loss, then the technique provides a lower limit to the damage cost estimate. Replacement cost approaches therefore do not necessarily bear any relation to ‘true’ social values: individuals’ willingness to pay (WTP) for the replacement/restoration of a damaged asset may be more or less than the costs that would be incurred in doing so.

The replacement cost technique can be used to estimate the cost of both marketed and non-marketed climate change impacts, but relies on replacement measures being available, and the cost of those measures being observable. For example, the replacement cost method is likely to be useful in costing the impacts of climate change on building and infrastructure, but less applicable to habitat/biodiversity or objects of cultural heritage which are essentially irreplaceable.

An example of the replacement cost technique is given in Box 4.7.

Box 4.7: Example of the Replacement Cost Approach to Valuation

General Procedure:

Step 1

Identify and quantify the climate change impact to be valued.

Step 2

Identify and estimate the expenditure incurred to replace (or restore) the asset damaged as a result of climate change.

Step 3

If practical, indicate the value of any ancillary benefits that can be subtracted from the value estimate derived in Step 2. In practice it is more straightforward to indicate their importance in qualitative terms.

Step 4

Calculate the total cost of the impact as follows:

total cost of the climate change impact (£)

equals

the number of affected units

times

the replacement/restoration cost (£ per unit)

Numerical Example:

Step 1

Suppose that as a result of a rise in the mean annual temperature, the rate of deterioration of external building fabrics is predicted to change. Specifically, two million m^3 of external fabric in a region will require maintenance once every 5 years as opposed to once every 10 years. Hence, an additional 0.2 million m^3 of external fabric will require maintenance per year – that is:

$$\frac{2 \times 10^6 \, m^3}{5 \text{ years}} - \frac{2 \times 10^6 \, m^3}{10 \text{ years}} = \frac{0.2 \times 10^6 \, m^3}{\text{year}}$$

Step 2

Assume that maintenance (restoration) costs are approximately £1.20 per m^3.

Step 3

Further assume that in this case the expenditure is a perfect substitute for climate change impact avoided – hence, there are no ancillary benefits.

Step 4

The total cost of increased rates of deterioration of external building fabrics in the affected region is therefore given by (note that this is a recurring annual cost):

$$\frac{0.2 \times 10^6 \, m^3}{\text{year}} \times \frac{£1.20}{m^3} = \frac{£240{,}000}{\text{year}}$$

Relocation Cost Technique

The **relocation cost** technique is a variant of the replacement cost technique. Here, the actual costs of relocating a physical facility or household - because of changes in the quality of the environment – are used to approximate the potential benefits of preventing the environmental change (or the damage cost resulting from the change).

The relocation cost technique can be used, for example, to cost one aspect of water resource scarcity resulting from changing precipitation rates. This may induce a water company to relocate a water intake, which in turn will incur expenditures. The incremental cost of relocation – that is the difference between the total cost streams with and without the 'new' intake - can then be taken as a proxy for the value of the climate change impact on water resource supply.

The relocation cost technique is subject to the same positive and negative points as the replacement cost approach.

Shadow Projects

The **shadow project** approach to valuation can be seen as a particular type of replacement cost, since it attempts to estimate the cost of replacing the entire range of environmental goods and services that are threatened by climate change, by examining the costs of a real or hypothetical project that would provide substitutes for the threatened/lost good/service.

The shadow project technique can be used to estimate the cost of both marketed and non-marketed climate change impacts. It can also be used to help estimate the social cost of adaptation measures – that is, to include some of the externalities that arise from the implementation of selected adaptation projects. The shadow project may be used, for example, when a water company opts to construct a reservoir in order to improve water supply, in the expectation that as a result of climate change, water supply from a river will become less reliable during summer months. The construction of the reservoir may entail the clearance of an area of woodland. The planting and maintenance costs of a 'new' woodland area, which provides the same output of goods and services as the original woodland, can be taken as a proxy for the foregone value of the original woodland. This foregone value is an external cost of the reservoir project.

The ability of this technique to provide a useful cost estimate depends on the human-built alternative being a perfect substitute for the original state of the environment. It is also implicitly assumed that the costs of the shadow project do not exceed the value of the lost productive services of the natural environment.

The shadow project method is subject to the same positive and negative points as the replacement cost approach.

An example of the shadow project valuation technique is given in Box 4.8.

Box 4.8: Example of the Shadow Project Approach to Valuation

General Procedure:

Step 1

Identify and quantify the resource that will be lost as a consequence of climate change or the proposed adaptation measure.

Step 2

Identify and cost a shadow project that will replace the goods and services that would have been generated by the lost resource.

Example:

Suppose that as a result of lower than expected summer rainfalls in an area, a river that is an important trout fishery, will suffer severe low flow problems. Further assume that the low flows will result in the loss of the fishery, among other things.

In the absence of refined data – e.g. the number of anglers affected and their WTP per fishing day – the cost of the lost fishery can be approximated by estimating what it would cost to build a lake, which would afford 'similar' angling opportunities. If the total annual cost of the man-made lake were £20,000, this could be taken as a proxy for the annual damage costs of the impact on recreational angling of low flows. However, note that this does not account for any environmental damages resulting from the construction of the lake - which should be included in the assessment.

4.4 Surrogate and Constructed Market-based Approaches

4.4.1 Introduction

The purpose of this guideline is to provide the user with an overview of valuation techniques that are based on data from **surrogate** or **constructed markets**. These techniques value impacts either indirectly using the market price of surrogates for the affected good/service (e.g. **hedonic analysis** or **travel cost**) or based on values observed in hypothetical or constructed markets for the affected good/service (e.g. **contingent valuation**).

As was explained above, the Green Book states that public sector analysts should generally consider using the surrogate market techniques to estimate values only when no markets for the cost or benefit exist. Similarly, only when there is no evidence available from surrogate markets should evidence from constructed markets be used. The logic of this hierarchy is likely to be one that private sector analysts also adhere to.

The goal is not to provide detailed 'step-by-step' guidance on the application of these methods, since it is unlikely that primary studies will generally be undertaken due to the time and resources that they require.[51] Instead, each of the techniques is briefly described below, in order to provide the user with a basic understanding as to how values reported in the preceding guidelines for use in **benefit transfer** (see Section 4.11) were derived. Those readers familiar with these valuation techniques can skip this guideline.

4.4.2 Hedonic Techniques

Environmental quality often affects the price individuals are willing to pay for certain goods/services. For example, hotels in travel brochures often charge a supplement for rooms with a 'sea view'. Econometric models can be used to examine the contribution of specific 'attributes, including environmental ones,' to property prices or wage rates.

If the hedonic analysis is conducted on housing data, it is referred to as the **property value approach**. When applied to wage data – to measure the value of changes in morbidity/mortality risks – it is often referred to as the (compensating) **wage differential** or **wage-risk approach**.

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[51] In the event that a primary valuation study is required, and the resources exist to conduct such a study, then the user should consult one of the following references: Markandya, Harou, Bellu and V. Cistulli (2000); Freeman III (1993); Garrod and Willis (1999); Ward and Beal (2000); Hanley and Spash (1993); O'Connor and Spash (1999); or the DETR manual on stated preference techniques.

Hedonic Property Value Approach

The hedonic property value approach measures the welfare effects of changes in environmental goods or services by estimating the influence of environmental attributes on the value (or price) of properties. In order to obtain a measure of how a specific environmental attribute of interest affects the welfare of individuals, the technique attempts to: (1) **identify** how much of a property price differential is due to a particular environmental difference between properties; and (2) **infer** how much people are willing to pay for an improvement in the environmental quality and what the social value of the improvement is.

The hedonic property value approach, as it becomes more standardised, is generally applied in a series of four steps (Rosen (1974) and Freeman, (1993)).

STEP 1 – Estimate a Hedonic Property Price Function

In attempting to isolate the effects of specific environmental attributes on house prices we have to 'explain' the price of a house in terms of its key characteristics. If we take house price to be a function of all the physical features of the house (e.g. number of rooms, central heating, garage space, number of bathrooms, etc.), neighbourhood characteristics (e.g. proximity to schools, emergency services, shops, etc.) and environmental attributes (air quality, visual amenity, etc.), then the following relationship can be estimated using econometric techniques:

$$P^h = f\left(S, N, E\right) \tag{4.12}$$

where

P^h = The market price of the property.

f = The function that relates the house characteristics to price.

S = The different structural characteristics of the property.

N = The different neighbourhood characteristics of the property.

E = The different environmental attributes of the property.

This function is the called a **hedonic property price** (or **implicit price**)

function. Fixing the level of all the structural characteristics of a property and the neighbourhood characteristics, we are able to focus on the relationship between the property price and the environmental attribute under investigation.[52]

STEP 2 – Derive the Marginal WTP Function

By partially differentiating the estimated hedonic property price function with respect to *E* we obtain the **implicit price** (or **marginal WTP function**) of the environmental attribute – that is

$$\frac{dP^h}{dE} \tag{4.13}$$

This partial derivative is interpreted as the price paid by the household for the last unit of the environmental attribute, purchased by choosing a given property instead of another one with a unit less of the environmental attribute, *other things equal*. As such, the **marginal WTP function** represents each household's benefit from a *marginal* improvement in *E*. It cannot be used in general however, to determine a *non-marginal* change in *E*.[53] It is therefore erroneous to simply multiply the implicit price for *E* by the expected change in the number of units of *E* in order to estimate the cost-benefit of the change.

A 'second stage' regression is required to identify the relevant inverse demand curve.

STEP 3 – Estimate the Inverse Demand Curve

The desired inverse demand curve is found by regressing the marginal WTP function on the observed quantities of *E* and some socio-economic characteristics of households – e.g. income, size, etc. Basically, one seeks to identify cases where the marginal WTP function varies independently of parameters that can shift the demand curve.

[52] The estimation of a hedonic price function is usually done using a multivariate regression technique. Data are taken either on a small number of similar residential properties over a period of years (time series), or on a larger number of diverse properties at a point in time (cross section), or on both (pooled data). In practice almost all property value studies have used cross section data, as controlling for other influences over time is much more difficult.

[53] Each marginal WTP function represents only *one* observation on the relevant inverse demand curve – from which measures of consumer surplus for changes in E are derived. As a result, only if all the individuals have the same structure of preferences and income will the marginal WTP function be the same as the inverse demand curve.

STEP 4 – Estimate the Change in Consumer Surplus

The area under the inverse demand curve - between two levels of *E* - represents the average change in consumer surplus caused by the expected change in *E*. By aggregating the consumer surplus of all households we obtain the overall value of the change in *E*.

The 'second stage' regression requires a large amount of data from several housing markets – data which are often not available or expensive to obtain. Thus in practice, only the first stage of the process is *usually* carried out, and the resulting cost-benefit estimates treated as first approximations.

A summary of the main steps followed in undertaking a hedonic property value study are outlined in Figure 4.3 below.

Figure 4.3: Step-by-Step Procedure for the Hedonic Property Value Approach

Steps	Assumptions-Notes
1a) Collection of data on prices and houses features	Various methods exist to collect these data. For complex studies these data must be complemented with information on the socio-economic characteristics of households investigated.
1 b) Estimation of the hedonic price function	This relates the price of houses to the characteristics explaining the house price.
2 Calculation of the implicit price of the environmental attribute in question	This is the first derivative of the house price function with respect to the environmental attribute
3 Estimation of the inverse demand curve of the environmental attribute	The price paid is explained by the quantity/quality of the environmental attribute but also by the socio-economic characteristics of households
4. Calculation of the consumer surplus	Integration of the implicit demand curve between the former level of environmental quality/quantity and the new one.

Source: Markandya *et a.l.* (2000)

Wage Differential Approach

The hedonic wage differential or wage-risk method is very similar, and is only briefly described here. Basically, to estimate the relationship between wages and risks we must control for other variables that influence earnings - as in the hedonic property value approach above - except this time we estimate a **hedonic wage function**:

$$W = f\left(Q, \mathrm{X}, \mathrm{R}\right) \tag{4.14}$$

where

W = Wage rate in each occupation.

Q = Qualifications/skills of worker.

X = Job attributes such as unionisation, desirability, etc.

R = Workplace risk, e.g. risk of death.

The partial derivative of this function with respect to R is the **wage premium** for accepting, say, an additional risk of death of 1 in 100,000. To estimate the value of a prevented fatality (VPF)[54] from this, the wage premium is factored by the additional risk (in this case 100,000). For example, if the 'average' wage premium is £20 in this case, then the VPF is given by

$$\uparrow \frac{1}{100{,}000} \times 100{,}000 = 1 \Rightarrow £20 \times 100{,}000 = £2{,}000{,}000 \,.$$

In other words, a population of 100,000 individuals would be willing to pay £2 million to avoid the statistical risk of one premature death among them.

Strengths/Weaknesses of Hedonic Analysis

Hedonic techniques have several advantages over constructed market techniques. Firstly, hedonic analysis uses (surrogate) market, i.e. observed, data on property sales or wage rates. The method is versatile and can be adapted to consider several possible interactions between market goods and environmental quality. Moreover, estimated values obtained from one study can be used in other policy areas if the environments have similar demand and supply characteristics. On the negative side, the results of hedonic studies are sensitive to the econometric assumptions adopted – for example, there is no theoretical guidance as to the choice of functional form, and the empirical results depend critically on the form selected. Furthermore, the assumptions necessary to interpret the results as measures of WTP are restrictive and,

[54] See Section 4.6 for further explanation of the VPF.

in many real world settings, unrealistic. From a practical perspective, full hedonic pricing studies require a considerable amount of data, which may be difficult and expensive to collect; such studies tend to be very time-consuming.

4.4.3 Travel Cost

The **travel cost** method (TCM) is another a technique that attempts to infer values from observed behaviour in surrogate markets. The TCM model, along with its many variants[55], is the most commonly used indirect approach to valuing site-specific levels of environmental resource provision and, to a lesser extent, quality. Information on visitors' total expenditure to visit a site is used to derive their demand curve for the services provided by the site. Among other things, the TCM model assumes that changes in total travel expenditures are equivalent to changes in an admission fee.[56] Given this, the model is used to predict changes in demand in response to changes in 'admission fees', thereby tracing out a demand curve for the site. This demand curve may then be used to measure the total (and average) benefits that visitors accrue from the site.[57]

There are two main variants of the TCM model: (1) the **Zonal** TCM model (ZTCM) and (2) the **Individual** TC model (ITCM). The ZTCM, which is described in Box 4.9, divides the entire area from which visitors originate into a set of visitor zones and then defines the dependent variable as the visitor or visitation rate (i.e. the number of visits made from a particular zone in a period divided by the population of that zone). The ITCM, which is described in Box 4.10, defines the dependent variable as the number of site visits made by each visitor over a specified period.

Box 4.9: The Zonal Travel Cost Model

The basic (**zonal**) travel cost model defines a trip demand curve for a given recreational site from zone j as (Markandya *et al.*, forthcoming):

[55] TC methods encompass a wide variety of models, ranging from the simple single-site TC model to regional and generalised models that incorporate quality indices and account for substitution across sites.

[56] The fundamental insight that drives this model is that if a consumer wants to use the (recreational) services of a site they have to visit it. The travel cost to reach the site is considered as the implicit or the surrogate price of the visit, and changes in the travel cost will cause a variation in the quantity of visits.

[57] The value of the site is not given by the total travel costs; this data is only used to derive the demand curve, from which the consumer's surplus of visitors is calculated.

$$\frac{V_j}{P_j} = f\left(TC_j, X_j\right) \tag{4.15}$$

where

V_j	=	the total number of trips by individuals from zone j to the recreational site per unit of time,
f	=	the function that relates travel cost and socio-economic characteristics to visitation rates,
P_j	=	the population of zone j,
TC_j	=	the travel cost from zone j to the recreational site[58], and
X_j	=	the socio-economic characteristics of the population of zone j, which include, amongst others, factors such as income levels, spending on other goods, the existence of substitute sites, entrance fees and quality indices of n substitute sites[59]

The **visitor** or **visitation rate** V_j / P_j is generally calculated as visits per unit of population, usually expressed in thousand persons, in zone j.

Based on data obtained from a survey of site users, the above equation is estimated using regression analysis. This leads to the creation of a so-called '**whole experience**' demand curve based on visitation rates and *not* the number of actual visits made. To estimate the consumer surplus accruing from the site, the '**whole experience**' demand curve is used to estimate the actual number of visitors and how the numbers would change subject to increases in 'admissions fees'.[60]

The base data set, from which the '**whole experience**' demand curve is created, defines one point on the demand curve for the study site – that is, the intersection of the present zero price line and the demand curve (V_0).

58 Travel cost is the sum of expenditures incurred for gasoline, opportunity cost of time for travelling and for the visit on-site.

59 All these variables allow the estimation of different demand functions according to the socio-economic characteristics of the visitors, thus enabling better estimates of the consumer surplus. In practice they have rarely been used in zonal travel cost studies, being easier to be exploit in individual travel cost models.

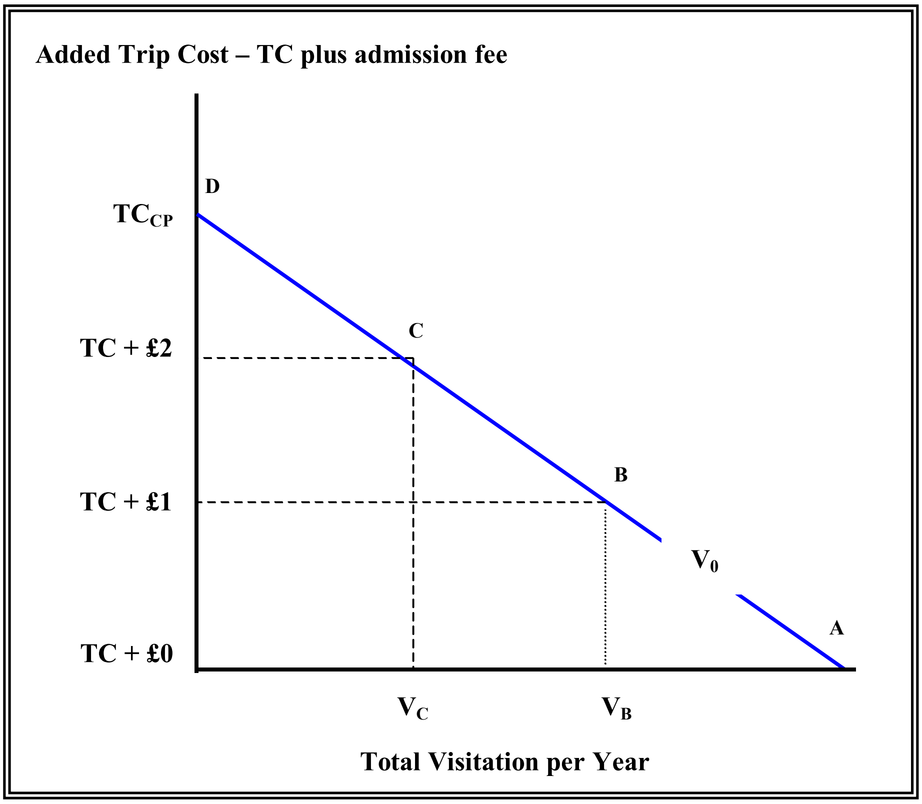
60 In essence constructing a classic inverse demand curve.

In Figure 4.4 this is given by point A, where admission fees or added trip cost is zero.

The remainder of V_0 is derived by assuming that visitors will respond to increases in admission fees in the same way they would to equal increases in travel cost. For each incremental increase in admission fees, the expected visitation rate from each travel origin zone is calculated using the above equation. The 'new' zone-specific visitation rates are then converted to expected numbers of visitors using data on P_j. These values are summed across all travel origin zones to find the predicted total number of visitors to the site at the added trip cost (i.e. original travel cost plus, say, \$1). For example, a \$1 increase in trip costs may lead to point B in Figure 4.4; a \$2 increase in trip costs may lead to point C, etc. This process is repeated until the added trip cost is sufficient to result in zero visitors to the site across all travel zones (the so-called '**choke price**' given by point D in Figure 4.4) – until the entire demand curve (V_0) is traced.

The area under V_0 provides an estimate of the total consumer surplus enjoyed by present users of the study site.

Figure 4.4: Demand Function based on Travel Cost



Box 4.10: The Individual Travel Cost Model

The basic (**individual**) travel cost model relates an individual's annual visits to the costs of those visits – that is (Markandya *et al.*, forthcoming),

$$V_i = f(TC_i, X_i) \qquad (4.16)$$

where

V_i = The number of visits made in a time period, say a year, by individual *i* to the site.

TC_i = Travel cost faced by individual *i* to visit the site.

X_i = All other factors determining individual *i*'s visits (income, time, and other socio-economic characteristics).

This demand function can be extended to allow for the specification of a number of explanatory variables. These include the individual's estimate of the proportion of the enjoyment of the overall trip imputed to the specific site under investigation; the individual's view of the availability of substitute sites; size of the individual's household; and whether the individual is a member of an environmental organisation, as well as other socio-economic data.

Integrating the estimated demand curve between the actual travel cost TC_i and the **choke price** gives an estimate of the individual annual consumer surplus (ICS) for individual *i*. The total annual consumer surplus for the site is obtained by multiplying the ICS by the number of individuals visiting the site annually. The modelling of individual socio-economic features enables the estimation of consumer surplus for different socio-economic groups of visitors. Alternatively, the average ICS per visit can be calculated and then multiplied by the total annual number of visits to the site to get the total annual consumer surplus of the site.

Strengths/Weaknesses of the Travel Cost Method

Like hedonic techniques, the TC method has the advantage that it is based on observed behaviour. Also, TC is a well-tried technique, which is generally accepted to yield plausible results. The individual TC model, the zonal TC model, or similar specifications, have been used to assess changes in site quality, which include the degradation of water quality, changes in fish catches, etc. However, they are more commonly used to value the total benefit of a resource, rather than changes in that resource.

The TC method is not without disadvantages however. To start, in complex situations, especially when changes in environmental quality are being assessed, the data requirements are considerable. Moreover, "*a whole host of issues arises in the specification and estimation of the model and subsequent calculation of consumer surplus, all of which have enormous bearing on the final benefit estimates*" (World Bank, 1998). These issues include the development of multi-site models, the valuation of travel time and the treatment of non-visitors. As a result, TCM studies tend to be conducted as self-standing research studies, with sufficient resources to adequately address these complex issues.

4.4.4 Contingent Valuation Method

In contrast to the valuation techniques described above, which use observed data, the **contingent valuation method** (CVM) relies on structured conversations to elicit directly the values that respondents place on some, usually non-marketed, goods or services. The basic notion underpinning contingent valuation (CV) is that a realistic, yet hypothetical, market for buying or selling the use and/or preservation of a good/service can be described in detail to an individual. Individuals are then asked to participate in this hypothetical market, by responding to a series of questions (see Box 4.11).

Box 4.11: Expressing Preferences in CV Studies

An individual can be asked to express his or her subjective valuation of possible (environmental) changes in different ways:

Improvement. The value of the improvement can be measured either by:

- The individual's maximum WTP to obtain the improvement; or by
- The individual's minimum WTA compensation to forgo the improvement.

Damage. The value of the damage can be measured either by:

- The individual's maximum WTP to avoid the damage; or by
- The individual's minimum WTA compensation to consent the damage.

Adapted from Markandya *et al.* (2000)

The main features of the hypothetical or constructed market include:

- A detailed description of the good/service being valued. The situation before and after any proposed change in (environmental) quality and subsequent provision of the good/service should be clearly stated. In addition, it is vital that the respondents perceive accurately the affected good/service.

- A detailed description of the '**payment vehicle**', i.e. the means by which the respondent would pay for the change in provision of the good/service. The payment vehicle should be appropriate to the good/service and the constructed market. Moreover, it should be realistic and emotionally neutral.

- The procedure to elicit the respondent's valuation. The actual valuation can be obtained in a number of ways, for example by asking the respondent to name an amount, or by having them choose from a number of options. The respondent could also be asked whether they would pay a specific amount. In the case of the latter, follow-up questions with higher and lower amounts are often used. Statistical analysis of the responses is then undertaken to estimate the average WTP in the hypothetical market.

A general approach to follow when running a CV study is outlined in Figure 4.5.

Strengths/Weaknesses of the Contingent Valuation Method

The nature of CV means that, in principle, it can be used to value *any* change in (environmental) quality. Furthermore, CV can be used to accurately elicit values about very specific changes in the provision of goods/services, since it does not rely on observed data. Of course, this requires that the constructed market is correctly described and the elicitation questions appropriately worded. An additional advantage of CV is that, in contrast to the valuation techniques described above, which only provide a partial estimate of the value of a good/service, CV can provide a measure of the TEV of a change in environmental quality.

CV methods have nonetheless been the subject of much criticism, mainly relating to their reliance on hypothetical markets (see Box 4.12). In short, some economists argue that asking individuals hypothetical questions only provides you with hypothetical answers, which cannot be meaningfully used to value environmental quality changes. The controversy following the use of CV to value damages from the 1989 Exxon Valdez oil spill provoked the US Department of Interior and the National Oceanic and Atmospheric Administration to organise a 'Blue Ribbon' panel to assess the validity of using CV to value environmental damage.[61] The panel

[61] NOAA (1993)

concluded that CV could provide useful and reliable information for this type of assessment, as long as certain guidelines are followed. In general, the economic profession as a whole has also given CV qualified acceptance.

In addition to the above conceptual concerns over the validity of CV based cost-benefits estimates, survey-based research is expensive and time-consuming; valid cost-benefit estimates require properly designed sampling and enumeration procedures.

Box 4.12: Concerns Over Elicitation Formats in CV Studies

Several issues concerning the accuracy and reliability of valuations based on CV studies have been discussed in the literature. The major concerns regard the biases inherent in the technique, mainly the distortions in eliciting consumers' preferences. Indeed, in order to obtain answers that reflect the 'true' maximum WTP/minimum WTA of the respondent, different formats have been applied. The main formats are: (1) open-ended questions; (2) bidding games; and (3) dichotomous choice (referendum) questions.

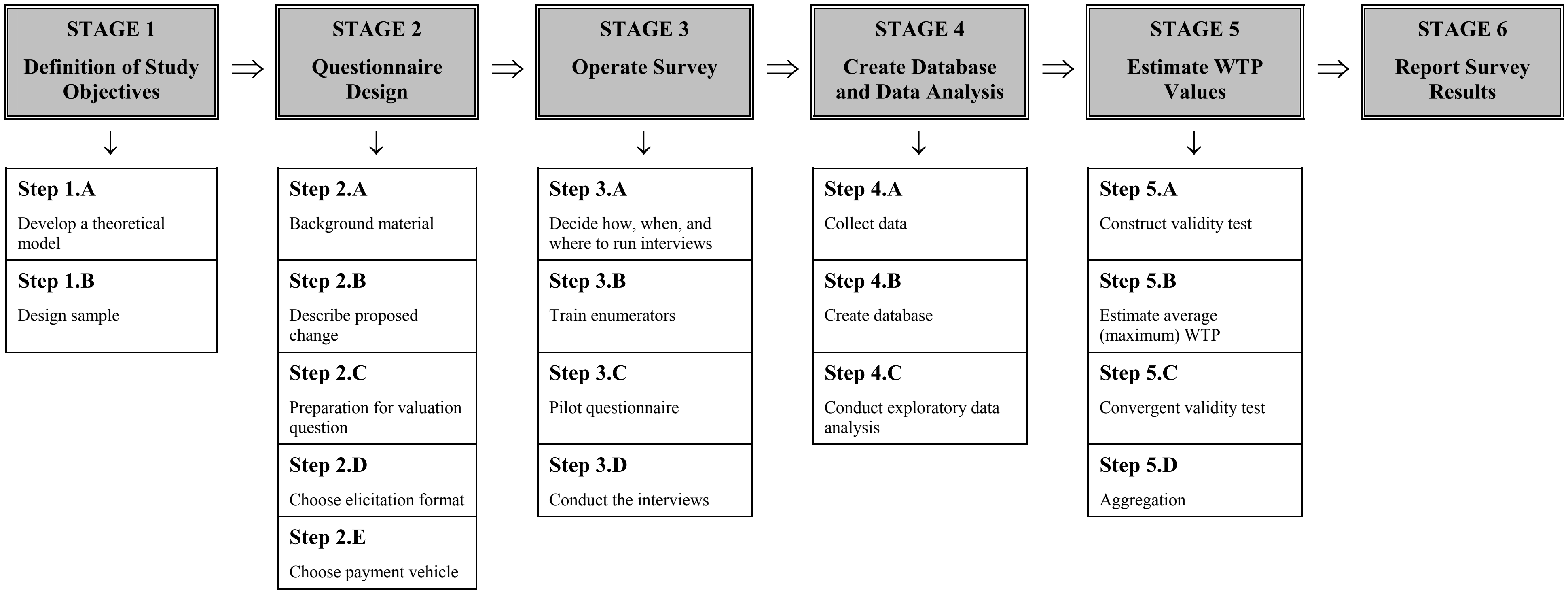
Simple CV exercises can be based on the so called '**open-ended**' elicitation format, where the individual is simply asked to state his or her maximum WTP or minimum WTA for a described change. In this case, simple descriptive statistics (such as means and medians) can be used to obtain rough estimates of values attributed to an asset. However, the main drawback of this approach is the ease with which the respondent can introduce **strategic bias**, i.e. to state a WTP/WTA that is lower or higher than the true one in order to influence the decision-making process for the sake of his or her own gain. A second drawback of the open-ended elicitation format is that the individual may not be prepared to express a value judgement starting without a reference point with which to bound their value judgement.

To avoid a high rate of misleading or missing answers caused by the lack of bounds typical of the open ended format, an iterative technique or '**bidding game'** can be used. In this case the respondent is asked whether (s)he is willing to pay (accept) a given amount of money for a change in the provision of an attribute. If they refuse, the proposed amount is reduced (increased) by a given percentage (say, 10%). The procedure is repeated until the respondent provides a positive answer. The penultimate amount proposed is taken as their maximum WTP (minimum WTA) for obtaining (to give up) the improvement. If instead the individual accepts the proposed amount, it is increased (reduced) by, say, 10%. The procedure continues until the individual answers negatively. Again the penultimate amount proposed is taken as their maximum WTP (minimum WTA) for obtaining (to give up) the improvement. This technique however has the potential to suffer from so-called '**starting point bias**'. It has been observed that the final value judgement is affected by the initial proposed amount. This means that the initial amount somewhat constrains the free expression of the true individual preferences.

To counter starting point bias and strategic bias, the **dichotomous choice** (**referendum**) format is often recommended. Here, a possible range of values for the maximum WTP (min WTA) of individuals is thoroughly researched and pre-set by the analyst. The sample of interviewed individuals is divided into sub-samples. A value within the pre-set range is assigned to each sub-sample. Each individual within a sub-sample is then asked whether they are willing to pay (to accept) the assigned value to obtain (or to compensate for) the improvement (damage). They are not allowed therefore to select a figure as in the case of the open-ended format or to play with subsequent acceptance/refusal answers as in the bidding game format. Besides, they do not know the range of values within which the proposed amount is bounded. In this case however, the outcome of the individual answer is not the maximum WTP (minimum WTA) but only the consent or refusal to pay (to accept as compensation) a given amount of money, i.e. a WTP (WTA) which is not necessarily the maximum (minimum) one. Specific (complex) statistical techniques are therefore required to calculate the average value of the environmental change.

Source: Markandya *et al.*. (2000)

Figure 4.5: Main Stages and Steps in Conducting a Contingent Valuation Survey



Source: Boyd (2000)

4.5 Valuing Loss of Habitat and Biodiversity[62]

4.5.1 Context of Guideline

Changes in climatic conditions and the expected rise in sea level[63] will have implications for the stability and sustainability of ecological systems, and for the plant and animal species that they contain. This guideline first outlines the major sources of economic value of natural habitats and ecosystems. It then summarises some of the effects on habitats and species associated with the expected impacts of climate change. A general methodology is then outlined with which to estimate the value of the effects on habitat and biodiversity of the expected impacts of climate change.

4.5.2 The Economic Services of Natural Habitats and Biodiversity

Natural habitats and biodiversity provide society with a broad range of economic services, and economic values can be attached to these services. This section provides a brief summary of the types of service that habitats and biodiversity provide. Under each of the three broad types of service described here, examples of habitat services pertinent to the UK are provided.

♦ The provision of marketed and marketable goods and services.

  Example: Natural habitats underpin the production of many marketed goods and services, the most obvious being agricultural products. Ecosystems are responsible for providing the conditions in which crops and fodder for animals can be grown, and for maintaining and replacing soils. Biodiversity in agriculture is critical for food security[64] as it contributes to the increased productivity of agricultural systems, and in particular increases the resilience of agricultural systems to environmental variability.

  An example of an indirect service that habitats provide is the hydrological regulatory services provided by forests and other habitats. The fact that these ecosystems absorb water and release it gradually means that, for a given rainfall pattern, the likelihood of

[62] Note that in order to avoid double-counting in aggregation, the user of these guidelines will need to assess which values are attributable to which affected individuals. The user is referred to section 3.2.3 on double-counting.

[63] Watson, Zinyowera and Moss (1997)

[64] Thrupp (2000)

both floods is lower. Thus, the loss of natural habitats is likely to exacerbate the effects of any increase in the irregularity of rainfall.

- Provision of Recreational, cultural and aesthetic values.

  Example: natural ecosystems provide recreational opportunities such as walking and other sporting activities, and the aesthetic pleasure that can be had, for example, from living near to an unspoilt wood, river or lake. See Section 4.7 for a discussion of recreational values.

- Provision of Non-use values.

  The third major type of value is non-use values, as discussed in Section 4.10. These consist mainly of existence value, which is the value that people place on the knowledge that a certain species or ecosystem exists, and bequest value, which is the value that people place on the fact that the current generation will be in a position to leave certain species or ecosystems to future generations.

4.5.3 The Impacts to Habitat and Biodiversity Associated with Climate Change

This section provides an overview of the types of impact on habitat and biodiversity that are expected to be associated with climate change in the UK.[65] One of the most important features of climate change pertaining to habitat and species loss is the speed of change, and the possibility that this change could be faster than the rate at which some ecosystems and species can adapt. Certain changes e.g. in mean temperature, could favour some species over others, and thus change the composition and nature of ecosystems.

Forests, particularly native pinewoods, may be affected by the fact that climate change is expected to occur rapidly, relative to the rate at which trees reproduce and re-establish themselves. In this case, the composition of some forests could change, with new types of ecosystem being established. Inland water systems could be affected by changed water temperatures: Biological productivity could increase, exacerbating the effect of organic pollution from e.g. agriculture. Flows of water are likely to change, and reduced summer flows and increased incidence of droughts could reduce water quality and the life-support capacity of streams.

Coastal Systems, in particular flat coastal systems such as mudflats, are vulnerable to increased sea level rise and in frequency and intensity of extreme events, such as storms. Moreover, protective measures such as

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[65] A principal source is: Hossell, Briggs and Hepburn (2000), Climate Change and UK Nature Conservation: A review of the impact of climate change on UK species and habitat conservation policy. Department of the Environment, Transport and the Regions, UK. 73pp.

coastal defence systems could harm ecosystems further.

Box 4.13 summarises the types of impact to habitat and biodiversity associated with first-order climate change impacts.

Box 4.13: Categories of Impacts to Habitat and Biodiversity

Increased mean temperatures:

Loss of some species as they become out-competed by other species, e.g. loss in Scotland of high altitude sub-arctic willows as a result of temperature rises.

Reduction in water quality and loss of some aquatic species.

Possible invasions of exotic species.

Reduced summer rainfall:

Deterioration in quality, and capacity of rivers and wetland and forest ecosystems to support flora and fauna.

Rising sea levels:

Loss of shoreline mudflats and salt marshes, which could affect internationally significant populations of ducks and geese that stage there during annual migrations.

Increased frequency of extreme events:

Increased risk of habitat (and therefore species) being lost or damaged due to storms or flooding.

Increased levels of pollution associated with increased mean temperatures:

Deterioration of the condition and productivity of all types of ecosystem.

4.5.4 A General Procedure for Measuring the Value of a Change in Habitat and/ or Biodiversity

In this section we outline the steps involved in estimating the monetary value of a change habitat or biodiversity associated with climate change impacts. These steps are summarised in Box 4.14 below.

Box 4.14: Estimating the Economic Value of a Change Habitat/Biodiversity

Step 1

Identify and quantify the impact on habitats and/or species associated with the expected climate change impact.

For example, as a result of reduced summer rainfall one of the expected impacts on habitats is reduced river water quality and thus reduced capacity of rivers to support aquatic species.

↓

Step 2

Identify the types of economic service that are affected by the impact on habitat

For the case of reduced river quality, the values affected would include use values such as recreational and aesthetic values and non-use values such as existence and bequest values, particularly if a high-profile species were at risk.

↓

Step 3

Identify the appropriate monetary value for the change in economic services identified in Step 2, and multiply this by the quantified change in the habitats and biodiversity from Step 1.

The first step is to identify the output of the climate change impact assessment. One major study currently being carried out that will provide the kind of information required for this step is the MONARCH (Modelling Natural Resource Responses to Climate Change) project.

Phase one of this project has been completed and is published[66] and provides a quantitative assessment of the likely direct impacts to species and habitats. Phase two is about to report and uses a downscaling approach in order to provide a detailed understanding of climate change impacts on species' distribution through incorporating climate change and land cover and applying a dispersal model, as well as examining impacts on ecosystem processes. As well as the background study by Hossell et. al., referenced above, a study examining the influence of climate change on the sustainability of grassland is being undertaken through Defra.[67] Another study that has recently been produced documents the practical impacts of climate change on gardens in the UK.[68]

Step 2 involves identifying the economic values associated with a particular habitat. For instance, if a habitat provides recreational values as well as non-use values, and constitutes an input to a marketed good, such as timber, then all these values must be accounted for.

The remainder of this guideline is devoted to explaining the means by which the unit values to be used in Step 3 are obtained. The next sub-section considers each of the habitat and biodiversity economic value categories in turn, describes briefly the methodologies available to measure the values of changes in these categories, and provides estimates of the value of changes in each type of health outcome.

4.5.5 Methods of Valuing Impacts on Habitats and Biodiversity

To place economic values on changes in the quality or quantity of habitats, and on the loss of species, a number of the valuation techniques described earlier in this Section can be applied. The application of these techniques under the heading of each of the main categories of services of habitats and biodiversity is summarised here, and where possible we give examples of values of natural habitat that have been estimated using these techniques.

The Provision of Marketed and Marketable Goods and Services

The unit values of the services of habitats and biodiversity in the

[66] Harrison, Berry and Dawson (Eds.), (2001), Climate Change and Nature Conservation in Britain and Ireland: Modelling natural resource responses to climate change (the MONARCH project): Summary and Technical Reports. UKCIP, Oxford. At: http://www.ukcip.org.uk/model_nat_res/model_nat_res.html

[67] See http://www.ukcip.org.uk/grass/grass.html

[68] Gardening in the Global Greenhouse: Summary and Technical Reports.

At: http://www.ukcip.org.uk/gardens/gardens.htm production of marketed goods and services are generally the most straightforward to estimate, since the products of those services have market prices attached to them. In this section we describe the two major methodologies with which the values of these services can be estimated.

The Input-output Method

This method, discussed in Section 4.2.2, is appropriate for valuing the direct and indirect services of ecosystems in the production of marketed goods. It involves measuring the impact of a marginal change in the availability of the ecosystem service on the production of a marketed good.

One of the early examples of the application of this method to valuing the services provided by natural ecosystems is Barbier (1994) who used the method to value the services of tropical wetlands. Further examples of the method are Williams and Tanaka (1996) who estimated the value of the contribution of topsoil to the production of wheat, and Bell (1997) who estimated the value of the contribution of a saltwater marsh to marine fishing in the South-eastern USA. The results of these studies are presented in Table 4-3.

Table 4-3: Studies Using the Input-output Approach to Valuing Ecological Services

Paper	Habitat	Service/Good	Value
Williams and Tanaka (1996)	Topsoil	Wheat	US$6.5-17 per hectare per year (1996 prices)
Bell (1997)	Saltwater Marsh	Recreational Fishing	US$127-833 per year (1984 prices) (depending on location)

The Replacement Cost Method

This method, described in Section 4.3.3, involves valuing ecosystem services at the cost of the marketed inputs that would be required in their absence. For example, expenditure on the irrigation to replace the hydrological services to agriculture of a lost wetland falls into this category.

The Provision of Recreational, Cultural and Aesthetic Values

Recreational, cultural and aesthetic values are primarily estimated using the Contingent Valuation Method (CVM), the Travel Cost Method (TCM) and Hedonic Analysis. For public sector analysis, the Green Book recommends that the travel cost and hedonic techniques should be considered before the contingent valuation method is implemented. The use of these methods in the context of habitat and biodiversity is described briefly, and some values from studies using these methods are reported.

The Contingent Valuation Method (CVM)

The CVM, as described in Section 4.4.4 is a hypothetical market-based method, and can be used to estimate all types of economic value. In the context of habitat, biodiversity and ecosystem services, the CVM is used to create a hypothetical market for the preservation or restoration of a natural habitat, and respondents to the survey are asked to value the good. Box 4.15 contains an example of a question used in a CVM study of the value of ecosystem and habitat services.

Box 4.15: An Example of a CVM Question in the Context of Habitat Valuation (Loomis, *et. al.*, 2000)

The WTP question used by Loomis et al to value water quality and river habitat was as follows:

"The purchase of water and 300,000 acres of conservation easements along 45 miles of the South Platte river from willing farmers as well as restoring these areas in natural vegetation costs a great deal of money. To fund these actions a South Platte river restoration fund has been proposed. All citizens along the front range from Denver to Fort Collins would be asked to pay an increased water bill (or rent if water is included in your rent) to: (1) purchase water from farmers to increase water for fish and wildlife from 17% … to 42%; (2) to manage the South Platte river … (for) increased ecosystem services

The funds collected can only be used to restore natural vegetation along 45 miles of the South Platte river and purchase water from willing farmers to increase instream flow to improve habitat for six native fish so they are not in danger of extinction.

If the majority of households vote in favour of the South Platte River restoration fund the 45 miles of river would look like ……..(show plan) with increased water quality and fish and wildlife. If a majority vote against, these 45 miles of the South Platte River would remain as they are today. If the South Platte River restoration fund was on the ballot in the next election and it cost your household $_ each month in a higher water bill would you vote in favour or against?

The estimated value for the improved habitat of the 45-mile stretch of the river in the Loomis et al. study was $71million. In another recent study, MacMillan and Duff (1998) investigate the value of restoring two native

Scottish pine forests, in Affric and Strathspey. This showed that the WTP of those supporting a return to forestry was £35 for Affric and £53 for Strathspey. However, in the case of Strathspey, some people preferred the current moorland landscape. Accounting for the compensation they would require meant that the net benefit of the forest landscape fell to £24.

The Travel Cost Method (TCM)

The travel cost method, as described in Section 4.4.3, uses the amount that people spend in visiting a site as the implicit 'price' of a visit. Thus, in the context of habitat valuation, this method can be used to estimate the value of recreational opportunities provided by natural habitats. An example of such a study is Douglas and Taylor (1998), who estimated the non-market benefits of flow-related environmental amenities for Trinity River at $412.1 million annually (1999 prices).

The Hedonic Pricing Method

Hedonic Analysis, as described in Section 4.4.2 can be used to estimate the contribution to the value of a marketed good, often housing, of an environmental asset such as a clean river or a wood. This involves performing a statistical analysis on the characteristics of the marketed good, such as the size of a house, its proximity to facilities etc., and the availability of an environmental amenity such as woodlands or clean air. This approach has been used in many studies, including Mahan et al. (2000), who used it to estimate the value of urban wetlands in Portland Oregon. The value of houses was related to characteristics of houses, their neighbourhoods, and of the local environment, including the distance to urban wetlands. The study estimated that the marginal effect of an acre of the closest wetland on the value of a house was $24.

Another study of this type is Luttik (2000). Luttik used the Hedonic Price method to examine the effect of a variety of environmental attributes on house prices in a various locations in the Netherlands. The study found that houses with a pleasant view, and particularly those overlooking a lake, attracted a considerable premium, up to 28%, over those with less attractive surroundings.

Summary

All of the methods discussed in this section can be used to value the various attributes of natural habitats. The descriptions and examples given are intended to allow users, given the characteristics of a habitat that they wish to value, to identify the appropriate method to use, either in terms of commissioning a primary study, or in terms of looking in the literature for existing studies whose results could be used in performing a benefit transfer, as described in Section 4.11. The paragraphs above have given an introduction to the valuation literature. More extensive literature reviews are available in OECD publications[69] and both Defra and the Forestry Commission continue to fund studies in the UK, and these organizations should be checked with prior to new costing analysis of the impacts of climate change on biodiversity.

The next section provides a numerical example of the valuation of an impact on a coastal habitat.

4.5.6 A Numerical Example: Valuing the Impacts of Coastal Habitat Loss

This example demonstrates the procedure that would be followed in measuring a particular aspect of the economic cost of an impact of climate change, namely the damage associated with habitat loss. There are various causes of habitat loss associated with climate change, but in this example we focus on coastal habitat loss, which could be caused by either a rise in sea level or an increase in the frequency of storms and flooding, resulting in damage to and loss of habitat.

The types of value affected by this damage include:

- Impacts on Use Values - loss of value to both visitors and locals who use the habitat.
- Impacts on Tourism - loss of value to the tourist industry that stems from loss of the habitat
- Impacts on Non-use values - loss to those who valued the existence of habitats without actually visiting them.

Techniques such as the contingent valuation method (CVM) and the travel cost method (TCM) can be used to estimate use values, while non-use values can be measured only using CVM. For impacts on tourism, conventional market techniques can be used to measure the loss in revenue from reduced tourism.

General Procedure:

Step 1 – identify and quantify impact on habitats and/or species associated with expected climate change impact, e.g.:

Indirect impact: Loss/severe damage of 10km of beach line and

[69] 'Handbook of biodiversity valuation: a guide for policy makers' and 'Valuation of Biodiversity Benefits: Selected Studies.'

associated habitats/species.

Step 2 – identify the types of economic service affected, e.g.:

Sectoral impacts: (i) Costs to 500 families – local residents.

(ii) Decrease in tourism by 80% - costs to tourists and tourist industry. Currently 5000 visitors annually, profits to industry being £200,000.

(iii) Loss of non-use values to general population of UK.

Step 3 – identify the appropriate unit monetary value for each change either by employing benefit transfer or by carrying out a primary study, and multiply by the quantified change in habitat. Methods for valuation are described in this guideline, and in more detail in other sections of this report.

(i) Costs to local families: Either carry out primary hedonic price/ CVM study to measure costs, or look for appropriate study in literature and transfer the values to the site of interest. For example, suppose a study measures the decrease in coastal property values due to a damaged coastline at £5000 (a 'one-off', non-recurring loss):

£5000 x 500 = £2,500,000.

(ii a) Costs to tourists: Either carry out primary study, CVM or TCM, or conduct benefit transfer. If the average consumer surplus of a visit to the site is estimated as £40, then annual tourist value is measured as:

£40 x 4000 = £160,000 per year (a recurring loss).

It may also be necessary to carry out a study to estimate the reduction in consumer surplus of those tourists who continue to visit the site.

(ii b) Costs to tourist industry: Use Market Data – annual profits lost can be estimated as:

£200,000 x 80% = £160,000 per year (a recurring loss).

(iii) Non-use values: Conduct a primary study, or identify study(ies) on value of coastal habitat and species. If the individual's average value of 10km of coastal habitat is £0.2, and the population that cares about habitat is estimated at 5 million, then the non-use values lost can be estimated as £1,000,000. (This is a non-recurring loss)

Step 4: Sum the different cost elements. To use the data, the costs must all be of the same type – e.g. annual costs and annualised capital costs, or present value costs and capital costs. Currently the costs under (i) and (iii) are capital costs ('one-off' losses), while those under (ii) are annual costs.

To convert all costs to capital costs, the annual recurring costs should be divided by the rate of discount, or interest, to give the present value of the stream of annual costs in perpetuity. If the rate of discount is 6%, then the capitalised value of the habitat is calculated as:

(i) £2,500,000 + (iia) £2,666,667+ (iib) £2,666,667 + (iii) £1,000,000 = £8,833,332.

This figure can be thought of as the benefits of a measure to prevent the damage, such as a coastal defence system. These benefits can be compared with the costs of intervention, to determine whether the costs of the climate change impact are greater or less than the costs of reducing or eliminating the impact. In this case if the cost of constructing a coastal defence system is less than £8.8 million, then based on the NPV criterion, the results indicate that it is economically efficient for the project to go ahead. Clearly, this is a simplification of a full analysis which would use ranges of values that reflect uncertainties in both the measurement of physical impacts and unit values.

4.6 Valuing Impacts on Human Health

4.6.1 Context of Guideline

A number of the expected climate changes will affect either health or life expectancy or both. The valuation of changes of health outcomes is thus an important aspect of costing the impacts of climate change.

This guideline introduces the type of health outcomes that are expected to be associated with the impacts of climate change. It goes on to explain how these outcomes can be categorised, and how the techniques used to estimate the values of changes in these outcomes vary according to the individual category.

The guideline presents the principal techniques with which the values of changes in health outcomes can be measured, and reports appropriate current values that have been estimated using these techniques. Finally, a worked numerical example is given that demonstrates how the unit values derived can be used to estimate the health costs of a specific climate change impact.[70]

4.6.2 What Impacts to Human Life Expectancy and Health are Associated with Climate Change?

The following is a list of the major impacts in terms of mortality and non-fatal (morbidity) impacts health that are expected to be associated with climate change in the UK. It is based on the findings on this subject reported in Department of Health (2001).[71]

♦ Changes in deaths and illness from heat-waves and heat-stress effects and sunshine intensity. Current research shows that an increase in the frequency of heat-waves is likely to entail an increase in mortality and morbidity, principally in older people due to cardiovascular and respiratory disease. However, for summers with higher mean temperatures but in which heat wave conditions do not develop, a negative relationship between temperature and mortality is predicted. There is also is likely to be a negative relationship between higher winter temperatures and mortality, due to fewer deaths from cold and cold-related illnesses. Whether or not climate

[70] See also Department of Health (1995) Policy Appraisal and Health: a guide from the Department of Health. London

[71] Department of Health (2001), Health effects of Climate Change in the UK, Institute for Environment and Health, Leicester. 290pp. At: http://www.ukcip.org.uk/health/health.html

change leads to a net increase in mortality will depend on the balance of these three effects over time.

- Increased risk of death and illness from food poisoning.

- Increased risk of death and illness from increased levels of air pollutants. It has been established that air pollutant levels rose during the UK heat-wave of 1976, and that this accounted for around half of the marked excess mortality associated with the heat-wave.

- Increased risk of death and injury due to extreme weather events such as storms and floods.

- Increased risk of death and illness from waterborne diseases due to flooding, and from imported cases of malaria and cholera. Whilst there is not thought to be a risk that malaria and cholera could become endemic in the UK, there is a risk that it could once more become endemic elsewhere in Europe. There would therefore be an increased risk of imported cases.

4.6.3 Categories of Impacts on Human Life and Health

In order to estimate more accurately the economic values of these different health outcomes, it is necessary to disaggregate the categories of outcome still further. For example, within the category of mortality impacts, the risk of sudden death is associated both with accidents and with the acute effects of exposure to an environmental hazard such as air pollution or high summer temperatures. The former is applicable to the population at large while the latter tends to affect only those who are elderly or suffering from an existing illness. Box 4.16 summarises the major categories of mortality and morbidity impacts.

Box 4.16: Categories of Mortality and Morbidity Impacts

Mortality Impacts:

Accidental mortality: Sudden death due to an accident.

Acute mortality: Sudden death due to exposure to an infection or another environmental hazard such as air pollution.

Chronic mortality: Death following exposure to an environmental hazard (or infection), with an intervening period of deteriorating health.

Latent mortality: A special case of chronic mortality in which death follows exposure to an environmental hazard, with an intervening period during which health does not deteriorate.

Morbidity Impacts:

Accidental morbidity: Injury due to an accident.

Acute morbidity: Sudden deterioration in state of health due to exposure to an infection or another environmental hazard such as air pollution.

Chronic morbidity: Deteriorating heath following exposure to an environmental hazard or infection.

4.6.4 A General Procedure for Measuring the Value of a Change in Health Outcome

In this section we outline the steps involved in estimating the monetary value of a change in health outcomes associated with climate change impacts. These are summarised in Box 4.17.

The first step is the output of the climate change assessment. The second step involves identifying the category into which the predicted health impact falls, while step 3 involves identifying the appropriate unit value of the health impact and using this to value the aggregate expected impact.

The remainder of this section outlines how the unit values to be used in Step 3 are obtained. The next subsection considers each of the health outcome categories in turn, describes briefly the methodologies available to measure the values of changes in the health outcomes, and provides current estimates of these values.

4.6.5 Methods of Valuing Impacts on Human Health and Life Expectancy

This section describes the main techniques used to estimate unit values for the risks to human life, and impacts on human health, that should be considered in the context of climate change impacts. Further guidance is given in the Treasury Green Book.[72] Techniques are described in turn for each of the impact categories listed in Box 4.16.

[72] http://greenbook.treasury.gov.uk/annex02.htm

Accidental Mortality

The unit value of interest in the case of accidental mortality is the value of a prevented fatality (VPF).[73] The VPF is calculated by taking a WTP value for a given mortality risk and transforming the value to a 'whole death' equivalent. For example, if the estimated WTP for a reduction in the risk of death of 1 in 10,000 is £100, then the value of a prevented fatality is estimated at 100 x 10,000, which equals £1 million. This is the amount that a group of 10,000 people would pay for that reduction, which in turn would be expected to save one life, hence the term 'value of a prevented fatality.'

Box 4.17: Estimating the Economic Value of a Change in Health Value

General Procedure:

The following three-step procedure should be used to estimate the economic value of the impacts of climate change on health.

Step 1

Identify and quantify the change in health outcome associated with the expected climate change impact.

For the case of more extreme temperatures, for example, one of the expected changes in health outcomes is increased mortality in summer from heat-stress.

↓

Step 2

Identify the category into which the change in health outcome falls.

For example, increased mortality from heat-stress falls into the category of acute mortality and will primarily affect individuals who are elderly and/or already ill.

↓

Step 3 : Identify the appropriate economic unit value for the change in health outcome and multiply this by the quantified change in health outcome from Step 1.

[73] Until recently the VPF has been known as the Value of a Statistical Life. However, the label has been changed in order to avoid the impression that the measure attempts to value human life.

The following two principal techniques have been used to estimate this value.

The Contingent Valuation Method (CVM)

One approach to valuing mortality risks involves applying the CVM approach described in Section 4.4.4, and is based on estimating the willingness to pay (WTP) for a change in the risk of death. In this application of the CVM, individuals are surveyed about their WTP and WTA for measures that reduce the risk of death from certain activities, for example driving. This is then converted into a VPF. A recent report for the HSE[74] has used this method.

The Wage-risk Approach

This technique is a type of Hedonic Analysis, described in Section 4.4.2, and identifies a relationship between the risk of death in a job and the wage rate for that job – with the assumption that a higher wage will be needed to compensate for a greater mortality risk. Thaler and Rosen (1975) were the first to point out a positive and statistically significant relationship between these two variables. Since then a large number of studies have estimated the VPF using the wage-risk approach.

The simplest way to use this approach would be to compare occupations that are similar in all respects except for the associated risks. However, jobs are very rarely similar in all respects other than the associated risks. For instance, many of the most common high-risk jobs, such as working on oil rigs, have other undesirable features such as long periods away from home. Thus it is necessary to use regression analysis in which all of the relevant characteristics of each job are included, and a value is derived for each characteristic, including the associated risk. The Treasury Green Book notes that estimates produced by this method are often not very precise.

The value recommended by the Department for Transport[75] for accidental VPF is £1.2 million (2002 prices).

Those at risk of acute mortality impacts, for example from heightened

[74] Beattie, Carthy, Chilton, Covey, Dolan, Hopkin, Jones-Lee, Loomes, Pidgeon, Robinson and Spencer (1999).

[75] See Highways Economic Note No 1. 2000: Valuation of the Benefits of Prevention of Road Accidents and Casualties. At: http://www.dft.gov.uk

levels of air pollution, tend to be elderly, ill or both. At present there are no empirical studies that directly address the valuation of acute mortality in the context of air pollution, though two studies are soon to be published – one by Defra, the other by the European Commission – which will make estimates for the UK. Unit values are therefore of necessity based on those derived for accidental mortality. This literature suggests that the VPF increases with age in early years, reaching a peak at 40-50 years and declining thereafter. This might be partly explained by the fact that income increases with age up to a certain point and declines thereafter. Another explanation is that there is a 'life-expectancy effect' in which people have a lower VPF as they get older and have fewer years to live. A UK government report on the health effects of air pollution[76] has considered these issues, and concluded that the VPF should be adjusted for age.

Before further empirical evidence is made available, the values recommended for use by Defra should be used by public sector analysts. These are presented in Table 4-4 The adjustment factor for ages between 40 and 65 is 1.

Table 4-4: Mean Estimates of VPF for Different Ages as a fraction of VPF at age 40

Age	Multiplier
65-69	1.00
70-74	0.80
75-79	0.65
80-89	0.50
90+	0.35

Chronic and Latent Mortality

Chronic and latent mortality impacts are defined in Box 4.16 of this guideline. In calculating unit values for these impacts by adjusting the accidental mortality VPF given above, analysts need to account for how far into the future the impacts are felt. Specifically, an appropriate discount rate should be used to account for the number of years in the future that the risk will be suffered. There is some dispute in the literature as to the amount by which these values should be discounted, and this is discussed in some detail in the Guideline on discounting in this manual.

It should be noted that in the case of chronic mortality, where the

[76] Department of Health Ad Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution (1999)

individual is ill for a period of time before dying, the appropriate morbidity value for this time period must be included in the total impact costing. A guide to morbidity values is presented in the section below.

Accidental and Acute Morbidity

The full value of illness and injury consists of

- The costs of any expenditures on preventing the illness or on minimising its effects should it occur, and
- The value of time lost,
- The value of lost well-being because of pain and suffering.

The first two components of the full value are measured by the **cost of illness** (COI). The COI is measured as the sum of:

The direct out-of-pocket expenses resulting from sickness (e.g. medicine, doctor and hospital bills)

+

Any associated opportunity costs (e.g. productivity loss/loss of earnings resulting from the sickness).

A recent study undertaken in the UK[77] has produced results that we suggest could be adopted in the context of these guidelines, though these values are not sourced from an official publication such as the Green Book. The mean cost of lost productivity from absenteeism in the UK is calculated at £40/day. The health service costs of a visit to casualty and hospitalisation are given as £55 and £202 per visit, respectively.

The third component of the full value of illness is the value of the effect on welfare of the individual affected. While the COI method outlined above estimates the financial cost of illness, another method is required to measure the welfare costs of illness. The main valuation technique that is used to obtain an estimate of an individual's willingness to pay to avoid an illness is the Contingent Valuation Method. In order to estimate a figure that could be added to the COI figure, the valuation question must refer only to the welfare effects, and not the financial costs of illness. WTP values of the welfare effects of illness from a UK study are given in Table 4-5.

[77] CSERGE, IOS-NLH, IVM, CAS, DAE-UoV (1999)

Table 4-5: WTP Values for Selected Health Outcomes (UK£[1999] per episode)

Health Outcome	WTP Estimate
Hospital	172
Casualty	137
Bed	87
Cough	21
Eyes	15
Stomach	27

Source: CSERGE *et al.* (1999)

Box 4.18 provides an example of a CV questionnaire designed to elicit the welfare as well as the financial costs, that is, the total costs, of illness.

Box 4.18: Example of CV question for Morbidity Valuation

The following contingent valuation survey question was asked in Taiwan in order to gain information about an individual's recent illness episode and associated costs (Alberini and Krupnick, 1995):

Suppose that you were told that, within the next few days, you would experience a recurrence of the illness episode you have just described for us. What would it be worth to you – i.e. how much would you be willing to pay – to avoid the illness episode entirely.

Remember that you are paying to eliminate all your pain and suffering, your medical expenditure, the time you spent visiting the doctor or clinic, your missed work, leisure or daily activities. Bear in mind, if you pay to completely avoid being ill this time, you have to give up some other use of this money. For example, you may reduce your expenditures for entertainment or education.

Additional value estimates relevant to the present context are for accidental injury; the UK DfT recommends the use of these values. They are:

- Serious Injury - £130,000; and
- Slight Injury - £10,000, (at 2003 prices).

These estimates may be relevant to some climate change impacts. For example, injury caused by falling trees in storms would be best valued using these figures.

An illustration of the application of these values in Box 4.19 demonstrates their usefulness.

Box 4.19: Example of Morbidity Costing

Suppose climate change is responsible for a heatwave that resulted in poor air quality, which itself results in an increase of severe asthma cases. Nationally, the heatwave results in 40 cases of hospitalisation for two days, 200 cases of hospitalisation for one day and 400 visits to casualty. Two thousand work-days are lost in total.

The total cost can be estimated thus:

Cost of lost productivity: £40/day × 2000 = £80,000

Health service costs: (£55 × 400) + (£202 × 200) = £22,000 + £40,400 = £62,400

WTP to avoid pain/suffering: (£137 × 400) + (£172 × 200) = £89,200

Total Cost = £80,000 + £62,400 + £89,200 = **£231,600**

4.6.6 A Numerical Example

This example illustrates the use of estimates of the value of a prevented fatality in costing an expected impact of climate change. In this example we wish to estimate the net cost to a UK city, in terms of increased acute mortality, of expected increases in both summer and winter temperatures.

There are three types of health impact that we consider here, namely

(i) Increased numbers of summer deaths due to heat stress.

(ii) Increased numbers of summer deaths due to heat-aggravated pollution.

(iii) Decreased numbers of winter deaths due to cold.

These types of mortality mainly affect the elderly and ill, and for simplicity we assume that the age distribution of all three types of death is identical. Thus, of the net increase in expected deaths per year, 10% are in the under-64 group, 20% are in the 65-69 age-group, 30% in the 70-74 age-group, 30% in the 75-79 age group, and 10% in the over-80 age-group.

We can apply the three-step procedure outlined in Box 4.14 to this impact.

Step 1 is to identify and quantify the change in health outcome associated with the expected climate change impact. In this example, the impact is estimated at 500 extra summer deaths per year due to heat stress and air pollution, and 300 fewer cold-related winter deaths per year. Thus the net increase in deaths is 200 per year.

Step 2 is to identify the category in which the health impact of interest falls. The impacts considered here fall into the category of acute mortality that affects mainly the elderly and ill.

Step 3: is to identify the appropriate economic unit value for the change in health outcome and multiply this by the quantified change in health outcome from Step 1. In this example the value attached to each unit depends on the age at which the expected death occurs. We take the basic value of a prevented fatality as £1,200,000, being the value suggested by DfT, and apply the adjustment factors shown in Table 4-4. Thus, the total annual cost of the impact can be calculated as follows:

Under 64:	200 x 0.10 x £1,200,000 x 1.00	= £24,000,000
65-69:	200 x 0.20 x £1,200,000 x 1.00	= £48,000,000
70-74:	200 x 0.30 x £1,200,000 x 0.80	= £57,600,000
75-79:	200 x 0.30 x £1,200,000 x 0.65	= £46,800,000
Over 80:	200 x 0.10 x £1,200,000 x 0.50	= £12,000,000
Total:		= £188,400,000

Thus, the cost of the net effect of increased mean temperatures on acute mortality in the city in this example can be estimated at £188.4 million per year.

4.7 Valuing Recreation And Amenity

4.7.1 Context of Guideline

Many of the expected impacts of climate change will have important impacts on recreation and on amenity. Such losses should be monetised if we are to try to cost climate change impacts. It may be, conversely, that adaptation strategies bring about benefits to recreation or amenity and these too should be included in the costing exercise.

The guideline identifies examples of the context in which climate change impacts or adaptation strategies result in impacts on recreation and amenity. The impacts are then categorised and the methodology with which the values of recreation and amenity are estimated is outlined.

Values that have been estimated using these methodologies are then reported and a worked numerical example presented, which shows how the values that are available in the literature can be used to estimate the time costs of a specific climate change impact.

4.7.2 What Recreational and Amenity Impacts are Associated with Climate Change?

A sample of the impacts of climate change on recreation that have been identified to date include:

- the effects of low flow of rivers on angling, walking and other river based recreational activity which may result from reduced summer rainfall;
- the effects increased insect activity and other biological reactions which may impact on the recreational quality of visiting forests;
- impacts on coastal recreation of increased coastal erosion, from a combination of increased storm frequency and strength and rising sea levels. Thus, visits to beaches, walking and other activities may be fewer in number and/or yield reduced satisfaction.

These impacts may be seen as reducing the **quality** and/or **number** of visits to a given recreational site. Assessment of these impacts is considered in the next section. Further consideration of the recreational and amenity impacts of climate change is to be found in the regional-based impact studies undertaken under the auspices of UKCIP.[78]

[78] See the regional reports at: http://www.ukcip.org.uk/sub_study/sub_study.html

The amenity impacts of climate change may include reduced forest cover in the surrounding areas, increased noise and other pollution as a result of a climate change induced adaptation policy. Techniques for the valuation of impacts on amenity are discussed later in this guideline.

4.7.3 A General Procedure for Measuring the Value of a Change in Recreational Usage

In this section we outline the steps involved in estimating the monetary value of a change in recreational use resulting from a climate change impact. The techniques that can be used to estimate these impacts are described later in the guideline.

Impacts on recreation of a degradation in environmental quality as a consequence of climate change fall into one of two main categories:

- reduction in benefit derived from a visit; and
- change in number of visits.

Both of these impacts on recreation have to be considered when estimating the recreational impacts of an adaptation option or of climate change itself. In addition, the potential transfer of recreation to other sites should be considered in estimating the economic loss due to climate change or adaptation strategies, otherwise damages may be overestimated.

Approaches for estimating the impacts on recreation of a change in water quality are provided in FWR (1996). A general valuation method is presented in Box 4.20. In essence, this technique is similar to that presented for other impacts, although there is a greater possibility of substitution of one recreation site for another, and this is reflected in the consideration of potential transfers to other sites.

Following Box 4.20 above, we can identify the steps to be taken in estimating the impacts of climate change or adaptation options on recreation in a step-by-step process.

Step 1: Identify the Expected Climate Change Impact

Here one has to take the scientific evidence of the expected climate change impact, e.g. sea level rise or temperature increase.

Step 2: Identify and Quantify the Expected Impact on Recreation

The expected impact of the climate change or adaptation option can be estimated, taking account of **participation rates** and the **average number of visits**. The participation rate is the number of people taking part in the activity and this may decline as a result of a climate change induced reduction in the quality of experience derived from a recreational activity. The average number of visits reflects the number of times that each participating individual takes part in a given recreational activity. Note that the impact of the transfer of a given recreational activity to another site should also be considered, to avoid over-estimation of the damages.[79]

Box 4.20: Estimating the Economic Value of a Change in Recreational Use

The following three-step procedure should be used to estimate the economic value of the impacts of climate change on recreation.

Step 1: Identify the expected climate change impact.

Example: Coastal degradation as a result of sea level rise.

↓

Step 2: Identify and quantify the expected impact on recreation.

Example: The increased rate of coastal erosion may lead to a reduction in the number of visits made.

Note: The possible shift in recreation to an alternative site should be considered.

↓

Step 3: Identify the appropriate economic unit value for the change in recreation; and multiply this by the quantified change in recreation from Step 2.

Example: In our example, an economic value for recreation may be known; this can be multiplied by the total number of trips taken in the changed environment. This can then be subtracted from a baseline case to allow the quantification of the total impact on recreation of climate impact.

[79] Note that there may be external costs arising from transferring to another site, in the form of congestion and so forth, and these will need to be considered.

Step 3: Identify the Appropriate Economic Unit Value for the Change in Recreation

The techniques for estimating the appropriate economic unit value for a change in recreation are investigated in the next section. Broadly they may involve the use of the **contingent valuation method**, the **travel cost method** or **benefit transfer**. For public sector analysts, the hierarchy of application of these techniques should comply with that recommended by the Treasury Green Book.[80]

The above steps are perhaps best illustrated in a numerical example like the one contained in Section 4.11. The exact approach employed in this example is shown in Box 4.21.

This methodology is generally applicable to the valuation of recreational responses to changes in the environment and has been applied in Willis and Garrod (1999) and FWR (1996) to estimate the impacts of water quality on angling and other recreational activities. A similar method could be used to estimate the impact on recreation in forests, on beaches and other recreational pursuits that may be impacted by climate change.

From Box 4.21 it can be seen that if there is a substitute site offering similar recreational amenities located near to the original site, then it may be reduced significantly. This approach is adopted in Willis and Garrod (1999).

Box 4.21: Valuation of Climate Change Impact on Recreation

Annual Cost of Climate Impact on Recreation

=

[WTP per recreational activity at a site (before Change)

x

Number of recreational visits per visitor to a site (before Change)

x

Number of visitors to a site]

-

[WTP per person per recreational activity at a site (after Change)

x

Number of recreational visits per visitor to a site (after Change)

[80] http://greenbook.treasury.gov.uk/chapter05.htm#valuing.

x

Number of visitors to a site]

-

[WTP per person per recreational activity in substitute site

x

Number of increased recreational visits per visitor at substitute site

x

Number of increased visitors after change at substitute site]

+

[Difference in travel cost *x* increased visits to substitute site]

4.7.4 Methods of Valuing Impacts on Recreation

There are various means by which economic values can be placed on costs of changes in the quality of a recreational experience that involve applying the valuation techniques described elsewhere in these guidelines. Firstly, one can derive values for recreation from the construction of surrogate markets, including:

- **Travel Cost**: this technique estimates the value of a recreational activity in terms of the travel cost of reaching the relevant site. A change in visitor numbers, or in the distance travelled by visitors, may result from climate change or adaptation strategies.[81] This technique involves the use of econometric techniques to assess the benefit derived from a given site, and site-specific features. Some authors have suggested that this technique is likely to be appropriate for recreational sites used by local residents. This technique is described in more detail in Section 4.4.3.

Alternatively, if evidence from surrogate market techniques are not forthcoming, constructed market techniques may be utilised.

- **Contingent Valuation**: this technique is applicable in the sense that an individual may place a higher value on recreation if the quality of the environment being enjoyed has degraded as a result of climate change or adaptation strategies. The recreational benefit of the adaptation measure to prevent such damages can be estimated as the difference between the value derived from the activity beforehand and

[81] Some authors have questioned the use of hedonic travel cost methods, and propose the use of **random utility models**, which treat quality of a site as an index which can be examined through the choice of a consumer of one site over other sites. These are distinct from hedonic methods, which consider the site attributes as goods which are combined into a single purchase. The estimation of preferences has been shown to depend on the method used, see Pendleton and Mendelsohn(2000).

the value derived in the case of the damage occurring. This technique is described in more detail in Section 4.4.4.

Alternatively, **benefit transfer** may be applied, whereby values for recreation from one site are transferred to another. There are certain methodological issues involved in this, including the issue of transferability of values from one site to another, similar to the issues raised in the habitat loss guideline. However, careful application of values for similar sites, or through the transfer of a benefit function, may prove the most cost-effective technique of estimating the cost of a given climate change impact or adaptation option. The benefit transfer of recreational values is discussed in Section 4.11.

The following section provides an overview of recreational values that have been measured in the literature.

Estimates of Recreational Values

Estimates of the recreational value of a given site should be treated with care when benefit transfer is being used to estimate the impact of climate change or an adaptation strategy. In this section, some indicative estimates for recreational value in the UK are provided. Water quality and recreation, in particular angling, have been studied in the UK. Studies have also been conducted into the recreational value of forestry and beaches.

Riverside Recreation

Riverside recreation, including angling and walking, has been valued in a number of studies in the United Kingdom. A selection of the main results of these studies is presented in Table 4-6 below. This survey is by no means exhaustive, but the Table does provide some guidance as to the types of studies and kinds of values that may be useful to refer to in estimating the damages from low flow.

Willis and Garrod estimated the recreational benefits of reducing the low flow problem due to over-abstraction in the River Darent in Kent (1995 and 1996) and in rivers in the South West of England (Willis and Garrod, 1999). These recreational benefits included informal recreation and angling.

Another study, conducted by Green *et al.* (1996) as a background to FWR (1996), yielded quite detailed willingness to pay values for different types of fishery that may result from a reduction in the pollution level. The transferability of such estimates should be assessed, as suggested in the benefit transfer guideline.

Forestry Valuation Studies in the United Kingdom

Forestry resources in the United Kingdom have been valued in a number of locations. A number of different attributes have been valued, including recreational use (CVM, travel cost or choice experiment approaches).

Environmental degradation has a detrimental impact on recreational use. However, the studies to date have focused not on environmental degradation, but on the total value derived from having access to the forest. Thus, it is difficult to measure the impacts on forest resources and their associated benefits from climate change impacts or adaptation strategies.

A summary of some of the main studies that have attempted to value forests in the United Kingdom is presented in Table 4-7 below. As the table shows, the values given to forestry resources are quite site-specific, and are dependent on issues such as access as well as the quality of the forest. The Green Book recommends a value of 1.5 per visit to a forest, for recreational use.[82]

[82] See http://greenbook.treasury.gov.uk/annex02.htm and http://www.forestry.gov.uk)

Table 4-6: Estimates of Riverside Recreation Benefits

Recreational Activity	Location	Environmental Impact Assessed	Study	Technique	Value	Notes
Angling	SW England	Improved fishing as a result of low flow alleviation	Willis and Garrod (1999)	CVM	Average angler: **£3.80/day**	Would fish 17.9 more days. Value includes benefit of days on which would have fished with low flow.
				CVM	Syndicate member: **£71.34/yr**	Would fish an additional 28.8 days.
				CVM	Club anglers: **£25.28/yr**	
Angling		Improved coarse fishing	Green and Willis et al cited in FWR (1996) £1996	CVM	Range: **£3.86 - £15.83 per person per trip** depending on improvement from no fishery	£1996
Angling		Improved Trout fishing from case of no fishery	Green and Willis et al cited in FWR (1996) £1996	CVM and estimate	Range: **£7.16-£22.65 per person per trip** depending on improvement	£1996
Angling		Improved Salmon fishing from case of no fishery	Green and Willis et al cited in FWR (1996)	CVM	Range: **£11.58-£25.66 per person per trip** depending on improvement	£1996
Informal visit	SW England	Benefits of riverside recreation: value of a 130km reduction in length of low-flow rivers	Willis and Garrod (1999)	CVM	**£6.16 to £10.78 per household per year**, depending on technique	Values similar for each technique, so suggests results are robust for SW England.
Use and Passive Use Value	40 rivers in England and Wales	Maintenance of current flow in 40 rivers	Willis and Garrod (1995). All figures £1993.	CVM	Residents: **£18.45/hh/yr**	After weighting to remove sample bias: ave £14.31.
					Visitors: **£15.06/hh/yr**	
		Increased flow in 40 rivers			Residents: **£12.32/hh/yr**	After weighting to remove sample bias: ave **£9.38/hh/yr.** All figures £1993.
					Visitors: **£9.76/hh/yr**	
					Non-Visitors: **£12.92/hh/yr**	
	River Darent, Kent	Maintenance of current flow in River Darent			Residents: **£10.19/hh/yr**	After weighting to remove sample bias: ave **£4.64/hh/yr**
					Visitors: **£7.16/hh/yr**	
					Non-Visitors: **£3.85/hh/yr**	
		Increasing flow of River Darent			Residents: **£6.26/hh/yr**	After weighting to remove sample bias ave **£2.75/hh/yr**
					Visitors: **£4.85/hh/yr**	
					Non-Visitors: **£3.00/hh/yr**	

Table 4-7: Selected Forestry Recreation Values

Location	Study	Method	Value	Payment vehicle	Prices
Wantage, Oxfordshire	Bateman et al. (1996)	CVM	£9.94 per household per annum	Annual payment	1991
			£0.82 per adult visit	Per visit, car parking	
Derwent Country Park, Gateshead	Bishop (1992)	CVM	£0.97 Max WTP per visit	Per visit entrance charge	1990
			£18.53 per year	Annual payment	
Whippendell Wood, Watford	Bishop (1992)	CVM	£1.34 Max WTP per visit	Per visit entrance charge	
			£27.03 per annum	Annual payment	
All Forestry Commission Forests 1969-71	Grayson et al. (1975) cited in Benson and Willis (1993)	NS	£0.33 per visitor	Consumer surplus for recreation	1987
Dalby 1975-6	Everett (1979) cited in Benson and Willis (1993	NS	£1.82 per visitor	Consumer surplus for recreation	1987
Gwydyr 1981	Christensen (1983)	NS	£0.53 per visitor	Consumer surplus for recreation	1987
Eight sites in UK	Willis and Benson (1989b) cited in Willis and Benson (1996)	NS	£1.97 per visitor	Consumer surplus for recreation	1988
New Forest	Willis and Benson (1989b) cited in Willis and Benson (1996)	NS	£1.43 per visitor	Consumer surplus for recreation	1988
Loch Awe	Willis and Benson (1989b) cited in Willis and Benson (1996)	NS	£3.31 per visitor	Consumer surplus for recreation	1988
Yorkshire Dales (1)	Bateman et al. (1994)	CVM	£26.03 per resident household per annum and £22.12 per visiting household per annum	Annual payment to preserve landscape	
"Ideal forest"	Hanley et al (1998)	CE	£38.15/household/year	Maximum value based on choice experiment. Used photographs to ask people to rank different choices.	
		CVM	£29.16/household/year		
UK Forests	Willis and Benson (1989)		£1.26-£2.51		1987
Lynford Stag	Brainard et al (1999)	TCM	£1.91 per person per trip	Based on benefit transfer	1994
Queen Elizabeth Forest Park, Scotland	Hanley and Common (1987)	CVM	£1.00 per person per trip	Visitors Permit	1987
60 sites in UK	Hanley and Ruffell (1991)	CVM	ave £0.93 per trip, impact of tree height diversity: £0.33, broadleaf trees £0.49 and water area £0.69	Payment card	1991

Abbreviations

CVM	Contingent Valuation Method
CE	Choice Experiment
HPM	Hedonic Price Method
ITCM	Individual Travel Cost Method
ZTCM	Zonal Travel Cost Method
NS	Not stated

Coastal Recreation in the United Kingdom

Coastal recreation includes such activities as bathing, informal recreation (walking, sunbathing) and water sports. All of these activities may potentially be affected by climate change or adaptation strategies. The erosion of beaches, caused by sea level rise and potential adaptation strategies such as the building of sea walls may negatively impact the enjoyment derived from a trip to the coast. Alternatively, an increase in the mean sea level temperature may increase the enjoyment of bathing. An illustrative set of values for some of these activities is presented in Table 4-8**.** The use of these values in desktop estimation of the value of climate change impacts or adaptation strategies should take account of the fact that many of the studies are site-specific and may be affected to a greater or lesser extent by issues such as the availability of substitute sites, the level of sea pollution and other factors not necessarily related to the climate policy case. Again, this is by no means an exhaustive survey of the valuation studies that have been done for recreation; for further studies see FWR (1996) and the EVRI database. Relevant public sector guidance for this context is provided by the Yellow Manual[83] and the *Flood and Coastal Defence: Project Appraisal Guidance Note* series.[84]

Table 4-8: WTP Valuation for Coastal Recreation

Beach Recreation	UK Beaches	One day recreation	Green et al. (1992) cited in FWR (1996)	CVM	Mean: £7.75	£1988
					North: £5.70	
					South: £9.20	
					Mean: £7.55	£1989
		Mean loss due to beach erosion			£1.90/day	
Beach Recreation	Herne Bay	Loss due to erosion	Tunstall et al (1990)	CVM	£1.82-£7.56 per visit depending on type of visitor	£1990

Tunstall *et al.* (1990) conducted an evaluation of the recreational benefit of the Herne Bay Coast Protection scheme. In a detailed study of alternative measures to protect the seafront they found that the creation of

[83] E Penning Rowsell, C Green, P Thompson, A Coker, S Tunstall, C Richards, D Parker, *The Economics of Coastal Management: A Manual of Benefit Assessment Techniques,* Belhaven Press, London, 1992. The 'Yellow Manual'[8].

[84] http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm

jetties or reefs was preferred to the creation of rock groynes, the former yield an estimated mean gain per visitor of between £1.77 to £3.94, with the latter yielding a loss per visit of between £1.24 and £2.00. This study was based on the contingent valuation method, using drawings of different alternatives to elicit preferences. These estimates also included additional travel costs for those who said they would visit another site.

In addition to the values placed on certain recreational activities, some data are available on user numbers for beaches for informal recreation purposes. A selection of this data is presented in Table 4-9 for illustrative purposes. As the table shows, the range and mean number of visitors vary quite widely from site to site. Thus, in the application of the benefit transfer technique to coastal recreation, care must be taken in the choice of an appropriate value to be transferred. Blackpool, which is a highly polluted beach, attracts vast numbers of visitors. Thus it must not be assumed that the damages resulting from the erosion of a highly polluted beach area will be negligible.

Table 4-9: Visitor Numbers to Beaches

Beach	Study	Mean Number of users	Range
Meols	NRA (1994)	5.9	0-23
Southport	NRA (1994)	26.05	0-200
Blackpool - Central	NRA (1994)	116.9	0-1000
Heysham	NRA (1994)	41.9	0-710
Seascale	NRA (1994)	1.7	0-10
Whitmore Bay	NRA (1993)	201.6	3-800
Caswell Bay	NRA (1993)	124.7	0-450
Llandanwg	NRA (1993)	21.3	0-180

A numerical example of the valuation of impacts on recreation of climate change or adaptation strategies is contained in the Benefit-Transfer guideline (Section 4.11).

4.7.5 A General Procedure for Measuring the Amenity Value of a Change in Environmental Quality as a Result of Climate Change or Adaptation

In this section we outline the steps involved in estimating the monetary value of a change in amenity value due to a reduction in environmental quality, resulting from a climate change impact or adaptation strategy.

Impacts on amenity of a degradation in environmental quality as a consequence of climate change has generally been valued through changes in house prices since direct market prices do not exist. Guidance for public sector analysts on this valuation topic is given in the FWR Manual relating to valuation of river water quality. The FCDPAG series is also relevant in this regard. In essence, climate change impacts may lead to changes in access to sites, the quality of forests and the flow of rivers. These factors all may form part of the 'amenity' value that is captured in house prices. **Note that amenity value may reflect a value placed on informal recreation, so care should be taken to avoid double-counting** (FWR, 1996).

Box 4.22 presents an overview of the technique that may be applied to estimate the amenity value of a reduction in environmental quality resultant from climate change or an adaptation strategy.

Box 4.22: Estimating the Economic Value of a Change in Amenity

The following three-step procedure should be used to estimate the economic value of the impacts of climate change on recreation.

Step 1: Identify the expected climate change impact.

Example: Forest degradation as a result of increased wind storms

↓

Step 2: Identify and quantify the expected impact on amenity.

Example: Establish the number and price of households located near to the affected forest. Quantify the impact on the forest.

↓

Step 3: Identify the appropriate premium for the change in amenity and multiply this by the quantity/quality change identified in Step 2.

Example: In our example, a premium for the decreased amenity value as a result of the forest degradation may be known from previous studies, or a primary study may be commissioned to estimate this value. Multiply this premium by the average house value and the number of houses affected. Note that the premium to be applied may vary with distance to amenity.

Box 4.23 presents a simplified overview of the technique that may be used to estimate the impact on amenity of a climate change impact or adaptation strategy.

The value placed on access to an environmental asset can be seen as a **premium** on the house value. Techniques to assess this premium are discussed in the next section. However, note that this premium may be different for households further away from the environmental asset being valued, and so a more disaggregated approach may be needed. There may be an explicit value placed on direct proximity to a forest or river, and this value would decline with the distance from the asset under consideration. In this case, houses at different distances from the asset should be taken together and the amenity value estimated. (See FWR, 1996).

Box 4.23: Measurement of Climate Change Impact

Annual Cost of Climate Impact on Amenity

=

Average house price in impacted region

x

Relevant Premium for environmental quality

x

Number of affected houses in impacted region

4.7.6 Methods of Valuing Impacts on Amenity Values

Preventative expenditures, relying on market data, can be measured to provide a lower bound estimate of the impact on amenity of a climate change impact or an adaptation measure. For example, the installation costs of double-glazing to reduce the impact of an increase in the noise level due to an adaptation response could be used to estimate the cost of the increased noise level.

In the absence of techniques that rely on market data, and which may be able to capture changes in economic value, one of the main techniques for estimating the impact on the value attributed to the accessibility or enjoyment of sites by householders is the use of the **hedonic pricing method, or HPM.** This technique takes house prices and estimates the premiums placed on the house value as a result of access to or enjoyment of a given facility. Thus, this method can be used to estimate, for example, the implicit value of access to forests. For an example of the application of this methodology to the impact of broadleaf coverage in streets to house values see Markandya *et al.* (forthcoming).

This technique has several methodological difficulties, in that the functional form needs to be correctly specified and the factors affecting house price need to be isolated. Otherwise the impact of the specific environmental asset being valued may not be accurately assessed. These issues, and other issues relating to the application of the hedonic pricing method, are discussed in the guidelines on valuation techniques, and will not be discussed here.

Green and Tunstall (1992) use the **contingent valuation method** to value changes in water quality and the related amenity provided to local residents. This study examined the amenity and environmental values of river corridors in Britain, based on studies of residents living near river corridors. This technique is presented in the guidelines on valuation methods.

Another technique described in FWR (1996) is that of approaching estate agents directly to find out the impact of a change in environmental quality on house prices. This would involve describing the property and change in the ambient environment to the estate agent and asking for the price differential between a property exposed to such an environmental change and one that is not. However, this technique makes the critical assumption that estate agents are aware of the secondary impacts of a change in the environment. Estate agents may be inexperienced in valuing properties with certain environmental assets, and thus the estimated premium may differ from the premium that householders place on that asset.

An alternative to a primary study to estimate the amenity value of an environmental good is to apply **benefit transfer** of the premiums estimated in previous studies. As with the application of benefit transfer to other impacts of climate change or adaptation strategies, care should be taken in the application of such premiums. However, this technique has been used to estimate the amenity damages attributable to river water pollution on an aggregate scale in the UK, and can be fairly readily applied to the climate change or adaptation policy case.

4.7.7 Estimates of Amenity Premiums

Previous studies have identified a number of premiums on house prices due to high environmental quality. These may potentially be applied in the assessment of a climate change impact or in the evaluation of an adaptation strategy. This section will review some of the main literature on amenity premiums in the United Kingdom.

Some of the major studies that have been conducted into amenity premiums are presented in Table Table 4-10 below. The studies to date have not focused on the value of environmental degradation to any great extent, though Green and Tunstall (1992) have attempted to estimate the amenity value attributable to a change in water quality.

Willis and Garrod (1993, cited in FWR (1996) estimated the value placed on living near water, yielding premiums of 8.26% on average for property on the waterfront, and 8.14% on average for property located near to the waterfront, and this estimate should be used by the public sector analyst since the FWR is the only official source of unit values on this welfare impact. Another study, relating to the disamenity of waste disposal and aggregates mining, which may be useful is referenced by the Green Book.[85]

[85] London Economics (1999) *The External Costs and Benefits of the Supply of Aggregates: Phase II.* Report for DETR, now found on the ODPM website (see http://www.odpm.gov.uk)

Table 4-10: Studies on Amenity Value in the UK

Amenity	Study	Method	Result
Forest: All areas UK	Garrod and Willis (1992)	HPM (Amenity Value)	£353,323 amenity value (in addition to consumer surplus benefits) (£1988)
Forest:60 sites	Garrod and Willis (1993)	HPM (Amenity Value)	1% increase in prop. of Forestry Commission land into broadleaf woodland leads to £42.81 increase in the average selling price, 1% increase in mature conifers reduces the selling price of a house by £141. (£1988)
Waterfront	Willis and Garrod (1993, cited in FWR (1996))	HPM (Amenity Value)	8.26% on average for property on the waterfront, and 8.14% on average for property located near to the waterfront.
Canal Frontage	Garrod and Willis (1999)	HPM (Amenity Value)	Midlands: 5.18%; London 2.92%; Adjacent to canal: London 1.46%
Landscape: Central England	Garrod and Willis (1999)	HPM (Amenity Value)	Woodland (20% in 1km radius): 7.1%; Proximity to river: 4.9%, Railway -5.43%
River: River Severn and Yarrow Brook	Green and Tunstall (1992)	CVM	Value of water: if good enough for water birds £546; if good enough to support many fish and flora £562; to be safe for paddling or swimming £582 (£1988)

4.7.8 A Numerical Example

Climate change and adaptation strategies may have negative impacts on the quality of forests in the United Kingdom. Suppose that increased storm activity is expected to reduce the level of forest cover by broadleaf trees in a Forestry Commission owned forest by 10%.

Assuming an average selling price of £60,000 per property in 1988, the change in house price, estimated by Garrod and Willis (1993), represents a -0.11%[86] premium on a 1% reduction in the level of broadleaf forest cover. Assuming house prices are on average £100,000 in 2000, the

[86] This is estimated by dividing the premium of 1988 by the average house price in 1988 (note this is an assumed figure) and multiplying by 100: 42.81/40000*100=0.1070. This provides a measure of the percentage change in the average price of a house as a result of a 1% change in Broadleaf cover.

impact on houses within a 1 km radius of the Forestry Commission site can be estimated. If there are 20 houses in a 1 km radius, following the technique outlined in Box 4.23 above, the amenity value can be estimated as shown in Box 4.24 below.

Box 4.24: Numerical Example of the Impact on Amenity Value of a 10% Reduction in the Level of Broadleaf Trees in a Forestry Commission Site

Average house price in impacted region

£100,000

×

Relevant Premium for environmental quality[87]

1.1%

×

Number of affected houses in impacted region

20

=

'One-off' reduction in house value (cost of climate impact on amenity)

£22,000.

Thus, the amenity impact of a 10% reduction in broadleaf trees in a Forestry Commission site for such a 1 km radius as assumed above is approximately £22,000.

[87] Note that this has been estimated on the basis of a 10% reduction in broadleaf trees due to increased storms. Thus, the premium of 0.11% was multiplied by 10, on the assumption of a linear relationship between house prices and forest cover. Note also that the values used here are indicative only and may not conform to those recommended by the Forestry Commission in this particular context.

4.8 Valuing Impacts on Cultural Objects

4.8.1 Context of Guideline

Changes in regional temperature and other climatic conditions, such as precipitation and wind storms, that are expected to characterise climate change have implications for the fabric and structure of many building and other man-made edifices that are exposed, or are susceptible to, the elements. We therefore use the classification of 'built heritage' to include all types of man-made structures and remains that are thought to have value over and above any functional worth, as a result of historical, artistic or other cultural factors.

This guideline will first outline the major sources of economic value of built heritage before summarising some of the effects associated with the expected impacts of climate change. A general methodology with which to estimate the value of these impacts will then be presented.

The costing methodology consists firstly of the identification and quantification of the expected effects of climate change on built heritage in the UK. The second step is to identify the types of economic value that will be affected by these impacts. The third step is to identify a unit value for each expected effect (either by conducting a primary study or by using the benefit transfer approach) and the final step is to multiply the unit value by the expected change in the quality or existence of the built heritage. The final section in this guideline describes briefly the methods that can be used to identify unit values and presents some values for each type of method that have been reported in the literature.

4.8.2 The Economic Services of Built Heritage

The built heritage provides society with a number of economic services, and economic values can be attached to these services. This section provides a brief summary of the particular types of service that these cultural objects provide as a first step in measuring the economic value of the expected changes to these objects as a result of climate change. Under each of the three broad types of service described here, examples relevant to the UK are provided.

The Provision of Marketed and Marketable Goods and Services

The main marketed service that historic or cultural buildings can have is the provision of residential or business accommodation. Many buildings that are valued by people as having historic significance are also utilised as living and working space, thereby providing an economic service. For example, many of the National Trust properties in the UK, open to the public on a regular basis on account of their historical and cultural interest are also home to small businesses or provide domestic accommodation.

Provision of Recreational, Cultural and Aesthetic Values

Built heritage has been defined above with reference to its value in providing recreational, cultural and aesthetic services. These categories are closely linked, as many sites are visited for their ability to provide all these services simultaneously. Other sites, such as archaeological remains may provide a combination of recreational and cultural services.

Provision of Non-use Values

The third major source of value is non-use values. This consist mainly of existence value, which is the value that people place on the knowledge that a certain historical or cultural artefact exists, and bequest value, which is the value that people place on the fact that the current generation will be in a position to leave certain artefacts to future generations.

4.8.3 The Impacts to Built Heritage Associated with Climate Change

This section provides an overview of the types of impact on cultural and historical objects that are expected to be associated with climate change in the UK.

Buildings

The UKCIP South Eastern Regional Report on potential climate change impacts highlights the fact that an increase in extreme events, humidity and temperature will impact on historical buildings as well as new buildings. An increase in temperature could alter the distribution and severity of fungal and insect attacks on building structures and artefacts. Any materials subject to thermal movement, such as timber framed buildings, could be affected. Cracking of masonry could increase if subjected to regular extreme temperature and moisture variations. Increased wind speed may cause greater potential structural damage particularly to historic roof structures.

The South Eastern Regional Report also suggests that it is likely that the stability of building foundations in the region will be affected by lower ground water and clay soil shrinkage, and by ground effects such as damper sub-soil and rising damp. Timber framed foundations are likely to be particularly vulnerable as they are stable only as long as they remain wet. Repair and underpinning of structures may therefore be required. Furthermore, energy usage will require review, as rising temperatures will cause a rise in humidity within buildings, which could affect artefacts.

More detailed findings relating to the impacts of climate change on the built environment are likely to be forthcoming from the research programme launched recently by the EPSRC.[88]

Archaeology

A chief concern is that a fall in the water table will bring about desiccation, whereby sites dry out, with the potential for losing organic artefacts and palaeo-environmental data preserved by water-logging. Additionally, there may be a risk of losing pollen records, from which information on climate and associated vegetation change can be derived if, the mires within which pollen is currently preserved dry out.

An increase in summer desiccation and winter rainfall may lead to greater scouring of the land and river courses which may, in turn, accelerate the erosion of archaeological sites. Dry land sites will be most affected by secondary impacts such as changes in development pressure and agricultural practice. Coastal sites may be affected by rising sea levels.

Box 4.25 below summarises the types of impact to the built heritage associated with the major first-order impacts expected as a result of climate change.

Box 4.25: Categories of Impacts to Built Heritage

Increased mean temperatures: change in distribution and severity of fungal attacks on fabric of historical buildings.

Reduced summer rainfall: Desiccation of archaeological sites with subsequent loss of historical information. Reduced stability of building foundations.

Rising sea levels: Long term threat to coastal archaeological and e.g. fortressed sites.

Increased frequency of extreme events: Risk to building infrastructure.

[88] See http://www.ukcip.org.uk/built_enviro/built_enviro.html for further details

4.8.4 A General Procedure for Measuring the Value of Changes in Built Heritage

In this section we outline the steps involved in estimating the monetary value of a change in built heritage, which are summarised in Box 4.26.

Box 4.26: Estimating the Economic Value of Damage to Cultural Objects

General Procedure:

The following three-step procedure should be used to estimate the economic value of the impacts of climate change on built heritage.

Step 1: Identify and quantify the impact on built heritage associated with the expected climate change impact.

For the case of an increased frequency of high wind speeds, a likely impact is that in any given locality or region, a certain square meterage of roof area on historic properties will be damaged in a wind storm. In the South West region, for example, it is assumed that 2,000 m^3 of wooden-pegged slates are damaged per annum.

↓

Step 2: Identify the types of economic service that are affected by the impact on the built heritage

For the case of roof damage, accommodation services, recreational, cultural and aesthetic services and non-use services are all affected.

↓

Step 3: Identify the appropriate monetary value for the change in economic services identified in Step 2, and multiply this by the quantified change in the built heritage from Step 1.

A value of £400/m^3 is identified for the total services given by the wooden-pegged slates identified as being at risk.

Total cost of this impact in the South West is £800,000 per annum.

4.8.5 Methods of Valuing Impacts on Built Heritage

The application of the most appropriate techniques under the heading of each of the main categories of services of the built heritage is summarised, and, where possible, examples of the values that have been estimated are given.

The Provision of Marketed and Marketable Goods and Services

The unit values of the services of built heritage in the production of marketed goods and services are the most straightforward to estimate, since the products of those services have market prices attached to them. In this section we describe the two major methodologies with which the values of these services can be estimated, namely the production function method and the replacement cost method.

Production Function Method

The marketed services identified as being provided by historic buildings are residential and business accommodation. Thus, the change in value as a result of a climate change impact can be estimated as resulting change in the annual rental equivalent for the space. If, for example, roof damage resulting from a climate change windstorm renders a section of the property unusable for a period of time, the appropriate value will be the entire rental equivalent for the period.

Preventative and Replacement Cost Methods

This technique, outlined in detail in Section 4.3, is very useful in deriving values in this context, since there exist building techniques and expertise, costs of which are known, to repair and prevent many actual or potential damages to building structures. If the measures are undertaken then these values can be seen as minima. Clearly, if the decision-making context is that of considering adaptation options, these values will not help in deciding whether the option should be undertaken since what is being measured is the cost of the adaptation option.

The Provision of Recreational, Cultural and Aesthetic Values

There are three major methods with which recreational, cultural and aesthetic values can be estimated, namely the Contingent Valuation Method (CVM), the Travel Cost Method (TCM) and the Hedonic Price Method although of these only the CVM is applicable to all types of value. These methods will be described briefly, and some values from studies using these methods reported. Note that the Green Book hierarchy for applying these valuation techniques recommends that CVM should be considered only after TCM and HPM are judged to be inappropriate in the given specific context. The Green Book refers to some specific research that should be reviewed for its relevance when valuing cultural heritage in the context of climate change.[89]

The Contingent Valuation Method (CVM)

The CVM, as described in Section 4.4.4 is a hypothetical market-based method, and can be used to estimate all types of economic value. In the context of the built heritage it can be used to measure the consumer surplus derived by visitors to the particular site, from local residents and from those individuals who value the site's existence but who do not visit it. We are not aware of any studies that have been undertaken that relate specifically to the costs of climate change impacts. However, a number of studies do exist that have attempted to value individual cultural assets.

Table 4-11: Studies Using the CVM to Value Built Heritage

Author	Cultural Asset	Economic Service Valued	Mean Value
Powe and Willis (1996)	Warkworth Castle	Recreation & Education	£1.62/visitor (1994)
		Preservation (user)	£1.41/visitor (1994)
Garrod *et al.* (1996)	Newcastle's Grainger Town	Renovation/restoration (user)	£13.76/resident (1995)
Willis (1994)	Durham Cathedral	All use (access)	£0.88/visit (1992)

The Travel Cost Method (TCM)

The travel cost method is described in Section 4.4.3. It is a technique well suited to valuation of changes in visitor rates and WTP to visit a specific site. It has, to date, been widely used in recreation studies, although not the recreational opportunities afforded by built heritage sites.

The Hedonic Pricing (HP) Method

Residential proximity to particular cultural assets may be reflected in higher property prices. The hedonic price method, described in Section 4.4.2, is therefore likely to be valid in the present context. However, it should be noted that it is, in practice, likely to be very difficult for the analyst to separate out the price effect specific to the change in condition

[89] See http://greenbook.treasury.gov.uk/annex02.htm

of the cultural asset. It is therefore advised that primary studies be undertaken using either the contingent valuation or travel cost methods rather than the hedonic technique.

The Provision of Non-use Values

Non-use values of natural habitats and biodiversity, as noted above, tend to consist of existence and bequest values. By their nature, these values cannot be measured using market-based techniques since they are not associated with market activity. Therefore, as emphasised above, they can only be estimated using the Contingent Valuation Method.

4.9 Valuing Impacts on Leisure and Working Time

4.9.1 Context of Guideline

A number of the expected impacts of climate change will lead to time being lost out of planned work or leisure activities. Such losses should be monetised if we are to fully cost climate change impacts. Conversely, adaptation strategies can bring about time savings, and values for these too should be included in the costing exercise.

The guideline identifies examples of the contexts in which climate change impacts or adaptation strategies result in time losses or savings. The time impacts are then categorised and the methodology that should be used to derive aggregate values of time is outlined.

Techniques that can be used to estimate the unit values are identified, and recommended unit values are referred to. Finally, a worked numerical example is presented that shows how unit values can be used to estimate the time costs of a specific climate change impact.

4.9.2 What Time Impacts are Associated with Climate Change?

The time impacts associated with climate change identified to date primarily affect the transport sector and relate to travel time. Two types of time impacts have been identified as having potentially significant welfare effects:

- The loss of productive, or working time, i.e. time spent in travel that would otherwise be spent on productive work activities.

  Working time may be lost, for example, as a result of disruption to the transport network from climate change-related storm frequency and severity.

- The loss of leisure time, i.e. time spent in travel that would otherwise be spent on leisure activities.

  Leisure time may be lost, for example, as a result of congestion brought about by more trips taken to recreation sites in a warmer mean climate.

These categories have been further disaggregated into different types of in-vehicle travel time and out-of-vehicle travel time, reflecting markedly contrasting results from studies that have assessed these contexts. Where values exist for these categories, therefore, and where the incidence of the climate change effect on these different groups can be estimated, this degree of disaggregation can be undertaken in the costing exercise.

4.9.3 A General Procedure for Measuring the Value of a Change in Time Availability

In this section we outline the steps involved in estimating the monetary value of a change in time availability associated with climate change impacts. These are summarised in Box 4.27. For public sector analysts, further detailed guidance is given in the Treasury Green Book[90] and the Department for Transport Economics Note series.[91]

Box 4.27: Estimating the Economic Value of a Change in Time Availability

General Procedure:

The following three-step procedure should be used to estimate the economic value of the impacts of climate change on time availability.

Step 1

Identify and quantify the change in time availability associated with the expected climate change impact.

For example, damage to a road bridge as a result of severe storms may increase the commuting time to an urban centre by 30 minutes, affecting 15,000 individuals.

Step 2

Identify the category into which the change in time availability falls. In the example given above, commuting time is extended. It is commonly assumed that commuting time should be categorised as work time and values are derived on this basis.

Step 3

Identify the appropriate economic unit value for the change in time availability; and multiply this by the quantified change in time availability from Step 1.

In our example, an economic value for commuting time is known and this can be multiplied by the total time lost in additional commuting time. It may be possible to further dissagregate the type of individual affected, depending on the data available

[90] http://greenbook.treasury.gov.uk/annex02.htm

[91] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504932.pdf

4.9.4 Methods of Valuing Impacts on Time Availability

This section is devoted to explaining the means by which the unit values to be used in Step 3 of the general procedure above are obtained.

The unit value of interest is **time cost/minute**. There are various means by which economic values can be placed on units of time. These involve applying the valuation techniques described elsewhere in the guidelines. The first category of techniques that can be used to derive values of time are the **conventional market-based** techniques, including:

- **Replacement cost** (see Section 4.3.3): This technique is applicable in the sense that an individual may spend an additional amount of money on an alternative, quicker, mode of transport that allows the journey to be completed in the same time as before the disruptive impact. The value of the time saving of the alternative transport mode can be estimated as the additional expenditure required to use this mode.

- **Production function technique** (see Section 4.2): Time is valued according to the wage rate that the individual would receive for a given unit of time. Clearly, this is most appropriate for valuing productive work time that has been lost.

The second category of techniques is **constructed market-based** techniques. Foremost amongst these is:

- the **contingent valuation method** (see Section 4.4.2): in which individuals are surveyed about their WTP and WTA for events or measures that result in a change in time availability.

In the UK, studies of time costs are generally undertaken in the planning stage of a new transport initiative – by a local authority or a national transport provider. The UK DfT[92] publishes standard recommended values for time based on a review of existing studies.

[92] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504932.pdf

Table 4-12: Unit Value of Time (pence/hour – 1998 prices)

Working Time, by vehicle type (in-vehicle):	
Car Driver	2109
Car Passenger	1656
LGV Occupant	884
HGV Occupant	884
PSV Driver	807
PSV Passenger	1341
Rail user	3043
Underground user	2558
Walker	2903
Cyclist	1449
Motorcyclist	1137
Average of all workers	1399
Non-working Time:	
Standard appraisal value	452

The DfT guidance note referenced above also gives current vehicle occupancy rates, those predicted to 2036, and journey purpose splits – both disaggregated for different times of the day and week – that are recommended to be used in any analysis.

It should be noted that valuation of (lost) time can be problematic since it is not always possible to identify whether the lost time is work or leisure. For example, it can be argued that any time not spent working should be seen as leisure time, whilst it can also be argued that when a person would otherwise be working, it is working time foregone. The latter reasoning is adopted in these guidelines.

4.9.5 A Numerical Example

Suppose that climate change has resulted in excessive, prolonged, rainfall, which has led to soil subsidence around the foundations of a road bridge. As a consequence, the bridge has to be closed for ten working days whilst reinforcements are added to the bridge support structure. The bridge closure means that the traffic that would otherwise use the bridge has to find an alternative route. This re-routing of the traffic entails extra journey time and this time loss has an economic welfare value that can be estimated as illustrated below.

Assume that during the rush hour periods of 7.30-9.30am and 5-7pm, diverted traffic is equal to 3000 individuals/hour, adding an average of 30 minutes to the journey time. In this period, 70% of the traffic is commuter/business and thirty percent is leisure.

Between 9.30am and 5pm, 2000 individuals/hour are diverted, adding an average 20 minutes to the journey time. It is assumed, for simplicity, that there is negligible traffic to be re-routed between 7pm and 7.30am.

The following information is assumed to exist regarding the composition of the normal traffic that uses the route across the bridge to enable the data in Table 4-13 to be generated.

Table 4-13: Percentage of Total Individuals Affected

Car drivers	40%
Car passengers	45%
LGV occupants	10%
HGV occupants	5%

Using the unit values suggested by DfT[93] we can calculate the value of the time loss climate change impact **Steps 1 and 2**

In this example, it is straightforward to combine steps 1 and 2 to give the total aggregate time lost for each traffic category. Therefore, for the work traffic affected, the calculation is:

individuals affected per hour

multiplied by

no. of hours

multiplied by

fraction of total in work category

multiplied by

% individuals affected in each vehicle category

equals

total number of individuals affected in each category.

[93] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504932.pdf

Next, multiply this total by the number of minutes (hours) lost for each type of time lost to get the total number of hours lost per vehicle category, and these can be disaggregated further by work and non-work by applying the data given in the DfT guidelines. The results are shown in the following table.

	Cars		LGV		HGV	
Time period	Work	Non-work	Work	Non-work	Work	Non-work
7.30-9.30am	538	2012	264	36	150	0
9.30am-5pm	1011	3238	440	60	250	0
5-7pm	362	2188	264	36	150	0

Step 3

The unit values relevant in this example are given in the table above. The hour totals from steps 1 and 2 should be multiplied by the respective unit values to give monetary totals per vehicle and time categories. These results are summarised in the table below.

Table 4-14 Travel time costs per day (£)

The daily total of £81,391 simply has to be multiplied by ten to give the total time disruption cost.

	Car passengers		Car drivers		LGV		HGV		Total by
	Work	Non-work	Work	Non-work	Work	Non-work	Work	Non-work	time period
7.30-9.30am	4717	4280	5340	4280	2334	163	1326	0	22439
9.30am-5pm	8868	6889	10039	6888	3890	271	2210	0	39054
5-7pm	3175	4654	3594	4654	2334	163	1326	0	19898
Total - by vehicle	16760	15822	18973	15822	8557	597	4862	0	**81391**

4.10 Valuing Impacts on Non-use Benefits

4.10.1 Context of Guideline

The concept of Total Economic Value is discussed in Section 6.3.2. **Total Economic Value** is often thought of as being broken down into Use Value and Non-use Value, where Use Value refers to all direct, indirect, and potential future uses of a good or service, and Non-Use Value refers to Pure Existence Value and Bequest Value. Pure Existence Value is the value the people place on an asset, such as a particular habitat or species, purely on the basis of its existence, independently of any use, or potential future use, of the asset. Bequest Value is the value that people place on an asset due to the fact that the current generation will be able to pass it on to future generations.

This guideline points out the potential importance of Non-Use Benefits in the context of climate change, and provides a general costing methodology with which the monetary values of these benefits may be estimated.

4.10.2 The Changes in Non-Use Values Associated with Climate Change

It was noted in section 2 of this report that in costing the impacts of climate change, care must be taken to consider all of the aspects of value that are affected by an impact. An example of this (illustrated in section II) is of the loss of moor-land, from climate change-induced temperature variations, that is used both for agriculture and recreation. In addition, people may place non-use values on the moor-land habitat. Many impacts of climate change affect assets that are sources of more than one type of value, and for many assets, part of their value is non-use value.

For each impact of climate change to be costed, an analyst must consider the types of value associated with the affected assets, including any non-use values that would contribute to the total economic value of the asset, and thus the cost of its loss or damage. In the climate change context, impacts that are most likely to affect non-use values are those that damage habitats and species, in particular those that are unusual, well-known or well-frequented. For instance, people may place non-use value on maintaining the quality of the UK's coastal waters. Cultural assets such as ancient buildings and monuments are also likely to be associated with non-use values; for instance many people may value the existence of York Minster for its own sake, quite independently of any intention to visit it.

Use values and non-use values cannot be thought of as being mutually exclusive. That is, people might have non-use values for an asset even if they actively use it. Likewise, people who have yet to use an asset, e.g. those who have yet to visit York Minster, may nonetheless place use value on it if they intend to make a visit in future. It is also important, in aggregating the total costs of a climate change impact, to avoid double-counting, by, e.g. including use values in measures of non-use values.

Table 4-15 below provides a selection of climate change impacts from the Coastal Zones and Water Resources Matrices in Section II that have potential Non-Use Values. The table shows that the types of asset that have non-use value are likely to be environmental assets such as natural habitat and ecosystems, sites of special scientific interest and well-known landscapes, as well as manmade assets that have particular cultural value. Many of these assets also have use values, which must be valued separately.

Table 4-15: A Selection of climate change impacts with consequences for non-use values

Climate change Impact	Direct Consequence	Indirect Consequence	Sectoral Impact with Non-use Values
Increased Frequency of Storms and Flooding (Coastal Sector)	Increased Coastal Erosion	Loss/damage of soil	Loss of species/ecosystem
		Loss/damage of beaches/cliffs	Loss of species/ecosystems
			Loss/degradation of cultural objects
		Negative impact on water quality	Impact on coastal/ bathing water quality
	Direct Physical Impact	Damage	Damage to ecosystems
			Loss/Damage to historical/cultural heritage
Sea Level Rise (Coastal Sector)	Permanent Loss of territory	Loss of non-agricultural land	Loss of species/ecosystems
		Flooding of wetlands/marshes	Loss of species/ecosystems
		Loss of land with cultural heritage	Loss of cultural objects
Decreased Summer Rainfall	Low flow in rivers	Reduced reservoir recharge	Damage to habitat/ ecosystems
		Reduced dilution of pollutants	Damage to habitat/ ecosystems
		Reduced groundwater recharge	Damage to habitat/ ecosystems
		Reduced oxygen availability	Damage to river habitats/ species
Increased Winter Rainfall	Increased volume of run-off	Flooding of wetlands/ marshes	

It is important to emphasise, however, that the degree to which the assessment of the different types of value is critical for practical purposes varies depending on the use to which they are to be put. When considering non-use values, the analyst will need to make a judgement as to whether the monetisation of these values is essential, given the difficulties inherent in this measurement. The two following sub-sections give some guidance on these questions.

How should Non-Use Benefits be valued?

Because, by definition, non-use values are not associated with any direct use of or contact with an asset, none of the methods that infer values for an asset or other environmental change from people's behaviour can be applied. Thus, the only approach that can be used to directly estimate non-use values is the Stated Preference method which relies on asking hypothetical questions in a survey format. Principal stated preference techniques include the Contingent Valuation Method (CVM). As Section 4.4.4 of this report explains in more detail, the CVM is a hypothetical market-based method, and can be used to estimate all types of economic value. It involves asking respondents hypothetical questions about their willingness to pay to avoid, e.g. the loss of an environmental asset or gain an environmental improvement. For the measurement of non-use values, the survey design has to ensure that these values are not confused with use values in the mind of the respondent. The procedure for developing the design of a survey is outlined in Section 4.4.4.

In addition to the inherent weaknesses associated with stated preference techniques that rely on hypothetical questions and decisions the derivation of non-use values using these techniques has the additional challenge of ensuring that the use- and non-use value components are separately identified by the respondent. It is also difficult to be certain to be certain as to the appropriate population over which non-use values should be aggregated. Consequently, in practice the monetisation of non-use values remains at a formative stage and few estimates exist for benefit transfer to the climate change context.

One study relevant to the UK climate change impact context that attempts to monetise non-use values is that by Bateman and Langford (1997). They use CVM to estimate the non-use values placed on the Norfolk Broads, which has both national and international importance as a wildlife site. Respondents to the survey were provided with information about the current state of the site, the condition of its flood defences, and the damage to the site that would be likely without action to strengthen the flood defences. The authors note that more than 50% of the respondents had visited the site at least once, which meant that the sample was skewed towards users rather than non-users. The mean willingness to pay to conserve the site was £23.29; willingness to pay was higher for respondents who lived closer to the site, and for higher socio-economic grouping.

It should be noted that the cost-based valuation techniques also implicitly include non-use values in their estimates. For example, expenditure on restoring the storm-damaged exteriors of a cultural asset has the result of restoring the exteriors for both users and others who have no intention of visiting the site but who value its continued preservation. The hierarchy of techniques recommended to be used by the Treasury Green Book in valuing non-market impacts suggests that public sector analysts should consider these cost-based approaches prior to adopting the contingent valuation method. As highlighted in the Guideline on Cost-based measures, values measured using these techniques cannot be used in cost benefit analysis.

When might non-use values associated with climate change be used?

Non-use values are likely to be potentially relevant to two principal situations:

- When greenhouse gas mitigation measures are being appraised and designed. For example, climate change mitigation policy may be subject to cost-benefit analysis. Thus non-use values should be considered in the valuation of the benefits (i.e. reduced future climate change impacts) resulting from this policy. In addition, non-use values may be considered in the design of certain mitigation policy instruments. For instance, a proposed carbon tax that aims to more fully internalize the environmental costs of carbon emissions should consider the non-use components of these environmental costs.

- When project-level decisions have to consider climate change impacts. For example, flood defence schemes might be subject to cost-benefit analysis where – as with mitigation policy appraisal – non-use values should be considered in the valuation of the benefits.

These are two situations where decisions need to be made and where non-use values may potentially be critical. However, given the difficulties mentioned above of identifying the non-use value components and avoiding double-counting with use values, the decision analyst in these contexts must be sure of the need for estimating and including these values in the policy/project appraisal. Guidance on the treatment of non-use values in the project appraisal of flood and coastal defence by public authorities in given in the revised FCDPAG3. This suggests that an assessment of existence values may be necessary where:

1. a proposed scheme protects only an environmental asset from loss or damage, or;

2. a proposed scheme would protect an environmental asset, amongst other properties, but the readily valued benefits are not sufficient on their own to justify a scheme.

These rules may be generalized for the other contexts that we have identified. Thus, existence values should be assessed where they are expected to be significant in the total monetary cost estimate or where their inclusion is thought likely to affect the outcome of the cost benefit analysis. In the latter case, as suggested in the revised FCDPAG3, it may in any case be preferable to "quantify, in non-monetary terms, the relative impact of existence values on the options under consideration, on the basis of consultations with interest groups and the wider public". Alternatively, the 'switching value' of the non-use component can be estimated by identifying the value that this component would have to take for it to affect the decision outcome. On the basis of benefit transfer estimates or a new empirical study, the analyst would then have to decide whether to recommend proceeding with the project/policy or not. In all instances where non-use values are considered representation should – in any case – be made of the uncertainty attached to these values as a consequence of the empirical difficulties.

4.10.3 A General Procedure for Measuring the Value of a Change in Non-Use Values

This section provides a general process for valuing changes in non-use values associated with climate change impacts. These are summarised in Box 4.28 below.

Box 4.28: Estimating Changes in Non-Use Values Due to Climate Change Impacts

Step 1 Identify and quantify the impacts associated with the expected climate change impact.

For example, one of the expected impacts of increased storms and flooding is damage to natural habitat such as forests. All such expected impacts should be measured.

↓

Step 2

From the impacts identified in Step I, identify the impacts to assets that have Non-Use Values.

For the case of damage to natural habitat, these would generally be thought to have some non-use value.

↓

Step 3

Identify the appropriate monetary value for the change in Non-Use Values identified in Step 2, multiply this by the quantified impact from Step 1, and aggregate over the relevant population.

For the case of damage to natural forest habitat, step 1 would identify the amount of expected forest loss. This would be multiplied by the identified unit (non-use) value, and multiplied by the number of people affected.

A Numerical Example: Valuing the Impacts of Coastal Habitat Loss

This section provides a numerical example that demonstrates the procedure to be followed in measuring the non-use values that would be lost following a deterioration in coastal water quality as a result of increased rates of coastal erosion from greater winter storm frequency. The study area is the coast of the North West of England.

<u>Step 1</u> of the costing methodology involves identifying and measuring all of the impacts. These could include:

- Damage in the quality of coastal habitat
- Reduced recreation opportunities – bathing water compromised
- Reduced visitation rates to tourist sites – damage to local tourist industry.
- Damage to commercial and recreational fisheries

Step 2 of the costing methodology involves identifying the impacts that are associated with non-use values. Of the four impacts that have been identified, only the first one, damage to coastal waters and habitat can be thought of as being associated with non-use (as well as use) values. One hundred miles of coastline are expected to be affected.

Step 3 of the costing methodology involves estimating the effects on individuals' non-use values of the deterioration in water quality, and multiplying the estimated costs by the relevant population. In this case we assume that a primary contingent valuation study is carried out, which establishes that the average willingness to pay to avoid the anticipated reduction in coastal water quality for the 100 miles of affected coastline is £3 per household ('one-off' payment) for households in the North West Region, (total households: 2,618,000) and £2 per household ('one-off' payment) in the rest of England and Wales (total households: 13,525,300). These studies are formulated so as to measure non-use values; it is quite conceivable that respondents would place a higher non-use value on environmental assets from their own region than on those from other regions since they are more familiar with the asset.

The total economic value of the non-use benefits lost as a result of the deterioration in water quality is therefore:

£3 x 2,618,000 + £2 x 13,525,300 = £34,904,600 ('one-off' payment).

Thus, the non-use values that would be lost due to the deterioration in coastal water quality in the North West is estimated in this example at almost £35 million. This value may then be added to use value, for example, to give the total benefits of a coast protection scheme.

4.11 The Practice of Benefit Transfer

4.11.1 Context of Guideline

In looking at the impact matrices presented in Section 3, it is clear that a complete assessment of the economic value of climate change impacts in a sector of interest on receptors where there is no market 'price' requires the application of **surrogate** (revealed preference) or **constructed** (stated preference) **market**-based techniques – e.g. hedonic analysis, travel cost or contingent valuation studies. More often than not however, the user will not have the time and resources necessary to design and implement primary studies of these types. Indeed, some economists have suggested that economic analyses should themselves be subjected to a 'benefit-cost' test.[94] In response to this suggestion, and the reasoning behind it, analysts began to investigate whether alternatives to conducting full-scale primary valuation studies existed. The obvious alternative is to apply the results from existing studies to new valuation contexts or locations. Smith and Desvousges (1986) referred to this as **benefit transfer**.

Benefit transfer therefore provides an economical way to cost the impacts of climate change in the context of these guidelines when full-scale primary valuation studies are either not practical or not necessary.[95] Confidence in benefit transfer is reflected in recent additions to the UK literature on the valuation of water resources, which place much emphasis on benefit transfer to value non-marketed goods/services.[96] Moreover, the Green Book states that: "*the results of previous studies may sometimes be used to estimate the economic value of changes* […] *although care must be taken to allow for different circumstances*."

In this guideline we explore the key issues arising from the use of benefit transfer. Specifically, we formally define benefit transfer, outline the main approaches, identify sources of error in transferred values, and discuss how we can test their reliability. We also identify the main data sources for use in benefit transfer.

4.11.2 Defining Benefit Transfer

While there is no single accepted definition of benefit transfer, in these

[94] That is, a study should not incur costs beyond the point where the cost of improving the study's quality – e.g. perhaps through the implementation of a primary contingent valuation survey – exceeds the expected benefits. See, for example, Freeman III (1984)

[95] In other words, they fail the 'benefit-cost' test alluded to above.

[96] See, for example: EA (1997); EA (1998a); EA (1998b); FWR (1996); and UKWIR (1998).

guidelines we define the term as the use of existing estimates of non-market values derived in one context/location to estimate values in a different context/location. The context/location in which the original estimates were obtained is often referred to as the **study site**; and the context/location to which the original estimates are now to be applied, is known as the **policy site**.[97] Benefit transfer is therefore the practice of adapting available estimates of the economic value of changes in the quality or provision of a non-marketed good/service at a study site(s), to evaluate a change in the quality or provision of a 'similar' good/service at a policy site(s).

4.11.3 Methodology of Benefit Transfer

Benefit transfer usually proceeds in seven steps.[98] These steps are presented in Figure 4.6 and discussed below.

Step 1

The first step is to define the value(s) to be estimated at the policy site. This in turn requires you to identify the **specific good** or **service affected** by the climate change impact(s) of interest - identified with the aid of the impact matrices in Section II. What type of land is lost? What type of habitat is damaged? What specific crops will experience yield reductions? What specific recreational activities will be impaired?

Step 2

In the second step you will need to conduct a thorough **literature review** to identify valuation data relating to the specific good(s) or service(s) identified in Step 1. For example, if wetland habitat is damaged, then you will need to identify studies, which value individuals' WTP to avoid damage to wetlands. Potential sources of such valuation data are identified in the Annex to this section below.

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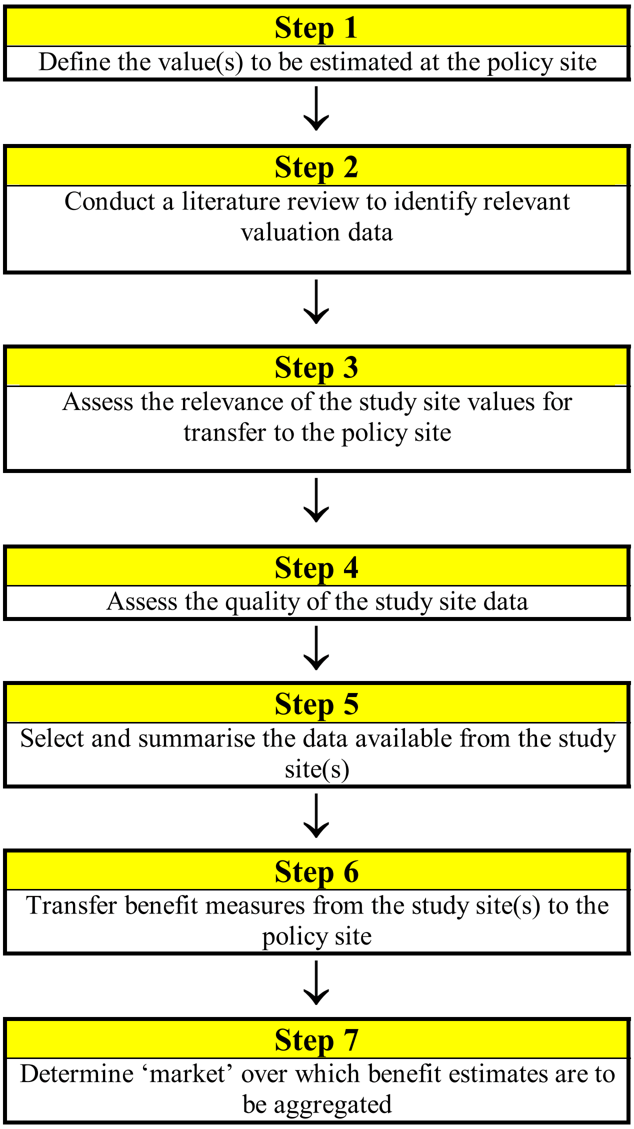
[97] This terminology was first introduced by Desvousges, W., M. Naughton and G. Parsons (1992)

[98] Boyle and Bergstrom (1992); Kask and Shogren (1994); and Desvousges, Johnson and Banzhaf (1998).

Figure 4.6: The Benefit Transfer Process



Step 3

Step three involves assessing the **relevance** (suitability) of the study site values for transfer to the policy site. This requires you to consider a number of criteria. The suitability of the original valuation data to the problem at hand depends primarily on how similar the study site is to the policy site with respect to: (a) the magnitude of the environmental change; (b) the environmental good/service in question; (c) the socio-economic and cultural characteristics of the affected population; (d) the availability of substitutes; and (e) the assignment of property rights (this will dictate whether WTP or WTA is the appropriate welfare measure to use).

Step 4

After ascertaining the relevance of the study site values for transfer to the policy site, the fourth step involves assessing the quality i.e. **scientific soundness** and **richness of information** of the study site estimates (see Table 4.16 below, which identifies specific criteria for evaluating existing studies.) After all, the estimated values at the policy site are only as accurate as the study site values upon which they are based; measurement error implicit in the original values is compounded when applying benefit measures or valuation functions in the new situation.

Table 4.16: Criteria for Evaluating the Quality of Candidates for Transfer

Scientific Soundness – the transfer estimates are only as good as the methodology and assumptions employed in the original studies	
Specific criteria:	Data collection procedures
	Sound empirical practices
	Consistency with scientific and economic theory
	Appropriate and rigorous statistical methods
Relevance - the original studies should be similar and applicable to the 'new' context	
Specific criteria:	Magnitude of impacts should be similar
	Baseline levels of environmental quality should be comparable
	Affected good(s) or service(s) should be similar
	The affected sites should also be similar, where relevant
	The duration and timing of the impact should be similar
	The socio-economic characteristics of the affected populations should be similar
	The property rights should reside with the same party in both contexts
Richness of Information - the existing studies should provide a 'rich' data set and accompanying information	
Specific criteria:	Include full specification of the original valuation equations, including precise definitions and units of measurement of all variables, as well as their mean values
	Explanation of how substitute commodities were treated, where relevant
	Data on participation rates and extent of aggregation employed
	Provision of standard errors and other statistical measures of dispersion

Source: Desouvsges, Johnson and Banzhaf (1998)

Step 5

The next step is to select and summarise data from the existing valuation studies for transfer. Frequently only a single relevant valuation study exists, in which case selecting a 'best' benefit measure to transfer presents few problems. However, when several relevant studies are available, the selection process becomes more problematic. You could still attempt to identify a 'best study', but this approach ignores other, potentially valuable, information contained in the studies neglected. In order to take advantage of all the information available, other approaches to transfer have been developed to utilise data from multiple studies.

- First, you could develop a range of parameter and benefit estimates from the available studies. For example, you could search the existing studies to identify a low estimate, which would define a lower bound for the transferred data; and likewise use a high estimate from the existing literature to define an upper bound.

- Second, you could collect data from the existing literature and develop simple descriptive statistics of model parameters and benefit estimates - e.g. mean and standard errors - and transfer these data to the policy site.

- Third, you could adjust these measures of central tendency - based on expert (subjective) judgement - and transfer the adjusted data.

- Fourth, in order to take full advantage of the information available from multiple studies, you could undertake some form of **meta-analysis** to develop a 'new' benefit model for transfer.[99]

It should be noted that the analyst must consider whether the available data are of sufficient quality to be used in the new context. It may be the case that no studies are identified as appropriate for benefit transfer purposes.

Step 6

The sixth step involves actually transferring the benefit measures from the study site(s) to the policy site(s). Most benefit transfer methods utilised to date involve either the **benefit value** or **benefit function** approach.

<u>Benefit Value Approach</u>

In the most basic application of the **benefit value approach**, a scalar-

[99] In short, meta-analysis allows analysts to identify 'criteria' for improved benefit transfer, by using the entire data set available in order to determine those factors exerting the greatest influence on variances in WTP estimates across all studies. For an introduction to meta-analysis see, for example, Eddy, Hasselblad and Shachter; or Rosenthal (1991)

The use of meta-analysis for benefits transfer is discussed in: Desvousges, Johnson and Banzhaf (1998); and Van den Bergh and Button (forthcoming).

An example application of meta-analysis, which considered the use and non-use values generated by wetlands across North America and Europe, is found in Brouwer, Langford, Bateman and Turner (1999) valued 'best' estimate (typically, the mean or median WTP per affected unit) is used to represent the results of an existing study, or selection of existing studies, that have been conducted in a specific context. The average consumer surplus per angling trip, for example, might be taken from a travel cost study, which assessed the benefits of recreational angling at a specific site. This unit value could then be used to value a change in the quality or provision of recreational angling opportunities at different locations. Specifically, the total cost-benefit of a change in recreational angling opportunities at the policy site is equal to the predicted change in the number of angling trips made to the site multiplied by the corresponding measure of average consumer surplus per angling trip.

To improve the quality of the benefit value transfer, you could make some adjustment to the scalar-valued estimate. These adjustments are typically *ad hoc*, and usually reflect the subjective judgment of the analyst. Brookshire (1992) makes some suggestions to help guide such adjustments.

An example application of the **benefit value approach** is provided in Box 4.30.

Benefit Function Approach

With the **benefit function approach**, an empirical relationship (function) between WTP and characteristics of the affected population and the resource being assessed is specified.[100] The entire function is then transferred to the policy site and adjusted to conform as closely as possible with to the population and resource characteristics at that site. The adjusted valuation function is in turn used to value changes in the quality or provision of the resource in question – data from the policy site are substituted for the right-hand-side variables in the valuation function. A travel cost demand model for angling trips estimated at the original study site, for example, may be used in conjunction with the average travel costs, income, water quality conditions, etc. at the policy site, in order to estimate the recreational angling dis/benefits of a deterioration or improvement in water quality at that site.

Benefit function transfer may thus be seen as a way of making the *ad hoc* adjustments to scalar-valued estimates more systematic, since you can explicitly control for differences between the existing literature and the policy context with respect to e.g. environmental quality, site attributes,

[100] These empirical relationships typically come from one of two sources: (1) the user can use either the valuation function from the study site(s) directly, or create a reduced form valuation equation from a statistical summary of the original valuation function(s); or (2) the user can employ regression techniques to estimate a 'new' valuation relationship based on data that generally uses summary statistics from the original sources, and includes characteristics of the affected resource and population, and the original valuation techniques used. As mentioned above, this latter approach is referred to as **meta-analysis**.

and socio-economic characteristics.

Even in the case of benefit function transfer - whether based on the transfer of equations from individual studies or 'new' models derived from meta-analytical techniques - you may still feel that the parameters in the transferred valuation model are not fully applicable to the policy context. As with the transfer of scalar-values, you may decide that adjustments to the model parameters are required. Again these adjustments tend to be *ad hoc*, but protocols have been suggested in the literature, essentially to make such adjustments systematic.[101]

An example application of the **benefit function approach** can be found in Crutchfield, Feather and Hellerstein (1995).

Step 7

The final step is to determine the so-called 'market' over which impacts at the policy site are **aggregated** in order to obtain a measure of **total** cost-benefit. Desvousges, Johnson and Banzah (1998) identify three interdependent issues that must be considered during the aggregation task:

- The **geographical extent** of the affected 'market'.[102] In some cases this may be defined by geographical (e.g. river catchments) or political boundaries (e.g. counties), it may also be based on the extent of the predicted physical impacts (e.g. the area at risk to increased flooding or coastal erosion).

  Another possibility is to define the geographical boundaries of the costing analysis as the point where individuals' WTP in respect of the affected good/service decays to zero. Some empirical evidence is emerging that indicates a negative relationship between WTP for the services provided by a resource and distance to that resource.[103] Consider the example given in Box 4.29 below.

- Related to the geographical boundaries of the transfer, is the **number of affected units** (or **receptors**)- e.g. households, building types, varieties of agricultural products, etc. - within the geographical 'market'. In some cases the identification of the affected population will be obvious - e.g. all buildings in a floodplain or all households receiving potable water from a particular water supply company. In other cases however, it may be

[101] See, for example, Cameron (1992).

[102] This is referred to as the **exposure unit** in Willows and Connell (2003).

[103] See, for example: Pate and Loomis (1997); Bateman and Langford (1997); and Bateman, Georgiou and Langford (1998).

necessary to identify participation rates for certain affected sub-groups - e.g. the number of day trips expected to an affected recreation site per year. A useful set of guidelines for estimating participation rates in selected recreational activities, in the absence of site-specific data, is presented in EA (1997).

- In determining the total cost-benefit of a climate change impact on a specific exposure unit it is also important to take possible **substitute** goods/services into account. Other things being equal, a good or service will have a higher value, the fewer alternatives that are available. Adjusting for the availability of substitutes is particularly relevant in the context of impacts on services provided by natural resources - e.g. recreation activities. EA (1997) provides some guidance on adjusting participation rates to account for the availability of substitute recreation sites.

In general, identifying the relevant 'market' for aggregation at the three levels listed above will inevitably require some 'new' data from the policy site.

Box 4.29: Example of How Distance Decay Relationships Can be Used to Define the Geographical Boundaries for Aggregation[104]

Suppose that a contingent valuation study of the recreational use value of a park yielded the following relationship between WTP and distance to the park:

$$WTP = 65.8 - 0.35km$$ [105]

Rearranging the above equation we can find the distance from the park at which WTP equals zero. This can then be used to define the geographical area which that should encompass all individuals that have a positive valuation of the park. Hence,

$$0 = 65.8 - 0.35km = \frac{65.8}{0.35} = 188km$$

In this case, a circle with a radius of 188 km should encompass all individuals that have a positive valuation of the park. We could then define the **geographical extent** of the affected 'market' as 188 km from the policy site.

[104] This example is adapted from Moran (1999)

[105] A number of distance decay relationships are given in Bateman, Georgiou and Langford (1998).

Box 4.30: Example Application of the Benefit Value Approach – the Case of Recreational Angling

As a consequence of climate change-induced deterioration in water quality in a catchment, assume that a river reach in this catchment can no longer support a ‘good’ quality non-migratory salmonid fishery; rather water quality is expected only to be sufficient to support a ‘good’ quality coarse fishery.[106]

One approach to valuing the cost of the deterioration in water quality on the fishery – in terms of the recreational angling benefits forgone – is to estimate the total WTP for recreational angling before the deterioration (without climate change) and the total WTP for recreational angling after the deterioration (with climate change), and take the difference between the two WTP valuations.

Let us assume that we do not have the resources to conduct a primary valuation study to ascertain ‘the WTP per angling trip’ and how visitation rates to the affected river reach will change as a result of the change in fishery class, and must therefore transfer existing benefit measures to the policy site. In this example we will utilise the most basic version of the benefit value approach.

General Procedure:

In this case study the general approach consists of the following two steps.

Step 1 - Determine the ‘market’ over which costs (foregone benefits) are to be aggregated:

[106] The assumed average density of >20 cm fish in a ‘good’ (T1) non-migratory salmonid fishery is >2.0 fish per 100 m^2. The assumed average biomass of a ‘good’ (C1) coarse fishery is >2,000 g per 100 m^2 (FWR, 1996).

Annual number of angling trips after the deterioration (with climate change)

equals

Visitation rate after the deterioration (with climate change)

times

Number of affected anglers

Annual number of angling trips before the deterioration (without climate change)

equals

Visitation rate before the deterioration (without climate change)

times

Number of affected anglers

Step 2 - Calculate the foregone recreational benefits as follows:

Annual cost (foregone benefits) to recreational angling

equals

[WTP per angling trip after the deterioration (with climate change)

times

Annual number of angling trips after the deterioration (with climate change)]

minus

[WTP per angling trip before the deterioration (without climate change)

times

Annual number of angling trips before the deterioration (without climate change)]

Calculations:

Step 1

Assume we have data on the number of anglers that currently use the site: 100 individuals who define themselves as predominately coarse anglers; 80 predominately trout anglers; and 40 predominately salmon anglers. We therefore need data on predicted visitation rates before and after the deterioration in water quality. Suppose our literature review obtained the following 'best' estimates from FWR (1996):

- predominantly coarse anglers will make an average of 21.28 trips per person per year to a C1 fishery and 3.83 trips per person per year to a T1 fishery;
- predominantly trout anglers will make an average of 8.76 trips per person per year to a C1 fishery and 10.98 trips per person per year to a T1 fishery; and
- predominantly salmon anglers will make an average of 1.16 trips per person per year to a C1 fishery and 18.40 trips per person per year to a T1 fishery.

The required calculations are summarised in Table 4.17.

Table 4.17: Changes in the Number of Angling Trips per Annum

Climate Change Case	Predominately Coarse Anglers	Predominately Trout Anglers	Predominately Salmon Anglers
Number of affected anglers (persons)	100	80	40
With Climate Change (C1 fishery):			
Visitation rate (trips/person/year)	21.28	8.76	1.16
Total trips (person-trips/year)	2,130	701	46
Without Climate Change (T1 fishery):			
Visitation rate (trips/person/year)	3.83	10.98	18.40
Total trips (person-trips/year)	380	878	736

Step 2

In order to implement this step we need data on the WTP per angling trip before and after the deterioration in water quality. These data must be disaggregated by type of angler (i.e. coarse, trout and salmon) and by type of fishery (C1 and T1). Again, suppose our literature review obtained the following 'best' estimates from FWR (1996):

- predominantly coarse anglers are WTP an average of £6.21 per person-trip to a C1 fishery and £11.86 per person-trip to a T1 fishery;
- predominantly trout anglers are WTP an average of £7.16 per person-trip to a C1 fishery and £16.28 per person-trip to a T1 fishery; and
- predominantly salmon anglers are WTP an average of £11.58 per person-trip to a C1 fishery and £18.70 per person-trip to a T1 fishery.

The required calculations are summarised in Table 4.18. The cost of the climate change-induced deterioration in water quality, in terms of foregone recreational angling benefits, is therefore given by:

+£8,650 + (- 9,300) + (-13,270) = -£13,920 per year.

Note that this represents only a partial estimate of the cost of the deterioration in water quality – many other exposure units might be affected – e.g. other forms of recreation, industrial abstractors, agriculture abstractors, etc.

Table 4.18: Estimated Annual Cost (Foregone Recreational Angling Benefits) of Deterioration in Water Quality

Climate Change Case	Predominately Coarse Anglers	Predominately Trout Anglers	Predominately Salmon Anglers
With Climate Change (C1 fishery):			
Total trips (person-trips/year)	2,130	701	46
WTP (£ per person-trip)	6.21	7.16	11.58
Annual angling benefits (£ per year)	13,200	5,000	530
Without Climate Change (T1 fishery):			
Total trips (person-trips/year)	380	878	736
WTP (£ per person-trip)	11.98	16.28	18.70
Annual angling benefits (£ per year)	4,550	14,300	13,800
Climate Change Impact (with – without):			
Foregone angling benefits (£ per year)	+8,650	-9,300	-13,270

4.11.4 How Good Are Benefit Transfers?

It is apparent from the above description of the benefit transfer process that there are two general sources of error in the estimated values: (1) errors associated with estimating the original WTP/WTA measure at the study site(s); and (2) errors arising from the transfer of these study site values to the policy site. Concerning the former, McConnell (1992) identified five key sources of such error. These are:

- Choosing the wrong functional form for the value function.
- Omitting important explanatory variables from the value function.
- Measuring the independent variables incorrectly (e.g. income, the change in water quality).
- Measuring the dependent variable incorrectly.
- Incorrectly specifying the random process that generates the data (e.g. truncating the number of trips made in a TC model).

McConnell also identified key sources of error in calculating the total WTP/WTA at the policy site, including:

- Incorrect handling of the random components of the value function.
- Aggregation errors in calculating the 'group' means, where required, for the independent variables.
- Errors in calculating the population over which to aggregate individual estimates of WTP/WTA.
- Errors in calculating the extent of the market for the affected environmental service at the policy site.

Clearly, there are multiple sources of error in transferring benefits, and consequently, care must be taken when undertaking benefit transfer. Indeed, it may well be judged to be the case that no study values of sufficiently good quality are identified – in which case the analyst will be forced to decide whether a primary study is needed, or whether to include the impact in the analysis in non-monetary terms. If however the data quality/suitability checks listed above (in particular, during Steps 3 and 4) are fully adhered to, then these potential sources of error can, to some extent, be limited. Nonetheless, as with all types of decision-support tools, transfer studies are most useful to the end-user when sources of uncertainty are identified and, where possible, quantified.

Dealing with Uncertainty in Transfer Estimates[107]

One method of dealing with uncertainty in transfer studies is to use **inferential statistics.**[108] For example, if you use mean values in the benefit transfer, then you can use statistical measures such as **standard error**[109] and **confidence intervals**[110] to provide an indication of how 'precise' the estimate is (see Box 4.31 below for an example).

[107] This section only identifies the techniques that can be used to consider uncertainty in benefit transfer. These techniques are examined in more depth in the guideline on 'Dealing with Risk and Uncertainty' (see Section 5.7).

[108] **Inferential statistics** uses the attributes of a sample in order to provide information about the attributes of the population as a whole.

[109] The **standard error** is used to construct a **confidence interval** that reflects the variability of an observed response relative to the variability of the explanatory variable(s).

[110] A **confidence interval** is the range of values within which some percentage, say, 95 percent of repeated estimates would fall. In other words, a confidence interval provides a range of values within which the 'true' value would actually fall with 95 percent certainty.

Box 4.31: Using Confidence Intervals to Indicate Precision in the Transfer Estimates

Suppose, for example, that an epidemiological study on the impact of heat stress on the elderly arrives at the following (hypothetical) relationship:

cases of premature death in 65 + year olds = exp (0.036 *x* change in ambient temperature) *x* crude mortality rate in affected population.

The figure of interest here is the (dose-response) coefficient 0.036, which is the mean value derived from available data. If this coefficient is normally distributed with a standard error of 0.041, the 90 percent confidence interval is given by:

$$0.036 \pm 1.645 \times 0.041.$$

Hence, the 'true' value of the coefficient will fall between 0.00[111] and 0.103 90 percent of the time. Note that the lower bound of zero implies it is possible that a change in ambient temperature does not alter the base mortality rate in the elderly.

More often than not in transfer studies, you will need to combine several uncertain estimates. For example, the uncertain dose-response coefficient in the above example might be combined with a unit mortality cost, which itself is uncertain, in order to estimate the cost of climate change-induced heat stress. In general, estimates - each with their own confidence interval - will need be multiplied and summed. You therefore need some way of evaluating how combining components in benefit transfer affects the overall level of uncertainty in the final results.

- ♦ Probably the most straightforward approach is to take the lower value of each range of individual estimates and combine them to yield a lower bound to the final results; likewise, the upper value of each range of individual estimates can be combined to derive an upper bound to the final results. This is known as **interval analysis**. Note that since the probability of all the lower (upper) values occurring simultaneously is relatively small, the confidence interval for the final results would be wider than those corresponding to the individual estimates.

- ♦ A more rigorous approach to combining uncertain components is to use **Monte Carlo simulation** techniques. In a Monte Carlo

[111] The lower bound is actually –0.031, but zero is the lowest plausible value for the confidence interval.

simulation, values are randomly drawn from the distributions underlying each of the individual estimates that are to be combined. For each random draw a combined value is estimated. After a sufficient number of draws have been conducted, a distribution for the combined value is constructed, from which mean values and associated confidence intervals can be derived. Monte Carlo simulation thus provides a more robust indication of the overall level of uncertainty in the final results.

The treatment of uncertainty in costing the impacts of climate change, including the use of interval analysis and Monte Carlo simulation, is dealt with in more detail in Section 5.7.5.

As mentioned above, transfer studies also involve the summation of uncertain estimates, particularly when it comes to aggregating impacts across exposure units. As when multiplying uncertain estimates, you can evaluate the uncertainty inherent in the final result in one of two ways.

- The first involves simply summing the distributions of impacts to be combined. Suppose damages from climate change impacts X and Y are valued at £1.0 million and £2.5, respectively. The corresponding 90 percent confidence intervals are £0.5-1.5 million for impact X, and £1.2-3.8 million for impact Y. Simple summation of the individual distributions yields a mean damage cost of £3.5 million, with a lower bound of £1.7 million and an upper bound of £5.3 million.

- Alternatively, one could use Monte Carlo simulations to develop the distribution for the summation of impacts X and Y, from which a mean value and confidence interval can be derived.

Before concluding our discussion of uncertainty, you should note that transfer studies are also likely to be restricted by time and other resource constraints. In order to allocate these limited resources efficiently, it is often useful to perform some form of **sensitivity analysis**, to identify which areas of uncertainty have the greatest impact on the accuracy and reliability of the costing analysis. A separate guideline on sensitivity analysis is provided (see Section 5.8).

Overall, when conducting benefit transfer, the **results should be accompanied with a careful evaluation, discussion and, where possible, quantification of uncertainty**. Moreover, when using benefit transfer a central estimate along with a plausible maximum and minimum estimate should to be provided.

Finally, it is worth noting that research is currently being done into the reliability of benefit transfer, and ways of improving benefit transfer estimates. While it is not possible to examine these research efforts in detail within the scope of this report, brief overviews are provided in Box 4.32 and Box 4.33, respectively.

Box 4.32: Testing for Convergent Validity

In an attempt to assess the reliability of benefit transfer, several researchers have tested for **convergent validity**.[112] In the context of benefit transfer, convergent validity is tested in two ways:

1. The first type of test compares the results of a benefit transfer to those of a primary study to see whether they yield similar estimates. Of course, this test assumes that the estimate produced by the primary study is the 'true' valuation.

2. The second type of test compares two (or more) benefit transfer estimates; again, in order to see if the different transfers produce similar results.

A review of these studies is provided in Brouwer and Spaninks (1999).

Box 4.33: Improving Benefit Transfer: Integrating GIS and Benefit Transfer

The following two quotes provide an insight into one set of recent research into improving approaches to benefit transfer.

"*…successful benefit transfer must necessarily rely on development of reliable visitor demand functions that incorporate travel time, demographic and substitute factors. Previous efforts to include all of these elements in a single arrivals model are rare. By integrating data from numerous sources within a geographical information system (GIS) we developed a model to predict the number of visitors to a recreational woodland in eastern England….Our analysis highlighted both substantial promise and some caveats in using GIS for future benefit transfer work.*"

Lovett, Brainard and Bateman (1997)

"*This work forms the basis for tackling an important research topic in environmental economics: the feasibility of transferring benefits between studies. Using* [geographical information system] *GIS allowed us to implement such transfer with greater ease, consistency, and recognition of the spatial aspects of study design and variable handling than normally seen in such research*."

Brainard, Lovett and Bateman (1999)

112 For example - Bergland, Magnussen and Navrud (1995); Brouwer and Spaninks (1999); Downing and Ozuna Jr (1996); Kirchhoff, Colby and LaFrance (1997); Loomis (1992); Loomis, Roach, Ward and Ready (1995) Parsons and Kealy (1994).

4.11.5 Sources of Benefit Transfer Data

In order to undertake benefit transfer, using either the benefit value or benefit function approach, data are needed on average unit values or valuation functions, respectively.[113] Fortunately, several good databases of valuation data are available, two of which have been developed with benefit transfer in mind – namely the Environmental Valuation Reference Inventory (available at the EVRI web-page http://www.evri.ec.gc.ca/evri/) and the Environment Agency's Register of Environmental Values. A list of UK valuation studies is also available at http://www.environment.detr.gov.uk/evslist/index.htm. The Green Book also provides suggested values and references for valuing selected non-market items, and the most up-to-date information can be found at the Green Book homepage.[114] Each of the individual guidelines also provides economic unit values for selected receptors.

[113] Of course, other data are also required - e.g. the number of affected units in the case of benefit value transfer, and in the case of function transfer, the socio-economic characteristics of the affected population and the anticipated change in the affected resource.

[114] See - http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm.

SECTION V

GENERAL GUIDANCE ON ECONOMIC ANALYSIS

5 GENERAL GUIDANCE ON ECONOMIC ANALYSIS

5.1 Introduction

The purpose of this section is to provide guidance on standard aspects of economic analysis, which should be followed when: (1) using the valuation guidelines to cost specific climate change risks and adaptation responses; and (2) using the resulting cost-benefit estimates in the appraisal of alternative courses of action (e.g. adaptation options). Concerning the former, detailed guidelines are provided on each of the following topics:

- Dealing with relative price movements.
- The process of discounting and the selection of appropriate discount rates.
- Dealing with the non-marginal impacts of climate change.

To support the selection of the 'best' (or preferred) course of action guidelines are also provided on the following topics:

- Cost-effectiveness analysis.
- Options appraisal in the presence of uncertainty.
- The use of sensitivity analysis.
- The treatment of unvalued impacts in options appraisal.
- Assessing the distributional effects of alternative options.

5.2 General Issues in Costing Analysis: Making Adjustments for Relative Price Movements

5.2.1 Context of Guideline

The **general price level**[115] and the **relative price**[116] of individual goods and services in the economy, change with time. This implies that the cost of individual goods or services affected by climate change, and thus the overall total cost of residual climate change impacts, will also change with time. This presents two potential problems for climate change costing studies that we must deal with.

- expressing cost-benefit data in the prices of a common base year; and
- the price basis for future costs/benefits.

5.2.2 Expressing Cost-benefit Data in the Prices of a Common Base Year

Firstly, when making cost comparisons between, say, two adaptation responses, it is important to ensure that all cost data are expressed on an equivalent price basis, i.e. in the prices of a 'common' year. For example, you may have investment expenditure data on two potential adaptation options; one set of cost data may be measured at **current prices**[117] in 1991 whereas the other set of costs may be measured at current prices in 1995. If the economy experienced **inflation**[118] in the intervening period, direct

[115] The **general price level** is given by the weighted average price of a representative 'basket' of consumer goods and services traded in the economy, relative to the price of that 'basket' at some fixed date in the past. As such, the general price level shows what is happening to consumer prices on average, and not what is happening to the price of individual consumer goods and services. Consequently, increases in the price of a specific good or service over time do not necessarily imply that the general price level has changed. For example, subject to the weights assigned to two items in the 'basket' of consumer goods and services, increases in the price of one item may be offset by decreases in the price of another item, to the extent that the average price level remains unchanged. Therefore, for the general price level to move upward, the prices of a majority of items in the 'basket' must increase. In the UK, the **Retail Price Index** measures changes in the general price level.

[116] As the term implies, this defines the price of a particular good or service relative to other goods and services in general. If any good or service is expected to change relative to the **general price level**, then it is said to have changed in **real** terms.

[117] **Current** (or **nominal**) **price** variables refer to values at the prices ruling when the variable was measured. Such prices have not been adjusted for the effects of **inflation**. Nominal price is interchangeably used with current price.

[118] **Inflation** is the term economists use to refer to increases in the general price level over time. The **inflation rate** defines the rate at which the general price increases over a specified time period – e.g. monthly or yearly.

comparison of the two data sets would be misleading.

For the same reasons, if the cost data are to serve as an input into some form of economic analysis, the results of which are ultimately to be integrated into a database for cross-study comparisons, it is advisable that this 'common' year corresponds to the **base year**[119] of the analysis. For example, a reference may quote the cost of particular good vulnerable to climate change at £500 per unit in 1992 current prices, yet the base year of the study for which the data are required might be 1995. Assuming the presence of inflation over the intervening period, if the quoted cost is used directly in the study, the final results will be biased downward. Equally, if the base year is 1990 and the quoted cost is used directly, the results will be biased upward.

A general procedure for expressing cost data in the prices of a selected year is given in Box 5.1 below, along with a numerical example.

[119] In the context of processing time-dependent data such as costs in some form of economic analysis, the **base year** is the year selected for assembly of the 'raw' input data. The base year may also serve as the year from which projections of the **baseline scenario** are made.

Box 5.1: Expressing the 'Raw' Cost Data on an Equivalent Price Basis

General Procedure:

The following two-step procedure should be used to express all 'raw' cost data on an equivalent price basis - i.e. in the prices of a 'common' base year.

Step 1

Price adjuster

equals

Price index corresponding to the base year

divided

Price index corresponding to the reference year of the 'raw' cost data

Step 2

Adjusted cost data (in prices of base year)

equals

Price adjuster

times

The 'raw' cost data

Numerical Example:

Suppose you know the current price of metered water to households (industry weighted average) in 1991/92 is 45.27 pence per m^3. Now suppose that it is necessary to express the price data in 1996/97 prices - because 1996/97 is the 'base year' for your study. The required adjustment is shown below – based on the data given in the accompanying Annex. The current price of metered water to households in 1996/97 is 62.65 pence per m^3.

Step 1:

price adjuster: 1.384

equals

current price index water charges for households (1996/97): 161.80

divided by

current price index water charges for households (1991/92): 116.92

Step 2:

current price of household water in 1996/97: 62.65 pence per m^3

equals

current price of household water in 1991/92: 45.27 pence per m^3

multiplied by

price adjuster: 1.384

5.2.3 The Price Basis for Future Costs

Changes in the price of various goods and services (e.g. water, energy, health care, plant, equipment, property, etc.) are not restricted to the intervening years between the ‘raw’ cost data you collect and the base year of the costing analysis, they are also likely to vary over the study’s time horizon (e.g. 2000 to 2080) - not least as a result of general price **inflation**. However, the affect of inflation on future prices, and thus the projected costs of climate change, can be removed if we work with so-called **constant** (or **real**) **prices**. In fact, the Green Book recommends that future costs and benefits be expressed in such prices. In this way, only relative price changes are reflected in the analysis – i.e. where the value of an impact is anticipated to in/decreases more or less than the general price level (see below).

A **constant price** is a value from which the overall effect of general price inflation has been removed.[120] The use of constant prices ensures that future costs are estimated in the same 'units' as the costs are measured in the study's base year, which may correspond to the time a decision to invest in alternative adaptation measures is to be made.

Some useful relationships for converting current price variables to constant price variables are given in the accompanying Annex, along with a numerical example.

When working with constant prices – i.e. where current prices have been adjusted for general inflation - it is assumed that inflation will affect the price of all affected items considered in the costing study to the same extent, such that prices retain the same general relationship to each other.[121] Even where general price increases are removed through the use of constant prices however, it is possible that the **relative prices** of affected goods or services would vary – possibly as a result of productivity and technology changes, natural calamity, and even differential inflation.[122] The price of an affected good or service may increase either slower or faster than the prices of other goods and services, or vice versa. In economic analysis, a change in the relative price of a good or service is expected to result in a change in the amount of resources that must be foregone, either damaged through climatic change or invested in adaptation measures, instead of being used elsewhere in the economy. Hence, changes in relative prices reflect changes in real resource use, and therefore should be recorded in the costing study in the years when such changes are expected. An example is given in Box 5.2.

If the **relative price** of an affected good or service is expected to change over the study's time horizon, then this change in its real value should be allowed for when computing costs, and justification for the forecast price movements should also be given. Otherwise, it is implicitly assumed that all cost data remain constant in real terms.

[120] **Real** or **constant** price variables adjust **current price** variables for changes in the general level of prices – that is, they are inflation-adjusted prices.

[121] That is, the use of constant price data presumes that the price of all cost components changes at the same rate as the **general price level**, so that price relativities are constant.

[122] **Relative prices** refer to the value of a good or service in terms of each other.

Box 5.2: The Use of Relative Prices in Costing Studies

Numerical Example:

Suppose that the current price of metered water charges for households is expected to increase at a rate of 2.5 percent per year over the first ten years of the costing study, when the annual rate of general inflation over the same period is placed at 4 percent. The annual change in the relative price of metered water charges is thus given by

$$\frac{(1+0.025)}{(1+0.040)}-1=-0.014\,.$$

Therefore, the value of metered water supplies in the costing study, expressed in **constant prices**, should be reduced by 1.4 percent per year - reflecting this relative price change over the period for which it will continue. Alternatively, suppose there is a scarcity of potable water supply and volumetric rates are expected to increase by 5 percent per year over the first ten years of the study. Again, if general inflation is assumed to be 4 percent per year for the same period, then the value of metered water supplies in the costing study should be increased by 1 percent per year for the first ten years – i.e.

$$\frac{(1+0.05)}{(1+0.04)}-1=+0.096\,.$$

The paragraphs above have outlined how changes in relative and general price levels might b treated in cost-benefit analyses. It should be noted that the application of these costing guidelines is likely to be in conjunction with explicit socio-economic scenarios for the economy (national, regional or global) concerned. For the UK, the socio-economic scenarios prepared for UKCIP are likely to be useful in this regard. These give quantitative and qualitative changes for a number of socio-economic indicators under four contrasting world scenarios. These indicators can be used as a basis for the estimation of price and quantity changes in marketed and non-marketed goods. Note, however, that these scenarios cannot prescribe in any detailed fashion the changes in prices and quantities. Consequently, the analyst is left to interpret and develop these scenarios further in generating the required information for any costing work.

5.3 Annex: Price Indexes – Essential Mechanics

In Table 5.1 below, column A shows the **current price** of volumetric water charges for household customers from 1990 to 1997. This series of number can be converted into index numbers as follows:

5. Select a reference base, say, 1990.
6. Divide the value in the reference base by 100 (i.e. 38.72 ÷ 100 = 0.3872).
7. Divide all number in the original price series by the result of Step 2 (e.g. 38.72 ÷ 0.3872 = 100.00 provides the index value for 1990, 45.27 ÷ 0.3872 = 116.92 provides the index value for 1991, etc).

The resulting **current price index** is given in column B.

Table 5.1: Water Volumetric Rates for Household Customers: Industry Average (Weighted)

	A **Current Prices** (pence/m^3)	**B** **Current Price Index** (1990=100)	**C** **Retail Price Index** (1990=100)	**D** **Constant Prices** (pence/m^3)	**E** **Constant Prices** (pence/m^3)
1990-91	38.72	100.00	100.00	38.72	100.00
1991-92	45.27	116.92	104.82	43.19	111.54
1992-93	49.60	129.10	108.08	45.89	118.52
1993-94	53.83	139.28	109.95	48.96	126.44
1994-95	57.86	149.43	112.98	51.12	132.26
1995-96	60.13	155.29	116.63	51.56	133.15
1996-97	62.65	161.80	119.43	52.46	135.48

Note that index numbers, which have no units, are values expressed as a percentage of a single base figure. For example, if the average (weighted) current price of water was 38.72 pence per m^3 and 45.27 pence per m^3 in 1990/91 and 1991/92 respectively, the price in 1991/92 was 116.92 percent of that in 1990/91. In index terms, the average (weighted) price of water in 1990/91 and 1991/92 was 100 and 116.92, respectively.

Price indices can just as easily be expressed in **real** (or **constant**) terms – as given by column E in Table 5.1 - by making the appropriate adjustments for **inflation**. To this end the following relationships are useful:

- The current price index (series) ÷ by the price deflator × 100 = the constant price index (series).

- The current price index (series) ÷ by the constant price index (series) × 100 = the price deflator.

- The constant price index (series) × the price deflator ÷ 100 = current price index (series).

The **price deflator** is the price indicator used to convert (to deflate) between current (nominal) and constant (real) values.

In the example given in Table 5.1 the **Retail Price Index,**[123] which measures general (consumer) price inflation in the UK economy, is used as the price deflator. A better measure of price inflation in the economy as a whole, including manufacturing, is the implicit Gross Domestic Product deflator.[124] More specific indices are also available for deflating specific goods/services, such as the construction price index,[125] and various producer price,[126] energy price[127] and (agriculture[128]) commodity price indices.

[123] Available from, for example, the National Statistics website (www.statistics.gov.uk/themes/economy/).

[124] Again, available from the National Statistics website (www.statistics.gov.uk/themes/economy/).

[125] Available from the Digest of Data for the Construction Industry (www.detr.gov.uk/planning/digest/index.htm)

[126] See the National Statistics website (www.statistics.gov.uk/themes/economy/).

[127] Available from the Digest of UK Energy Statistics (www.dti.gov.uk/epa/dukes.htm)

[128] Available from, for example, MAFF statistics (www.maff.gsi.gov.uk/esg).

5.4 Discounting and Discount Rates

5.4.1 Context of Guideline

Costing of climate change impacts and adaptation measures necessitates consideration of the treatment and reporting of economic values that are forecast to occur in the future. **Discounting** is the usual technique used to add and compare environmental costs and benefits that occur at different points in time. However, there is considerable discussion about the discount rate(s) that should be used in the context of climate change analysis. This section highlights the principal factors that should be considered in determining the use of discounting in the present context and presents estimates of discount rates that may be adopted in **sensitivity analysis** (see Section 5.8).

5.4.2 Issues in Discounting

The rationales for discounting in the public and private sectors differ and reflect the distinction between private costs and social costs. Private sector interests will be primarily interested in the costs of borrowing or lending money in the financial markets. Thus the market rate of interest(s) will be the most relevant in undertaking financial appraisal of projects.

The market rate of interest arises because individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now. Impatience, or **'pure time preference'**, is one reason why the present is preferred to the future. The second reason is that, since capital is productive, a pound's worth of resources now will generate more than a one pound's worth of goods and services in the future. Hence an entrepreneur is willing to pay more than one pound in the future to acquire one pound's worth of these resources now. This argument for discounting is referred to as the **'marginal productivity,** or **opportunity cost, of capital'** argument; the use of the word marginal indicates that it is the productivity of additional units of capital that is relevant. The individual rate of time preference would be equal to the opportunity cost of capital if there were efficient markets and no taxes. In practice the range of individual time preference rates is large and does not coincide with the rates for the opportunity cost of capital. Broadly speaking the individual rate of time preference in the UK would be around 6-20% (depending on whether the individual is borrowing or lending), whereas the (risk free) opportunity cost of capital rate would be around 7%. These effectively represent a typical range for the market rates of interest.

The private sector will, however, also be interested in how the public sector treat costs and benefits from climate change that occur in the distant future as part of their involvement in public policy decision making processes. The remainder of this section is concerned with the practice of discounting in the public sector in the context of climate change.

Basis for Public Sector Discounting

The derivation of discount rates that should be adopted in public sector analysis of future costs and benefits is set out in general terms in the Treasury's Green Book.[129] The rationale is summarised in the following paragraphs.

The **social discount rate** attempts to measure the rate at which social welfare or utility of consumption for society falls over time, and is therefore distinct from the private sector that relies on the market interest rate determined by individual preferences expressed in financial markets. The social discount rate, as determined by time preference, will depend on the rate of pure time preference, on how fast consumption grows and, in turn, on how fast utility falls as consumption grows. The social rate of time preference is given by:

$$i = z + n \times g \qquad (5.1)$$

where z is the rate of pure time preference (impatience – utility today is perceived as being better than utility tomorrow) plus catastrophe risk, g is the rate of growth of real consumption per capita, and n is the percentage fall in the additional utility derived from each percentage increase in consumption. (n is referred to as the 'elasticity of the marginal utility of consumption'). With no growth in per capita consumption therefore, the social rate of time preference would be equal to the private rate, z. The values for these components recommended by the Treasury's Green Book are: z = 1.5; n = 1; g = 2. Applying the formula above, a public sector discount rate of 3.5 is derived.[130]

Discounting over Long Time Periods: the Climate Change context

If the climate change impact, valued at £X today, but which will occur in T years time is to be discounted at a rate of r percent, the value of X is reduced to $X/(1+r)^T$. Clearly the higher is r and the greater is T, the lower will be the value of the discounted damages. It should be noted that when long time periods need to be considered, as in the context of climate change, the effect of adopting a positive discount rate is to weight present values over future values so that the damages associated with climate change become very small. For example, with a horizon of around 100

[129] http://greenbook.treasury.gov.uk/

[130] Note that this is a significant change made in the recently up-dated Green Book. Formerly, a discount rate of 6% was recommended.

years, a discount rate of 4 percent implies that damages of £1 at the end the period are valued at £0.08 today. The tyranny of discounting, as this is known has led some to question the appropriateness of using a constant discount rate, of the value derived above, in the climate change context. Below, we summarise the currently recommended practice in the UK.

The role of pure time preference, *z*, has been questioned particularly in inter-generational assessments – the context for climate change. In terms of <u>personal</u> preferences, no one appears to deny the impatience principle and its implication of a positive individual discount rate. However, arguments exist against permitting pure time preference to influence <u>social</u> discount rates, i.e., the rates used in connection with collective decisions. For example, it has been argued that public policy should reflect collective, not private, interests (Sen, 1982). The associated ethical argument is that to bring about intergenerational equity, impartiality implies that the well-being of one generation should not be counted differently from that of any other. There are indeed strong arguments for paternalism though there is no agreement on this issue.

An alternative reason for re-examining the appropriateness of the standard discount rate is given by Weitzman (1998). He argues that for any period, the real rate of interest is determined by the productivity of investment, (the marginal opportunity cost of capital referred to above), and for the distant future it is the same. By applying constant discount rates, economists are implicitly assuming that the productivity of investment will be the same in the distant future as in the recent past. Weitzman does not see fundamental reasons why this should not be so. But, the distant future is totally uncertain, and one of the most uncertain aspects of it is the discount rate itself. It is not the discount rate that should be probability-averaged over states of the world, but the discount factor. This makes a huge difference for very large time periods. Uncertainty about future interest rates provides a strong generic rationale for using certainty-equivalent social interest rates that decline over time from around today's market values down to the smallest imaginable rates for the far-distant future. This effect does not begin to operate until beyond the range of near-future, in which we can be fairly confident today's rates will prevail.

Weitzman's argument, then, is that when there is an uncertain discount rate, the correct discount rate for a particular time period - the certainty-equivalent discount rate - can be found by taking the average of the discount factor, rather than the discount rate itself. The table below illustrates this. Here, there are ten discount rate scenarios, with each scenario having an equal probability.

Table 5-2: Uncertain Discount factors and Declining Discount Rates

Discount rate		Discount factors in year t				
	Year (future)	10	50	100	200	500
Scenarios						
1%		0.91	0.61	0.37	0.14	0.01
2%		0.82	0.37	0.14	0.02	0.00
3%		0.74	0.23	0.05	0.00	0.00
4%		0.68	0.14	0.02	0.00	0.00
5%		0.61	0.09	0.01	0.00	0.00
6%		0.56	0.05	0.00	0.00	0.00
7%		0.51	0.03	0.00	0.00	0.00
8%		0.46	0.02	0.00	0.00	0.00
9%		0.42	0.01	0.00	0.00	0.00
10%		0.39	0.01	0.00	0.00	0.00
Certainty-equivalent discount factor		0.61	0.16	0.06	0.02	0.00
Certainty-equivalent discount rate		4.73%	2.54%	1.61%	1.16%	1.01%

Newell and Pizer (2001)

Table 5-2 shows that - in the limit - that as the time period considered becomes larger and approaches infinity, the certainty-equivalent discount rate approximates the lowest discount rate being considered - in this case 1%. The empirical values given here are derived from a study by Newell & Pizer (2001), based on uncertainty in relation to US market interest rates on long-term government bonds using Weitzman's approach.

This profile of a declining discount rate over future time periods is not uncontroversial. There is, for example, no reason why we need assume a fall in productivity growth. There is also no discussion of the social time preference rate. These issues are ripe for future research efforts. In the short-term, the Treasury's Green Book adopts the Weitzman approach and suggests the following discount rate profile over future years: for years 0-30, use a real annual discount rate of 3.5%. For the period from 31 to 75 years use a discount rate of around 3%. For the period from about 75 to 125 years, a rate of 2.5% should be used. For the period from 126 to 200 years, a rate of 2% should be used. For 201 years to 300 years, the rate should be 1.5%, whilst for 301 years and more a rate of 1% should be adopted.

5.4.3 The Use of Discount Rates

Present Value Calculations

In the context of the UKCIP, discount rates need to be applied to

- climate change impact costs that are borne, or avoided, over future time periods, and;
- climate change adaptation costs that are to be incurred, over future time periods.

In order to aggregate these impact/adaptation costs in terms of today's value it is necessary to calculate the **present value** of the future cost streams. These are calculated using the formula:

$$\text{PVC} = \sum_{t=0}^{T} C_t \times \frac{1}{(1+i)^t} \qquad (5.2)$$

where

PVC	=	the present value cost of the stream of costs from year *t* to year *T*,
C_t	=	the cost incurred in year *t*, and
i	=	the appropriate rate of discount.

Note that the second term on the right-hand-side of equation 4.2 is referred to as the **discount factor**.

Consider the example in Box 5.3, which demonstrates the concept of present value.

Box 5.3: Example of Present Value Cost Calculations

Consider the information given in Table 5-3 below for specific climate change impact that is forecast to occur over a four-year period. The estimated economic costs for each year are given in column II. The discount factors corresponding to a 6 percent discount rate are shown in column III. The discounted costs for each year are shown in column IV; the sum of which is the **present value cost** of the impact.

Table 5-3: Present Value Cost Calculations

Year	Economic Cost (£'000s)	Discount Factor	Discounted Value
I	II	III	IV = II * III
0	95	1.000	95
1	100	0.943	94.3
2	120	0.890	106.8
3	180	0.840	151.1
PVC			**447.3**

To assess whether an adaptation measure is economically beneficial it will be necessary to calculate the **net present value** (NPV) of the project, i.e. the difference between the discounted benefit (i.e. the impact cost avoided) stream and the required investment expenditures and recurring costs. The net present value of a project or policy is given by:

$$\text{NPV} = \sum_{t=0}^{T} B_t \times \frac{1}{(1+i)^t} - \sum_{t=0}^{T} C_t \times \frac{1}{(1+i)^t} = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+i)^t} \qquad (5.3)$$

where

NPV = the net present value of a project or policy which generates cost-benefit streams from year *t* to year *T*, and

B_t = the benefit accruing in year *t*.

All other notation is as above. An example calculation is provided in Box 5.4.

Box 5.4: Example of Net Present Value Calculation

Let us take as an example an adaptation measure that is being considered, say a reservoir, that yields benefits in terms of reliable water supply. It is assumed for our purposes that the reservoir has an artificially low lifetime of 9 years, and takes two years to build. The investment expenditures and maintenance costs are aggregated in column III. The benefits are also expressed in monetary terms (column V). Both cost and benefit streams have been discounted at a 6% discount rate, the annual discounted values are shown in columns IV and VI, respectively. The sum of column IV is the present value cost (PVC) of the project; the present value benefit (PVB) is given by the sum of column VI.

The difference between the PVB and the PVC is the net present value (NPV = PVB-PVC) of the reservoir. The calculations are shown in Table 5-4 below.

The NPV calculations show, since the NPV is **positive** (+£7,650), that the benefits outweigh the costs for the project, and the implementing agency would therefore be justified in going ahead with it on economic grounds.

Table 5-4: Net Present Value of Adaptation Project (£'000s)

Year I	**Discount Factor** II	**Costs** III	**Discounted Costs** IV = II * III	**Benefits** V	**Discounted Benefits** VI = II * V	**Discounted Net Benefit** VII = VI – IV
0	1.000	15	15.00	0	0	-15.00
1	0.943	10	9.43	0	0	-9.43
2	0.890	2	1.78	7	6.23	4.45
3	0.840	2	1.68	7	5.88	4.20
4	0.792	2	1.58	7	5.54	3.96
5	0.747	2	1.49	7	5.23	3.74
6	0.705	2	1.41	7	4.93	3.52
7	0.665	2	1.33	7	4.66	3.33
8	0.627	2	1.25	7	4.39	3.14
9	0.592	2	1.18	7	4.14	2.96
10	0.558	2	1.12	7	3.91	2.79
NPV			**37.27**		**44.92**	**7.65**

5.5 Treatment of Non-marginal Impacts

5.5.1 Context of Guideline

The 'costing methodology' outlined for UKCIP generally assumes that the climate change impact or adaptation measure under consideration is 'marginal', in the sense that it is of a small enough size as to have no effect on the prices of affected goods and services. As a result, the benefit/cost of the impact/adaptation measure is valued by multiplying the anticipated change in the quantity demanded by the appropriate price. In some cases, however, the impact may result in 'non-marginal' effects on the targeted market(s), which may in turn change the price in that market by changing the underlying demand and supply conditions. An example might be a loss of fish stocks due to warmer sea water, which results in a significant increase in the price of fish in the UK (since, in economic terms, the supply curve shifts to the left) We are now faced with the dilemma of which price to use in the costing analysis – the initial price or the price that prevails subsequent to the climate change impact/adaptation intervention? Moreover, depending on the nature of interrelationships between affected markets, a price change in the one market may disrupt price and quantity equilibria throughout the economy. A further question therefore arises - how many markets must we consider to derive an accurate measure of the 'true' economic effect of climate change?

In short, when a policy has a significant ('non-marginal') effect and prices change as a result, we must resort to the relevant supply and demand curves in order to attach an appropriate 'social' valuation to the resulting changes in output or inputs. This guideline identifies appropriate procedures for valuing 'non-marginal' impacts, however, it is not possible within the scope of this report to outline these methods in detail.

5.5.2 Methodologies for Estimating Non-marginal Impacts

Three different cases can be identified in which prices change as a result of climate change (adaptation responses). These are:

- where price changes in the directly affected (targeted) market;
- where prices change in indirectly affected (related) markets; and
- where price and quantity equilibria change throughout the economy.

Valuing a Change in Welfare in a Single Affected (Targeted) Market

The first two cases can be considered together because the analytical method is similar for both. Welfare changes in the first case are evaluated within a *partial equilibrium* method - that is, a method where welfare effects are considered for one market only, on the assumption that there are no significant welfare changes reflected in other markets. The example above relating to the changes in fish stocks and the resulting price change is an example of where only one market is considered.

The welfare change, i.e. the cost or the benefit of the impact, is measured in terms of the change in **producer surplus** and **consumer surplus**. In order to estimate this welfare change, the analyst needs to estimate the parameters of the supply and demand functions that exist in the particular market and the shift in one or both of these functions brought about by the climate change impact.

It is worth bearing in mind that the information requirement in this case may be significant. In practice, therefore, it is often the case that the practitioner is obliged to approximate the effect by using his or her judgment on the likely market parameter qualities, given knowledge of associated markets. If this is not possible, we suggest that the simple, marginal approach is adopted whereby the anticipated change is multiplied by the quantity demanded by the new price.

The same analytical principles apply to the second case, which may also be dealt with within a partial equilibrium method, albeit an 'extended' one - i.e. where welfare effects are measured in a small number of other impacted markets. This is therefore likely to take the form of a sectoral analysis. In this case, changes in one market are observed to have effects on the supply and demand conditions in another market. An example of the market mechanisms that give rise to extended partial equilibrium method is given in Box 5.5.

Box 5.5: Example of Extended Partial Equilibrium Analysis

Reconsider the previous example of declining fish stocks in UK waters due to higher sea temperatures. We may find that the higher price for fish that we have identified in the 'fish' market results in an increase in the demand for, say, chicken meat as consumers switch to an alternative to fish that is now 'cheaper' in relative terms. This is known as the **spillover effect**, whereby the change in one market 'spills over' to impact on another. In this example, therefore we may expect to see the consumer surplus and producer surplus change in the chicken market, producing a net welfare effect. The spillover effect may be tempered by the fact that, following through our example, the increase in demand for chicken leads to an increase in its price, which itself influences the demand for fish as consumers switch back in response to the change in relative prices. This is known as the **feedback effect**, and should also be considered when analysing the welfare changes in markets.

The analyst, in this example, therefore has to be careful that both of these effects are accounted for when identifying the total net change in producer and consumer surpluses that arises from the initial impact on the fish market.

Clearly, the recommendations that we make above regarding the estimation of the welfare effects in the one-market-partial equilibrium analysis apply also in this extended form of partial equilibrium analysis.

The number of markets that need to be examined is likely to be determined by the analyst's view on the significance of the change that occurs in the observed markets. However, there are some established propositions which identify the conditions under which it is advisable to extend the analysis beyond the specifically affected (targeted) market. These are:[131]

- When there are **price changes** in indirectly affected markets with **no distortions**, there is *no* net welfare change, and these markets can therefore by neglected. In effect, what we have is a **pecuniary external effect** – changes in consumer surplus in the indirectly affected market are approximately offset by changes in producers' surplus.

- When **distortions exist** in an indirectly affected market and **quantities change** as a result of the intervention in the directly affected market, these markets ought to be examined. (The welfare effect is approximated by multiplying the size of the distortion per unit by the change in the number of units.)

- When **distortions exist** in an indirectly affected market and **prices change** as a result of the impact (intervention) in the affected (targeted) market, these markets ought to be examined. (The welfare effect is approximated by multiplying the average value of the price distortion by the change in quantity.)

Therefore, depending on the questions to be answered by the economic analysis, an extended partial equilibrium analysis, or a full general equilibrium analysis – outlined below - may be required.

General Equilibrium Analysis

The third case, in which prices potentially change throughout the

[131] It is not practical herein to illustrate these proposition; detailed examples are provided in Sugden and Williams (1978, pp 134-147), Arnold (1995, pp 84-93) and Zerbe and Dively (1994, pp 144-153). Note that if welfare effects are determined allowing for substitution and income effects, then these propositions apply directly to general equilibrium analysis.

economy, must be examined within a **general equilibrium** method. In contrast to the partial equilibrium methods considered above, all determinants of prices are variable, and the analysis focuses on the simultaneous determination of equilibrium in *all* markets, although at a more aggregated level. Consequently, in general equilibrium analysis the interdependence of the prices and quantities of products and inputs in the economy are explicitly taken into account. It therefore provides a more complete method for evaluating significant climate change impacts/adaptation responses than partial equilibrium analysis.

Techniques which are capable of modelling the linkages between different economic agents in the economy, and therefore quantifying the 'general equilibrium effects' of a significant impact/adaptation response, include computable general equilibrium (CGE) models, and to a lesser extent, input-output models. Only CGE are considered below (see Perman *et al.* (1999) for a description of input-output modelling in an environmental context). See Box 5.6 for an example of general equilibrium analysis.

<u>Computable General Equilibrium (CGE) Models</u>

CGE models essentially simulate markets for production factors, products, etc. with systems of equations specifying supply and demand behaviour across all markets. There are many examples of CGE models, each 'tailor-built' with a specific purpose in mind. A recent summary is given in OECD (1997). Several applied CGE models have also been specifically designed to assess the overall economic impact of addressing the enhanced greenhouse effect.

The fact that CGE modules start at the 'top', i.e. with a representation of what should happen if the economy in question conformed to the assumptions of the model, rather than the more traditional bottom-up approach that takes a set of observations relating to what is actually happening, some commentators take the view that these models are too abstract for the real world (European Commission, 1996). In common with input-output models, the inherent complexity of CGE models means that the amount of time and effort required to collect the basic data, and build a suitable model, is often prohibitive.

General equilibrium analysis, as used by economists, typically involves studying the relationships between a few, highly aggregated sectors. Consequently, detail is sacrificed for completeness. By contrast, in partial equilibrium analysis one can take into account many specific factors underlying the workings of individual markets; completeness is sacrificed for detail.[132]

[132] The choice between bottom-up and top-down modelling approaches requires a similar trade-off to be made; the former is typical of partial equilibrium analysis, whereas the latter is typical of general equilibrium analysis.

Box 5.6: Example of General Equilibrium Analysis

Suppose that a prolonged summer drought has resulted in a serious water shortage across the UK. As a result, the regional authorities are given authorization to ration water consumption through the imposition of higher water charges. This will clearly have immediate welfare effects for both domestic water consumers and industrial water users. However, it is also likely that since water is an essential input to, for example, many industrial processes and agriculture, these higher water charges will result in higher prices for the final (and intermediate) goods produced by industry and agriculture – with corresponding welfare effects. Thus, in order to capture the true welfare changes of the water rationing it will be necessary to model the price and output effects economy-wide, through some type of general equilibrium model.

5.5.3 Recommendations

We recommend that the way in which the welfare effects of each climate change impact and adaptation measure considered by UKCIP are estimated should be determined on an individual basis, since there are no hard-and-fast guidelines on this issue. Nevertheless, we are able to draw some broad conclusions. They are:

- Partial equilibrium analysis is appropriate as long as either the supply or demand curve for the directly affected market can be characterised as being more or less flat, and no other markets are affected. This rule also holds if other markets are affected, but they too have highly elastic supply or demand curves.

- Extended partial equilibrium analysis is likely to be appropriate if distortions exist in an indirectly affected market and prices and/or quantities change. This will be most necessary where the effects are ‘sizeable’ and the directly targeted market is highly integrated with other markets or sectors of the economy.

- General equilibrium analysis is appropriate when there are strong inter-dependencies between the directly affected sector and the indirectly affected sector(s), and the effects result in a significant percentage change in resource costs. This rule is likely to be true if the impacts are on a number of sectors that provide inputs to final products, e.g. transport and energy.

Any recommendation made regarding the appropriate form of analysis also needs to consider the greater uncertainties that are inherent in more complex modelling forms that reduce the accuracy of the results. It also needs to be borne in mind that resource cost demands also rise with more complex modelling requirements.

5.6 Cost-effectiveness Analysis

5.6.1 Context of Guideline

Cost-effectiveness analysis (CEA) is used to evaluate trade-offs between benefits, measured in some units other than money, and resource costs. Specifically, CEA is concerned with finding:

- The least-cost (with minimal resource use) way of achieving a predetermined goal, e.g. the supply of a given quantity of potable water.
- The project or policy package that yields the greatest benefit (e.g. delivering the maximum reduction in risk exposure) subject to a cost constraint (or other resource constraint).

The mechanics of pursuing both agendas are the same – the difference is primarily a matter of emphasis – as are the cost definitions and the way in which they are quantified.

In contrast to CBA, CEA does not require the desired output (benefit) of the policy intervention to be expressed in money terms. Only the inputs (costs) of the intervention are valued; it is sufficient to express the benefits in physical units, e.g. m^3 of water delivered per year. This is particularly advantageous when valuation of the option deliverables is not practical, controversial, uncertain, or some combination thereof. However, CEA does not work so well when each options under consideration yield several deliverables that are measured in different units, and therefore cannot be aggregated into a single measure of 'benefit'. For similar reasons, CEA cannot be used to compare options that provide different outputs; CEA compares the costs of alternative options for providing the same, or similar, outputs.

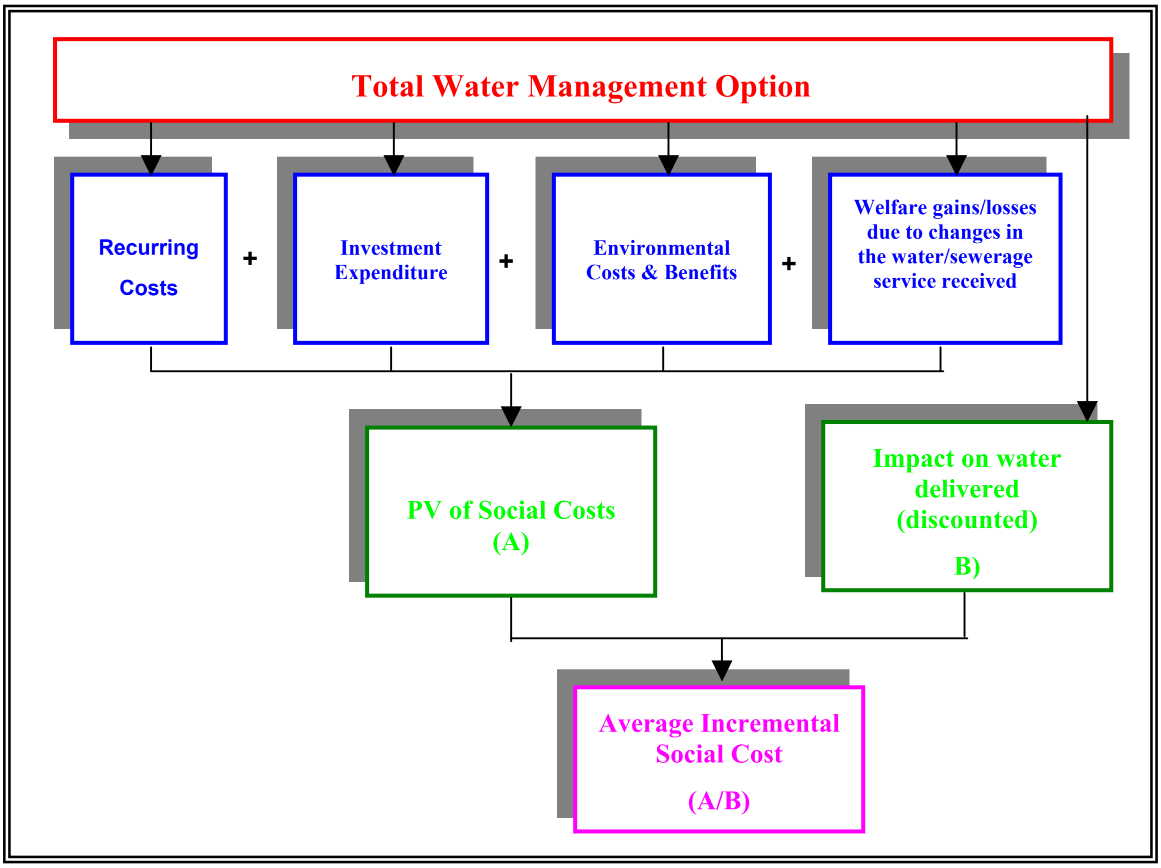
CEA has seen widespread use in the field of GHG mitigation, were it is used to identify the least-cost measure(s) to limit GHG emissions to a pre-determined level. In other sectors, the health and water resource sector for example, CEA may be used to identify the programme that saves the most lives for a fixed investment or the least-cost package of options for balancing supply and demand for water, respectively.

CEA is *not* restricted to **private costs**, as defined in Section 6.2.3. It is often desirable in some contexts, e.g. balancing water supply and demand, to work with a broader definition of costs - **social costs** (see Box 5.7 for example). Hence, in addition to resource inputs costs, the cost component may also include net environmental costs, ancillary benefits and welfare gains/losses. In this respect, *only* the desired deliverable of the policy intervention is not valued.

Box 5.7: Method for Assessing the Social Cost of Water Resource Management Options

Figure 5.1 below summarises a 'best practice method' recommended for use by the public water supply industry for balancing water supply and demand with an 'optimal' – i.e. minimising incremental social cost – mix of initiatives or schemes for water resource and production, water distribution management, and customer-side management (UKWIR/EA, 1996). The method identifies the 'optimal' solution by ranking the **average incremental social cost** (AISC) – a broad measure of cost-effectiveness – associated with various total water management options, and selecting in turn those options with the lowest AISC until a programme is formed with sufficiently addresses the supply shortfall. This programme, which may be part of an adaptation strategy to address a climate change-induced scarcity problem, should have the lowest present value total cost of all feasible programmes. Further details of this method are provided in UKWIR/EA (1996).

Figure 5.1: Average Incremental Social Cost of Water



In the context of these costing guidelines, CEA serves two purposes:

- Firstly, faced with a specific climate change risk, CEA may be used to identify the least-cost adaptation response to provide a specific level of climate change risk management. For example, suppose a regional water shortfall of 160 Ml per day in 2050 is projected under a climate change scenario. CEA can be used to identify the least-cost strategy from alleviating this supply-demand imbalance.

- Secondly, in Section 4.3 we talked about cost-based approaches to valuing the economic benefits foregone through damage caused by climatic change. For instance, one approach to valuation is to measure the cost of replacing or restoring the good or service damaged by climate change. The replacement cost provides a lower bound estimate of the presumed value of the damaged good or service. An example is the cost of fish produced in man-made ponds as a replacement for fish in the natural environment. An assumption embodied in the application of these cost-based valuation techniques is that the damaged good or service is replaced or restored at *least-cost*.

5.6.2 Measuring Cost-effectiveness

The cost-effectiveness of a project or policy intervention in delivering a desired output – e.g. an adaptation strategy that seeks to provide a given volume of untreated water - can be assessed in one of two ways. In general terms these are given by:

- Cost-effectiveness (pence per m^3) = the present value of the *net* incremental cost stream of the project ÷ the present value of the yield associated with the project or policy intervention.

- Cost-effectiveness (pence per m^3) = the **total annual cost**[133] of the project of policy intervention ÷ the average annual yield associated with the project.

In most situations, both approaches produce the same measure of cost-effectiveness. However, the (former) approach offers greater flexibility in terms of facilitating changes in key input parameters, e.g. accommodating

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[133] There are also two main approaches given in the literature for calculating the **total annual cost** of a project or policy intervention. In general terms, total annual costs are given by:

Total annual cost = annual investment cost (yearly depreciation charge plus average interest cost per year) + net annual operating and maintenance costs.

Total annual cost = the present value of the total cost stream (investment expenditure plus net operating and maintenance costs) x capital recovery factor.

Again, in most situations, both approaches produce the same estimate of total annual cost, with the second approach offering greater flexibility.

variation in prices or yield over time. The latter approach is really only appropriate if the project deliverable is assumed to be constant through time.

Box 5.8 below provides an example of how each of the above approaches can be used to calculate the cost-effectiveness of a (hypothetical) scheme - an interconnection to a new raw water supply source - in delivering raw water. This scheme may be one of several options being considered as an adaptation response to a water scarcity problem arising from climate change. If measures of cost-effectiveness are available for the set of feasible options, the minimum (social) cost programme of options to meet the supply shortfall can be determined.

Box 5.8: Illustration of Cost-effectiveness Calculations[134]

Calculating Annual Costs

The cost-effectiveness analysis of the proposed water supply scheme is based on the following data set:

Investment Expenditures:	
Construction of link pipe (Year 1)	£102,700
Recurring Costs:	
Operating and maintenance costs	£1.50/m^3
Environmental costs:	
Arising from reduced flows in River	£100,000/Ml/day
Arising from presence of link	£3,000
Benefits of avoided drought in affected region	£200,000/Ml/day
Other Assumptions:	
Capacity of new raw water supply scheme	75 Ml/year
Useful operating life	30 years
Cost of capital	6%

[134] The example provided below is adapted from UKWIR/EA (1996).

For simplicity, it is assumed that the capital goods have no resale or salvage value.

Total Annual Costs: Approach 1 - Depreciation Plus Interest Calculation

With this approach the **annual cost** of the project is obtained by summing the yearly capital and net recurring costs. The capital cost in each year is made up of a **depreciation charge** and the **interest cost** on the outstanding capital balance.

The simplest method for depreciating the capital goods is the straight-line method. This method assumes that these goods contribute their services equally to each year's operation so that the total investment expenditure is evenly allocated over the lifetime of the equipment. Thus the yearly depreciation expense is a constant given by:

$$R_t = \frac{W}{n}$$

where R_t is the depreciation charge in year *t*, W is the depreciation base of the equipment, i.e. the difference between the original cost of the capital goods (C_0) and the salvage value (S_n), and n is the estimated useful lifetime of the equipment in years (or write-off period).

The accumulated depreciation D_t at the end of year *t* is then given by

$$D_t = t\, R_t \, .$$

The book value B_t of the equipment, i.e. the unamortised portion, at the end of year *t* is

$$B_t = C_0 - t\, R_t \, .$$

Using the straight-line method, the **depreciation schedule** for the capital goods required to construct the link is given in the table below.

In purchasing the capital goods, £102,700 is essentially being tied up. If these funds were not invested in the construction link they could be invested either in something else, which will earn a return or, if there are loans which are repayable, this indebtedness can be reduced and the interest cost saved. An annual interest cost should, therefore, be included in the annual cost calculation.

End of year	Yearly depreciation charge	Accumulated depreciation	Book value
(t)	R_t	D_t	B_t
0	-	-	$102,700
1	3,423	3,423	99,277
2	3,423	6,846	95,853
3	3,423	10,269	92,430
4	3,423	13,692	89,007
⇩	⇩	⇩	⇩
29	3,423	99,277	3,423
30	3,423	102,700	-

It is incorrect however, to compute the annual interest cost as 6 percent of £102,700 (i.e. £6,162), as the investment is being reduced each year by the depreciation-recovery charge of £3,423. The £6,162 is the valid interest charge in the first year only. In general terms, the average interest cost per year is given by

$$\text{average interest cost per year} = \frac{1}{2}\left(C_0\, r + \frac{C_0\, r}{n} \right)$$

where r is the interest rate per period. In this case, the average yearly interest cost is £3,184. This is the appropriate amount to use in the annual cost calculations.

The annual capital cost of the capital goods is therefore equal to £6,607; that is, the sum of the average yearly depreciation charge (£3,423) and the average yearly interest cost (£3,184). To this the net annual recurring costs must be added to determine the **total annual cost** of the project. Hence, the total annual cost of the project should read:

Annual capital cost:		
Yearly depreciation charge	+£3,423	
Interest cost per year	+£3,184	
Sub-total	=	+£6,607
Net recurring costs:		
Operating and maintenance costs	+£112,500[1]	
Environmental costs - reduced flows in River	+£20,548[2]	
Environmental costs - presence of link	+£3,000	
Environmental benefits - avoided drought	-£41,096[3]	
	=	£94,952
Total annual cost	=	~£101,600

Notes:

[1] £1.50 per m^3 * 75,000 m^3 per year

[2] (75 Ml per year / 365 days per year) * £100,000 per Ml per day

[3] (75 Ml per year / 365 days per year) * £200,000 per Ml per day

Expressed in general terms, the total annual cost of a project or policy intervention, using the 'depreciation plus interest' approach, is given by

$$\text{total annual cost} = \frac{(C_0 - S_n)}{n} + \frac{1}{2}\left(C_0\, r + \frac{C_0\, r}{n}\right) + RC$$

where RC is the 'average' net annual recurring costs.

Total Annual Costs: Approach 2 - Discounted Cash Flow Approach

An alternative to the above approach, and one that offers greater flexibility, involves first determining the **present value total cost** of the project, and then applying a **capital recovery factor**. The present value total cost (PVC) of an investment is computed as follows:

$$PVC = \sum_{t=0}^{n} \frac{(C_t + RC_t)}{(1+r)^t}.$$

Where t is the year and all other symbols are as given above. The present value of the total cost stream of the scheme is £1,409,698; the calculations are summarised in the table below. This represents the total cost to be recovered in equal annual amounts (denoted by A_t) over the lifetime of the interconnection scheme. Therefore, the **total annual cost** of the scheme is given by:

$$A_t = PVC\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] = £1{,}409{,}698\left[\frac{0.06(1.06)^{30}}{(1.06)^{30} - 1}\right] = £1{,}409{,}698\,(0.0726) =\sim £102{,}000$$

The second term in the brackets is the **capital recovery factor**. This approach offers greater flexibility in that it provides a method for explicitly considering, for example, the effects of price escalation on the various recurring cost components. Moreover, it provides a more accurate estimate of total annual cost than does the depreciation plus average interest approach, although the two estimates are not significantly different.

Year	**0**	**1**	**2**	**3**	⇨	**30**
1 Discount factor	1.000	0.9434	0.8900	0.8396		0.1741
2 **Investment expenditure**						
Interconnection link	£102,700	-	-	-	⇨	-
3 **Recurring costs** (a+b+c):	-	£94,952	£94,952	£94,952	⇨	£94,952
O & M costs	-	£112,500	£112,500	£112,500	⇨	£112,500
Net environmental costs	-	-£17,548	-£17,548	-£17,548	⇨	-£17,548
4 **Total cost** (1+3)	£102,700	£94,952	£94,952	£94,952	⇨	£94,952
5 Discounted total cost (1*4)	£102,700	£89,577	£84,507	£79,724	⇨	£16,532
6 **PVC** (sum line 5)	£1,409,698					

Expressed in general terms, the **total annual cost** of a project or policy intervention may be calculated with the use of a capital recovery factor in one of two ways:

$$\text{total annual cost} = \left[\sum_{t=0}^{n}\frac{(C_t + RC_t)}{(1+r)^t}\right]\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] \text{ or}$$

$$\text{total annual cost} = C_o\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] + RC\,.$$

The latter method is a useful shortcut if the investment expenditures are incurred in the first year and the annual recurring costs are *constant* over the life of the project.

Measures of Cost-effectiveness

The cost-effectiveness of a project or policy intervention in delivering a given output may be assessed in one of two ways: one approach is based on the concept of **present value**; the second approach is based on **annualised cost** data. Using the output from the above cost calculations, we will illustrate how these two approaches are used to estimate the cost-effectiveness of the proposed scheme.

Cost-effectiveness: Approach 1 - The Present Value Approach

Under this approach, the cost-effectiveness the scheme (given by its **average incremental social cost**, which we denote by $AISC$) in delivering a given output (volume of raw water) is formally given by:

$$AISC = \frac{\sum_{t=0}^{n} \left(C_t + RC_t\right) \cdot \left(1+r\right)^{-t}}{\sum_{t=0}^{n} \left(Y_t\right) \cdot \left(1+r\right)^{-t}}$$

where Y_t is the unit output (e.g. yield of the proposed scheme in Ml) in year t, and all other notation is the same as that used above.[135] In this example the proposed interconnection scheme is estimated to deliver 75 Ml or raw water per year. The present value yield of the scheme is therefore 1,032 Ml or 1,032,000 m^3. We know from above that the present value of the total cost stream of the project is £1,409,698. Hence, the cost-effectiveness of the scheme in delivering raw water is given by:

$$AISC = \frac{£1{,}409{,}698}{1{,}032\ \text{Ml}} = £1{,}366/\text{Ml} \cong 137\ \text{pence per m}^3.$$

Cost-effectiveness: Approach 2 - The Annualised Cost Approach

Under this approach, the cost-effectiveness of the scheme in delivering a given output is formally given by:

$$AISC = \frac{\left[\sum_{t=0}^{n} \frac{\left(C_t + RC_t\right)}{\left(1+r\right)^t}\right]\left[\frac{r\left(1+r\right)^n}{\left(1+r\right)^n - 1}\right]}{Y_t} \text{ or } \frac{C_0\left[\frac{r\left(1+r\right)^n}{\left(1+r\right)^n - 1}\right] + RC_t}{Y_t}$$

where all notation is the same as that used above. Recall that the

[135] In the GHG mitigation literature, the denominator is commonly referred to as the **present tonnes equivalent** (PTE).

numerator is simply the **total annual cost**.

The total annual cost of the scheme, as calculated above, is about £102,000. Given that the scheme is estimated to deliver 75 Ml or raw water per year throughout its useful life, the corresponding average incremental social cost using this approach is given by:

$$AISC = \frac{£102{,}000}{75\ \text{Ml}} = £1{,}360/\text{Ml} \cong 136\ \text{pence per m}^3 .$$

In this example, the two approaches produce approximately the same measure of cost-effectiveness - $AISC$. As mentioned, the latter approach is really only appropriate if Y_t and RC_t are assumed to be constant over the scheme's useful life.

5.6.3 Incremental Cost (or Supply) Curves

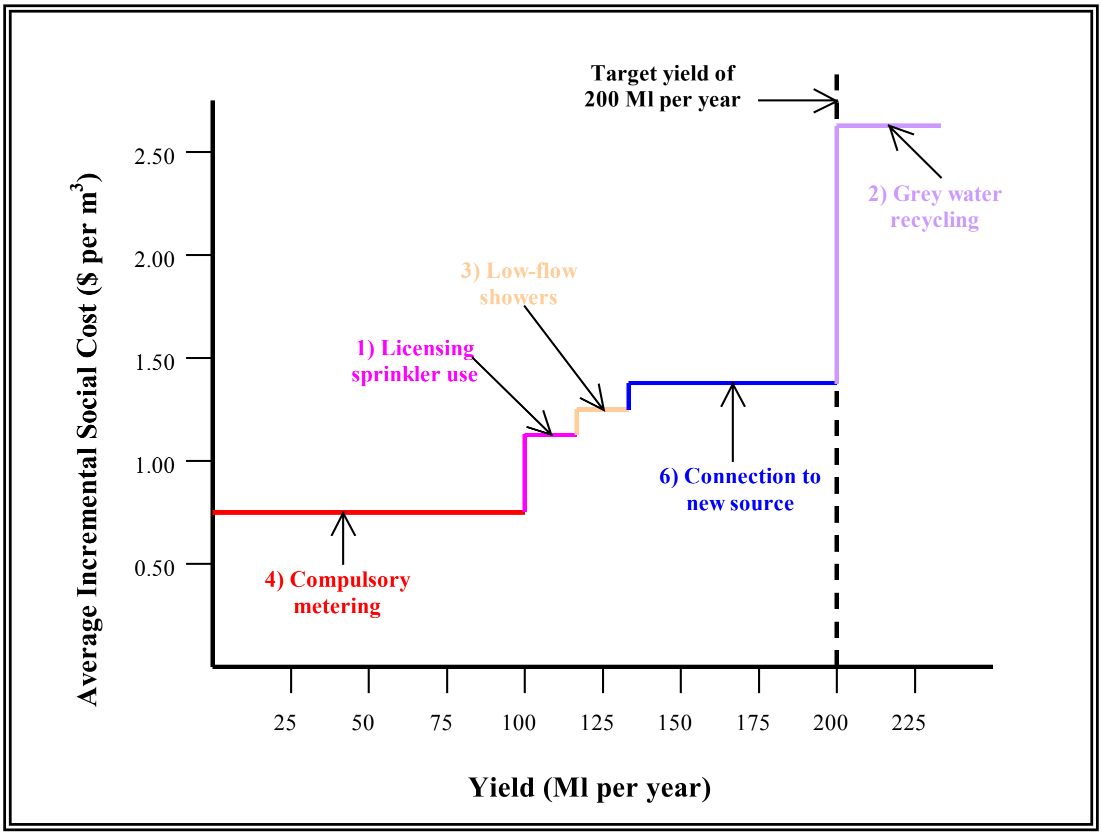
A useful way of presenting the analytical results from a cost-effectiveness analysis to use incremental cost curves. In the context of GHG limitation, incremental abatement cost curves are frequently used to express the relationship between the minimum cost to society of reducing an additional tonne of GHG and the corresponding level of emission reduction. Cost curves can also be readily developed for scenarios to balance water supply and demand, meet health targets, etc. Regardless of the exact context, costs and the desired deliverable are always defined relative to the reference case. Typically, the project or policy output (e.g. m^3 of raw water per day) is presented on the horizontal axis, and the cost of providing one unit of output (e.g. pence per m^3) on the vertical axis. Constructing costs curves begins by determining the cost-effectiveness of those (adaptation) options under consideration (using the methods described earlier). Adaptation options are then sequentially ranked in order of increasing unit costs. Incremental cost curves therefore tend to rise to the right, reflecting the fact that increased levels of climate risk management can be achieved at higher and higher unit costs.

An example of an incremental cost curve, in the context of a water scarcity problem, is shown in Box 5.9.

Box 5.9: Example of an Incremental Cost Curve

Figure 5.2 below summarises the results of a (hypothetical) cost-effectiveness analysis of various options to address a water supply shortfall of 200 Ml per year. The figure represents an incremental cost curve, in that the feasible set of total water management options considered are ranked in order of their (expected) average incremental social cost. From Figure 5.2 and the underlying data set, the minimum (social) cost programme of options to meet the supply shortfall can be determined. In the example portrayed in Figure 5.2 options 4 (implementation of compulsory metering), 1 (licensing of sprinkler users), 3 (installing low-flow showerheads) and 6 (building an interconnection to a new water source) represent the least-cost programme to achieve the yield objective of 200 Ml per year.

Figure 5.2: Incremental Social Cost Curve for Total Water Management Options



Adapted from UKWIR/EA (1996)

5.7 Options Appraisal Under Uncertainty

5.7.1 Context of Guideline

Decision problems may be classified according to the degree of knowledge the decision-maker has about future outcomes. In general, there are two states of knowledge, which a decision-make can have: (1) perfect certainty and (2) uncertainty (where, in the extreme case, the decision-maker has very poor knowledge of the probability of an event being realised, and the magnitude of the likely consequences arising from this event). In general, as the decision-maker's knowledge of the exact nature of each possible outcome increases, we move from a situation characterised by uncertainty towards one of certainty. Most climate change-related decision problems will involve situations between extreme very poor knowledge and perfect foresight. To support the decision-maker in selecting the 'best' (or preferred) option(s) in the presence of uncertainty, alternative techniques are required to those typically used under conditions of certainty. In this Guideline we consider techniques and decision-rules applicable to each level of knowledge.[136]

Since the estimated outcome descriptors determine the choice of the 'best' option(s) – regardless of the decision-rule used - the decision-maker may want to know how sensitive the cost-benefit estimates are to the input data and the modelling approach used by the analyst, as well as the key assumptions (s)he adopts. Several techniques exist for coming to grips with those key factors that underpin the estimated outcomes in a decision problem. Guidance on these techniques is also provided herein.

5.7.2 Making Decisions Under Conditions of Certainty

A situation of **certainty** exists if the decision-maker has complete knowledge of every element of the decision problem (e.g. the probability of an event or state-or-nature being realised, and the magnitude of the likely consequences arising from exposure to this event or state-of-nature). In this case the decision-maker is therefore certain of the outcome associated with each option. Since each option leads to a unique outcome, the decision problem of choosing among alternative options is reduced to one of choosing among outcomes. For example, if following the application of these Costing Guidelines we reduced the resource costs and associated benefits of each adaptation option to a single aggregate

[136] See DETR (2001b) for further guidance on this topic. Posted at: http://www.environment.detr.gov.uk/eramguide/index.htm

descriptor – net benefit – then, *if* the decision-maker's sole decision criterion were maximisation of net benefit, the solution to the decision problem would be simply a matter of selecting the option with the highest net benefit. The preferred option is the one, which leads with *certainty*, to the 'best' outcome.

To support the decision-maker in selecting the 'best' option under conditions of certainty, when outcomes are described in money terms, we can test the social decision rule embodied in **cost-benefit analysis** (CBA) through the application of one of the following option selection criteria:

- net present value;
- internal rate of return; or
- benefit cost ratio.

These three decision criteria are *only* applicable when the worth of an option is gauged solely in terms of a single dimension – namely, economic value. Multi-criteria techniques are required when attainment of the state of affairs desired is judged against multiple decision criteria (see Section 5.9.3).

Net Present Value

The **net present value** (NPV) of an adaptation option is given by the present value of the estimated benefits net of costs. For an independent option, i.e. a course of action that is not in any way a substitute for another course of action, the NPV decision rule is to "*accept the option if its NPV is greater than zero*". A positive NPV simply indicates that the incremental benefits of the option under study exceed the incremental resource costs.

Algebraically, the NPV of an adaptation option requiring an investment expenditure in year zero of C_0, and producing a stream of net benefits between the time periods 0 and *N* (given by the incremental recurring resource costs minus incremental recurring climate change impacts avoided) $NB_0, NB_1, NB_2, ..., NB_N$, is given by:

$$\text{NPV} = \sum_{n=0}^{N} \frac{NB_n}{(1+i)^n} - C_0 \qquad (5.4)$$

Alternatively, the NPV of an adaptation option yielding an incremental benefit stream of $B_0, B_1, ..., B_N$ and an incremental resource cost stream of $C_0, \mathrm{C}_1, ..., \mathrm{C}_N$ is given by:

$$\text{NPV} = \underbrace{\sum_{n=0}^{N} \frac{B_n}{(1+i)^n}}_{\text{Present value benefits}} - \underbrace{\sum_{n=0}^{N} \frac{C_n}{(1+i)^n}}_{\text{Present value costs}} = \underbrace{\sum_{n=0}^{N} \frac{B_n - C_n}{(1+i)^n}}_{\text{Present value net benefits}} \quad (5.5)$$

The above equations are equivalent; but the latter is more commonly applied in cases where the investment expenditures accrue over several years.

If the decision-maker is faced with a choice between options that are mutually exclusive - in the sense that they are alternative ways of adapting to the same impact, or they compete for the same site, (s)he should rank them in decreasing order of NPV, and select the option(s) with the largest NPV. Hence, if the NPV of option A_1 is greater than the NPV of option A_2, and only one option can be selected, the decision-maker should select the option A_1.

NPV Decision Rule: Select options so as to maximise the NPV of the investment expenditure, or equivalently, undertake those adaptation options who's NPV is positive at chosen discount rate.

Internal Rate of Return

An alternative to NPV for appraising options under conditions of certainty is the **internal rate of return** (IRR). The IRR is defined as the discount rate $\hat{i}$ that equates the present value benefits and the present value resource costs of an option, i.e. the IRR is the rate $\hat{i}$ that causes:

$$\sum_{n=0}^{N} \frac{B_n}{(1+\hat{i})^n} = \sum_{n=0}^{N} \frac{C_n}{(1+\hat{i})^n} \quad (5.6)$$

We can rearrange the above equation to yield:

$$\sum_{n=0}^{N} \frac{B_n}{(1+\hat{i})^n} - \sum_{n=0}^{N} \frac{C_n}{(1+\hat{i})^n} = 0 \quad (5.7)$$

The left-hand-side of the above equation is in fact the formula for NPV. Consequently, the IRR can also be defined as the discount rate ($\hat{i}$) that makes an option's NPV equal to zero.

When an option's IRR exceeds the discount rate, the investment expenditure generates sufficient benefits (forgone climate change impacts) to cover these costs and provide some additional net benefit. This leads to the following decision rule.

IRR Decision Rule: An adaptation option is acceptable if its IRR is greater than the selected rate of discount (in which case the NPV of the option will be positive).

The IRR is widely used in business, where decision-makers are used to rate of return concepts. However, one needs to be careful when using the IRR criterion to rank mutually exclusive options relative to one another. In some cases, the IRR criterion will produce different rankings to the NPV criterion.[137] This inconsistency when ranking options using the IRR is one of the reasons why the Green Book recommends that NPV is the primary criterion for deciding whether government action is justified. Readers in government departments and executive agencies should note this preference for the NPV rule.

Benefit-cost Ratio

The other main alternative to NPV is the **benefit-cost ratio** (B/C), which is simply the ratio of the present value benefits to the present value costs – that is:

$$\mathrm{B/C} = \frac{\sum_{n=0}^{N} \frac{B_n}{(1+i)^n}}{\sum_{n=0}^{N} \frac{C_n}{(1+i)^n}} \quad (5.8)$$

When the B/C ratio is greater than one the present value of the option's benefits must be greater than the present value costs. This implies that the option must also have a positive NPV, and consequently it should be accepted.

B/C Ratio Decision Rule: Accept adaptation options with a B/C ratio greater than one (in which case the NPV of the option will be positive).

137 As discussion of these concerns, and recommended corrective actions, is beyond the scope of this report, the interested reader is referred to any good text on capital budgeting, e.g. Bierman and Smidt (1993); or Brealey and Myers (1991).

As with the IRR, caution is required when ranking options according to their B/C (a higher B/C being preferred to a lower B/C), since it is possible to produce different rankings to the NPV criterion. Again, this inconsistency when ranking options leads the Green Book to recommend the NPV rule over the B/C rule.

The application of each of the above decision rules to a hypothetical option is illustrated in Box 5.10 below.

Box 5.10: Testing the Social Decision Rule Embodied in CBA Under Conditions of Certainty

Suppose an adaptation option requires an outlay today of £800,000 million and has recurring annual costs of £10,000, but is expected to reduce climate change-related damages annually by £100,000 for the next 30 years. Suppose the discount rate of the implementing agency is 8 percent.

The NPV of this option is positive, being £203,201. The calculations are summarised in Table 5.10 below. Since the NPV of this option is positive, it passes the social decision rule test.

Table 5.5: Summary of NPV Calculations

Year	0	1	2	3	→	30
1 Discount factor	1.000	0.9259	0.8573	0.7938	→	0.0994
2 Investment expenditure	£800,000	-	-	-	→	-
3 Recurring costs	-	£10,000	£10,000	£10,000	→	£10,000
4 Total costs (3 + 4)	£800,000	£10,000	£10,000	£10,000	→	£10,000
5 Discounted total costs (4 * 1)	£800,000	£9,259	£8,573	£7,938	→	£994
6 **PVC** (sum line 5)	£912,578					
7 Recurring benefits	-	£100,000	£100,000	£100,000	→	£100,000
8 Discounted benefits (7 * 1)	-	92,593	85,734	79,383	→	9,938
9 **PVB** (sum line 8)	£1,125,778					
10 **NPV** (9 - 6)	**£203,201**					

The IRR of this option is just over 10.7 percent; this is the discount rate that equates the PVB and the PVC. As expected, the option passes the social decision rule according to the IRR criterion, since the IRR is greater than the selected discount rate.

As the NPV is positive we would expect the B/C ratio also to be positive, which is the case:

B/C = PVB ÷ PVC = £1,125,778 ÷ £912,578 = 1.23.

Hence, the option is also accepted with the B/C criterion – the B/C is greater than 1.

5.7.3 Making Decisions in the Presence of Uncertainty: the knowledge is still good

Most climate adaptation decisions involve some degree of uncertainty about the possible range of outcomes for a given option (e.g. either the likelihood of an event or state being realised is unknown, and/or the consequences of that event or state for exposure units and receptors is unknown). Although not certain, the decision-maker may nonetheless have good knowledge of the probability of occurrence of each event/state.

The main ('**probabilistic**') selection criteria commonly used to aid decision-making under conditions of risk are:

- the expected value criterion;
- the expected utility criterion; and
- expected value-risk analysis.

While the following discussion is presented in terms of a monetary outcome descriptor, the former two methods can be applied to outcomes measured in other (physical) units.[138]

Expected Value

To explain the techniques that can be used to support decision-making under conditions of uncertainty it is first useful to introduce the concept of a probability distribution of outcomes. Consider an example in which the decision-maker has to choose between three adaptation options, where the NPV of each depends on the anticipated future flow regime in a river. Suppose the decision-maker is relatively confident about the probability

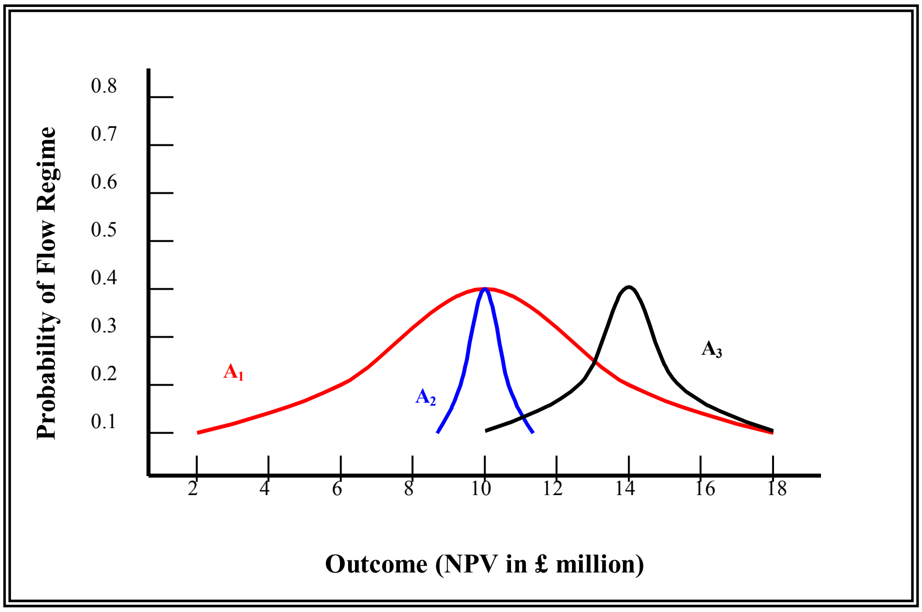
[138] For example, demographic statistics can assume expected values, and the von Neumann-Morgenstern utility functions, which underpin the expected utility criterion, also provide the foundations for multi-attribute utility theory.

of occurrence of each of five predicted flow regimes (or states of nature), and knows with certainty the consequences associated with each flow regime. This situation is shown in Table 5.6 below. The corresponding **probability distribution** of the outcomes associated with each option is shown in Figure 5.3.

Table 5.6: Example Outcome Array – NPV of Adaptation Options Under Five Flow Regimes (£ million)

Options	State-of-Nature				
	S_1	S_2	S_3	S_3	S_3
Probability	0.10	0.20	0.40	0.20	0.10
A_1	2.0	6.0	10.0	14.0	18.0
A_2	9.0	9.5	10.0	10.5	11.0
A_3	10.0	12.5	14.0	15.5	18.0

Figure 5.3: Example Probability Distribution – NPV of Adaptation Options Under Five Flow Regimes (States of Nature)



Since the decision-maker is able to assign a probability distribution to the likely flow regimes, (s)he can calculate the **expected net present value** of each option as follows (note that the Green Book refers to this as the **risk adjusted NPV**):

$$E(A_i) = P_1 \times O_{i1} + P_2 \times O_{i2} +,...,+ P_n \times O_{in} = \sum_{j=1}^{n} P_j \times O_{ij} \tag{5.9}$$

where

$E(A_i)$ = expected NPV of option i,

P_j = probability of state-of-nature j occurring,

O_{ij} = the outcome associated with option i when state-of-nature j occurs and

n = the number of possible states of nature.

The expected NPV of each of the adaptation options listed in Table 5.6 is thus:

$E(A_1) = 0.1 \times £2.0 + 0.2 \times £6.0 + ,\ldots, + 0.1 \times £18.0 = £10.0$ million

$$E(A_2) = 0.1 \times £9.0 + 0.2 \times £9.5 + ,\ldots, +0.1 \times £11.0 = £10.0 \text{ million}$$

$$E(A_3) = 0.1 \times £10.0 + 12.5 \times £10.0 + ,\ldots, +0.1 \times £18.0 = £14.0 \text{ million}$$

Since the outcomes in this case are described in terms of NPV, the decision-maker should select the option with the largest **expected net present value** (ENPV) – that is, option A_3. Conversely, if the outcomes are described in terms of net costs, the option with the lowest expected net cost should be chosen.

ENPV Decision Rule: Select adaptation options so as to maximise the ENPV – choose the option with the highest ENPV.

A criticism of ranking options based on the EPVV criterion is that it ignores the 'riskiness' (or the 'dispersion' of expected outcomes) of each option.[139] This is illustrated in the above example, where adaptation options A_1 and A_2 have the same ENPV, but different distributions of possible outcomes. The EMV criterion also makes an assumption about the decision-maker's attitude towards risk, specifically, that (s)he is risk-neutral. Decision-makers are not, in general, risk-neutral.

An alternative to the ENPV criterion is the expected utility criterion; another alternative is expected value-risk analysis.

Box 5.11: Common Measures of 'Riskiness'

Measures of the risk associated with an option relate to certain characteristics of the probability distribution of outcomes for that option. Roughly speaking, the 'riskiness' of selecting an option is measured in terms of the variability of its outcomes – the more dispersed the possible outcomes are from the expected (mean) value, the less likely the actual outcome will fall within a given range of the expected value, and thus the more risky the option.

One measure of the magnitude of variability around the mean, and hence risk, is the standard deviation. The **standard deviation** (SD) of a distribution of outcomes is defined as the square root of the **variance**. The variance itself is the average of the squared distance of each outcome from the mean. Using the same notation as above, the SD of option i is calculated as:

[139] Two of the most common measures of 'riskiness' are standard deviation and coefficient of variance. These are defined below.

$$\mathrm{SD}_i = \sqrt{\sum_{j=1}^{n} P_j \times \left(\mathrm{O}_{i\,j} - \mathrm{E}(\mathrm{A}_i)\right)^2} \qquad (5.10)$$

The higher the SD, the flatter the probability distribution of outcomes and the higher the risk; whereas, the lower the SD, the tighter the probability distribution and the lower the risk. For the decision problem presented above, the SD of each of the adaptation options considered is: $SD_1 = 4.38$; $SD_2 = 0.55$ and; $SD_3 = 2.02$. Hence, in terms of SD, option A_2 is less risky than A_3, which is less risky than A_1. These conclusions are confirmed by observing the distributions shown in Figure 5.3.

However, alternative options may have probability distributions which appear to differ in 'riskiness', but which have the same SDs; this is possible if the expected values differ significantly. To compensate for different magnitudes of outcomes, one can calculate the **coefficient of variance** (V) for each option under consideration. This is computed as:

$$\mathrm{V}_i = \frac{\mathrm{SD}_i}{\mathrm{E}\left(\mathrm{A}_i\right)} \qquad (5.11)$$

Returning to our example decision problem, the coefficient of variance for each of the options considered is: $V_1 = 0.44$; $V_2 = 0.05$ and; $V_3 = 0.14$. Using this measure of risk, option A_1 is more risky than A_3, which is more risky than A_2.[140]

Expected Utility Criterion

Preferences for risk typically are described in terms of the decision-maker's attitude toward actuarially fair gambles (see Box 5.12 below). If the decision-maker rejects all such gambles, then they are said to be **risk-averse**. The risk-averse decision-maker may also be viewed as someone who is willing to pay a positive amount to avoid risk. If the decision-maker prefers to take actuarially fair gambles, then they are said to be a **risk-lover**; such an individual would pay for the privilege of participating in the gamble. A decision-maker who is indifferent to such gambles is said to be **risk-neutral**.

[140] The reader should note that an accurate assessment of the 'riskiness' of an option will not solely be based on SD and V, but also on other aspects related to the shape of probability distribution of outcomes, e.g. skewness, range, modal outcome, etc.

Box 5.12: Actuarially Fair Gambles

An **actuarially fair gamble** exists when the mean outcome of the gamble is equal to the 'price' of playing. Suppose, for example, an individual is offered the privilege (free of charge) of playing the following gamble: They *receive* £1 if a tossed coin lands on 'heads'. However, they must *pay* £1 if the coin lands on 'tails'. Since the probability of 'heads' or 'tails' is one half, this is an actuarially fair gamble. The expected value of the gamble is

$$0.5 \times £1 + 0.5 \times -£1 = £0$$

which is the 'price' paid to play.

These different preferences to risk are captured in the decision-maker's utility function. Consider Figure 5.4, for example, which displays the utility function for a risk-averse (panel a) and risk-neutral (panel b) decision-maker.[141,142] (Utility is measured on the vertical axis and outcomes on the horizontal axis.) An improved understanding of both these attitudes towards risk can be gained from these curves.

Assume the risk-averse decision-maker in panel (a) starts with W_1 (baseline 'wealth'). The corresponding level of well-being or utility is $U(W_1)$. Now, suppose (s)he is offered a bet of £5 on the toss of a coin, which is accepted. If they lose, the new level of wealth will be W_2, where W_2 equals W_1 minus £5. Alternatively, if they win, the new level of wealth will be W_3, where W_3 equals W_1 plus £5. However, since this decision-maker is risk-averse, they are not concerned with additions to wealth per se. Rather, they are interested in changes in utility. One can see from panel (a) in Figure 5.4 that the absolute magnitude of the loss of utility associated with losing the gamble, $U(W_1)$ minus $U(W_2)$, is greater than the gain in utility from winning, $U(W_1)$ plus $U(W_3)$. In contrast, for the risk-neutral decision-maker, the absolute magnitude of the changes in utility are equal for the £5 loss or the £5 gain – that is, $U(W_1)$ minus $U(W_2)$ equals $U(W_1)$ plus $U(W_3)$.

[141] The convex utility function of a risk-lover is not shown.

[142] An explanation of how to construct the utility functions shown in Figure 5.4 is beyond the scope of this report; an explanation may be found in any good text on Decision Analysis or Applied Microeconomics.

It is important to note that the axioms, which must be accepted if we are to believe that individuals in a risky situation seek to maximise the expected utility of outcomes, have not escaped criticism; an accessible critique is provided in Turner, Pearce and Bateman (1994).

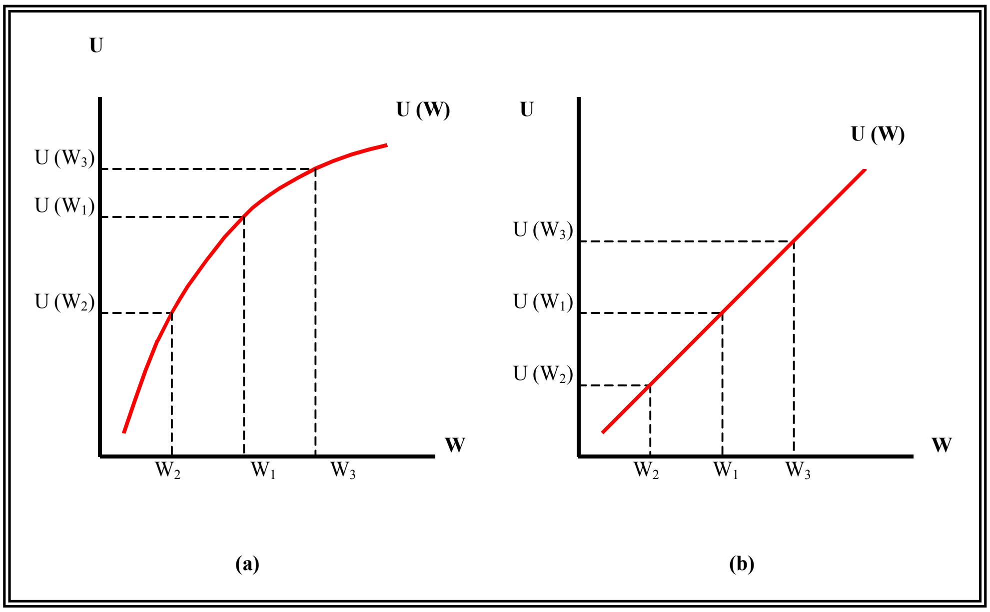


Figure 5.4: Utility Functions and Risk Preferences

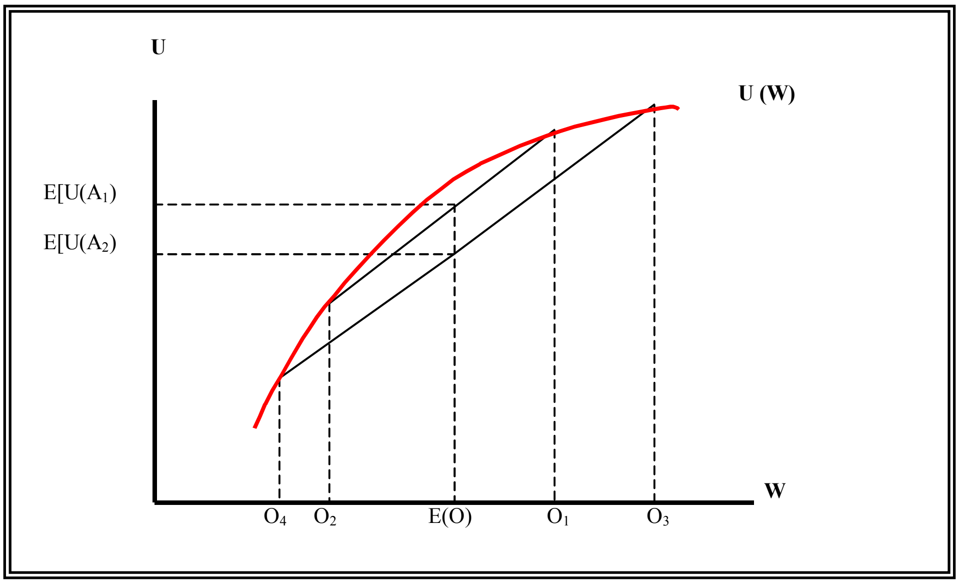
How can this method be used to make comparisons between options under conditions of risk? To answer this question consider Figure 5.5.

Suppose that adaptation option A_1 yields a NPV of O_1 or O_2, depending on which state-of-nature occurs, with probabilities p and $(1 - p)$, respectively. Hence the expected NPV, ENPV(O), is given as $p \times O_1 + (1 - p) \times O_2$. In contrast, option A_2 provides a chance of a much greater NPV, O_3, but also a chance of a much smaller NPV, O_4. (note that to simplify the diagram this example has been constructed such that both options have the same ENPV. This does not change any of the conclusions however.) Given the risk-averse utility function shown in Figure 5.5, the expected utility of option A_1 is greater than that of option A_2 – i.e. $E[U(A_1)] > E[U(A_2)]$.[143] As more utility is assumed to be preferable to less utility, the decision-maker will select option A_1.

Expected Utility Decision Rule: Select adaptation options so as to maximise expected utility – choose the option with the highest expected utility.

143 $E[U(A_1)] = p \times U(O_1) + (1 - p) \times U(O_2)$ and $E[U(A_2)] = p \times U(O_3) + (1 - p) \times U(O_4)$.

Figure 5.5: Option Selection Using Expected Utility: Risk-averse Decision-maker



One can also see from Figure 5.5 that the dispersion of outcomes associated with option A_2 is greater than for option A_1. A risk-averse decision-maker, when faced with a choice between two options with the same ENPV, will select the option with the smaller distribution of outcomes. Equally, if two options have the same dispersion of outcomes, but different ENPVs, the highest ENPV will provide the highest expected utility. This leads to the following decision rule: adaptation option A_1 is preferred to option A_2 if:

$ENPV(A_1) > ENPV(A_2)$ And $SD(A_1) = SD(A_2)$

or

$ENPV(A_1) = ENPV(A_2)$ And $SD(A_1) < SD(A_2)$

since in both cases the $E[U(A_1)] > E[U(A_2)]$.

However, the above example is a special case in which either the ENPV *or* the measure of 'riskiness' (e.g. SD) is the same for each option under consideration. What if:

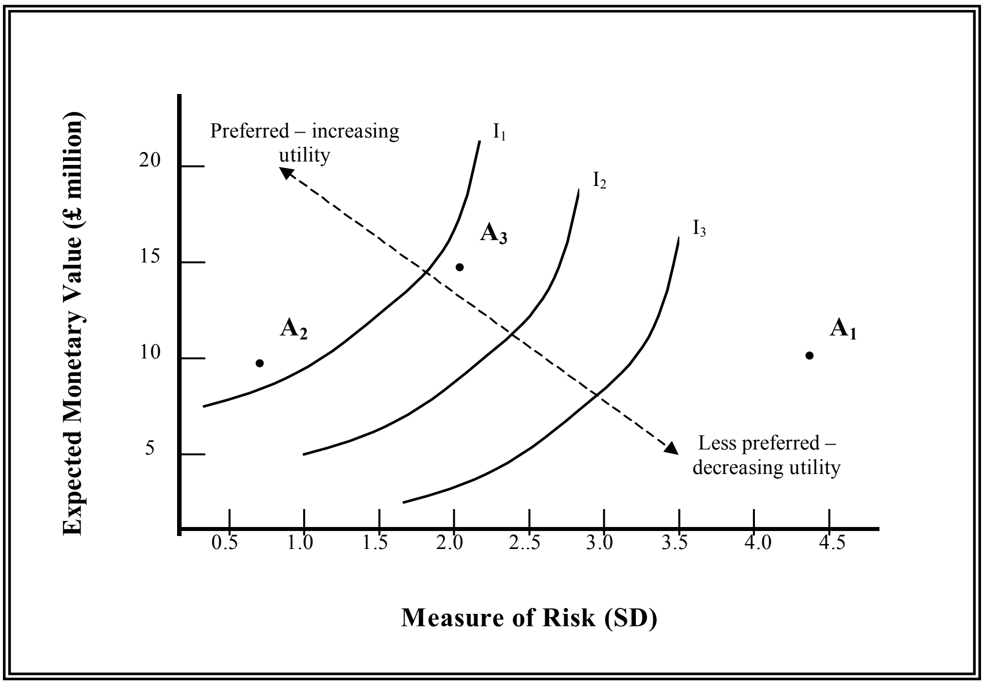
$ENPV(A_1) < ENPV(A_2)$ And $SD(A_1) < SD(A_2)$

In this case the decision-maker must trade-off expected value with the level of associated risk. In order to select the 'best' option, the decision-maker must therefore estimate the expected utility associated with each option, using the method described above. Alternatively, the decision-maker can use expected value-risk analysis.

Expected Value – Risk Analysis

The other suggested alternative to the use of the ENPV criterion is to use expected value-risk analysis (also known as **risk-benefit plotting**). This involves plotting on a diagram the ENPV and 'riskiness' of each option under consideration. Using SD as a measure of risk, Figure 5.6 shows the results for the example decision problem presented above.[144] The decision-maker's attitude towards risk is represented by so-called **indifference curves** – lines I_1, I_2 and I_3. Each of these curves joins combinations of ENPV and 'riskiness' to which the decision-maker is indifferent. For risk-averse decision-makers, ENPV has positive value whereas 'riskiness' has negative value. In order to induce the decision-maker to accept a 'riskier' combination of options, one must therefore increase the ENPV of that combination of options. As a result, the indifference curves have a positive slope.[145]

Figure 5.6: Example of Expected of Value-Risk Analysis



[144] This graphical representation of expected value and risk provides the basis for **portfolio theory**.

[145] For a given ENPV, a risk-neutral decision-maker is indifferent regarding alternative levels of 'riskiness', in which case the indifference curves would be horizontal lines. If the decision-maker is a risk-lover, (s)he would prefer a greater ENPV and 'riskiness', in which case the indifference curves would have a negative slope.

Since a higher ENPV is preferred to a lower ENPV for the same level of 'riskiness', the decision-maker increases utility by moving to the top left-hand corner. Given the indifference curves shown in Figure 5.6, the decision-maker should select option A_2; options A_3 and A_1 are on lower indifference curves.

EMV-Risk Analysis Decision Rule: Options on indifference curves closer to the top left-hand corner represent combinations of ENPV and 'riskiness' which are preferred (yield higher utility) to those on curves in the lower right-hand corner.

It should be realised that the above analysis ignores the possibility that the expected outcomes from one adaptation option may be correlated with those of other options. If correlation is suspected, then **portfolio analysis** should be used. Portfolio analysis is discussed in Willows and Connell (2003).

5.7.4 Making Decisions in the Presence of Uncertainty: knowledge is very poor

Various decision-support techniques have been developed which do not require knowledge of, for example, the likelihood of an event/state occurring, in which case the determination of an expected value would not be possible. These so-called '**non-probabilistic**' criteria simply involve the application of predefined rules to the outcome arrays.. The main rules suggested by decision theorists, which are considered below, include:

- the maximin criterion;
- the minimax regret criterion;
- the maximax criterion;
- the Hurwicz α-criterion and;
- the Laplace criterion.

In outlining each technique the example decision problem shown in Table 5.7 is used. For ease of presentation only a single outcome descriptor is used – i.e. NPV. In the case of multiple descriptors (objectives), then multi-criteria techniques are required (see Section 5.9.3).

Table 5.7: Decisions When Knowledge is Very Poor: Example Outcome Array

		State-of-Nature		
		S_1	S_2	S_3
Options	A_1	O_{11} = £200	O_{12} = £175	O_{13} = £150
	A_2	O_{21} = £0	O_{22} = £300	O_{23} = £600
	A_3	O_{31} = -£150	O_{32} = £150	O_{33} = £450

The Maximin Criterion

The first step with this criterion is for the decision-maker to identify the 'lowest' outcome (NPV) resulting from each adaptation option. If we do this for the outcome array in Table 5.7 we obtain:

Option	Minimum Outcome
A_1	£150
A_2	£0
A_3	-£150

The decision rule under this criterion is to select the largest of these 'lowest' outcomes, i.e. **max**imise the **min**imum NPV. Accordingly, the decision-maker should select adaptation option A_1.

This criterion is inherently 'conservative' or 'pessimistic' as it focuses on the minimum possible outcome associated with each option – that is, the decision-maker simply attempts to avoid the worst possible consequence. Indeed, it is the most risk-averse criterion. Since the criterion fails to consider the magnitude of each outcome, it could lead to the selection of one option, despite very large benefits being associated with alternative options. For example, the criterion completely disregards the fact that by selecting A_2 the decision-maker could possibly accrue £600.

The Minimax (Regret) Criterion

With this criterion the decision-maker is concerned with the 'loss' experienced if one state-of-nature occurred, but instead of selecting the option with the maximum NPV associated with this state, an alternative option is chosen. Consequently, the 'loss' experienced by the decision-maker is defined as the difference between the maximum NPV and the actual NPV. Performing this calculation for each outcome produces a so-called '**regret matrix**', like the one shown in Table 5.8 below.

Table 5.8: Regret Matrix

		State-of-Nature		
		S_1	S_2	S_3
Options	A_1	£200-£200=£0	£300-£175=£125	£600-£150=£450
	A_2	£200-£0=£200	£300-£300=£0	£600-£600=£0
	A_3	£200-(-£150)=£350	£300-£150=£150	£600-£450=£150

The aim of the criterion is to **mini**mise the **max**imum ('loss') regret. The maximum regret for each of the three options is given by:

<u>Option</u>	<u>Maximum Regret</u>
A_1	£450
A_2	£200
A_3	£350

Therefore, as the decision-maker wishes to minimise the maximum regret, the 'best' option is to select action A_2.

As the criterion strives to avoid the greatest foregone outcome it can also be regarded as 'pessimistic'. This criterion should be used with caution, since it can be inconsistent in selecting the 'best' option from a group of alternative options. It is possible to hypothesise situations where, for example, in the presence of three options (A_1, A_2 and A_3), A_3 represents the 'best' option, yet if A_1 is removed as an alternative, A_2 might turn out to be the 'best' option, even though A_3 is still among the alternatives.

The Maximax Criterion

This criterion is at the other end of the spectrum to the maximin criterion. The decision-maker first identifies the maximum (NPV) outcome associated with each option and then selects the largest of these maximum outcomes. In other words, the decision-maker simply selects the largest outcome in the outcome array, and chooses the corresponding option. From Table 5.8 the largest net benefit associated with each option is:

Option	Maximum Outcome
A_1	£150
A_2	£600
A_3	£450

Hence, in **maxi**mising these **max**imum outcomes, the decision-maker would select option A_2.

Clearly, this criterion is overly 'optimistic' and can expose the decision-maker to significant risks. According to the maximax criterion action a_2 is the optimal strategy. Again, it is possible to hypothesise decision problems where the NPV associated with the 'best' option – according to the maximax criterion - is only marginally greater than that of the alternative options under the same state-of-nature, yet it exposes the decision-maker to the risk of significant losses (e.g. costs) if other states of nature occur.

The Hurwicz α-Criterion

The Hurwicz α-criterion is an attempt to bridge the gap between the two extremes of the maximax and maximin criteria. It requires the decision-maker to calculate an α-index, $h(a_i)$, for each alternative option:

$$h(a_i) = \alpha \; O_i^{\min} + (1-\alpha) \; O_i^{\max} \tag{5.12}$$

where

$O_i^{\min}$ = the minimum NPV from option i,

$O_i^{\max}$ = the maximum NPV from option i and

α = A pessimism-optimism index.

The index is essentially a weighted average of the minimum and maximum outcomes associated with each option.[146] The option with the largest α-index is then selected.

The first step in using this criterion is for the decision is to identify the 'worst' and 'best' outcomes associated with each alternative option – that is:

[146] Note that when α = 1 all the weight is put on the minimum outcome, hence the criterion is equivalent to the maximin criterion. In contrast, when α = 0 all the weight is put on the maximum outcome, and the criterion is equivalent to the maximax criterion.

Option	**Maximum Outcome**	**Minimum Outcome**
A_1	£200	£150
A_2	£600	£0
A_3	£450	-£150

Next the value of α must be derived. One method of accomplishing this is to present the decision-maker with a series of hypothetical choices between two alternative options, as is shown in Table 5.9. In this example the value of x is gradually increased from an initial value of zero until the decision-maker declared indifference between A_1 and A_2. For example, when x is equal to 0.25 the decision-maker may declare a state of indifference. At indifference, both options are assumed to have an identical α-index (i.e. $x = 1 - \alpha$). As x is known, α can be readily calculated - in this case α is equal to 0.75.

Table 5.9: Generating a Value for Alpha

Options	**State-of-Nature**		
	S_1	S_2	$h(a_i)$
A_1	0	1	$1-\alpha$
A_2	x	x	x

Given that α = 0.75, the α-index corresponding to the outcome array displayed in Table 5.7 is:

Action	**Alpha-index**	
A_1	162.5	$= 0.75 \times 150 + 0.25 \times 200$
A_2	150.0	$= 0.75 \times 0 + 0.25 \times 600$
A_3	0.0	$= 0.75 \times -150 + 0.25 \times 450$

The adaptation option with the largest α-index represents the 'best' option, thus action A_1 is selected.

A criticism of the criterion is that it only considers the maximum and minimum outcomes, and therefore ignores the intermediate outcomes of the 'best' option under other states of nature, even if they are significantly lower than those of other options.

The Laplace Criterion

This criterion, which is also known as the **principle of insufficient reason** or **Baye's criterion**, simply involves assigning **equal** probabilities to each state-of-nature. The rationale behind the assignment of equal probabilities is that because the decision-maker has no idea as to which state-of-nature will occur, everything is equally probable – hence, the so-called 'principle of insufficient reason'. Therefore, if there are n states of nature, the probability that each will occur is $1/n$. Once a probability is ascribed to each state-of-nature, the ENPV of each option can be computed. The decision-maker can then simply select the option with the highest ENPV in this case (i.e. employ the ENPV decision criterion).

Returning to the example, as there are three states of nature, the probability that each state will occur is 1/3 or 33.33%. The expected value of each option is thus computed as follows:

Action	ENPV	
A_1	£175	= 1/3 × £200 + 1/3 × £175 + 1/3 × £150
A_2	£300	= 1/3 × £0 + 1/3 × £300 + 1/3 × £600
A_3	£150	= 1/3 × -£150 + 1/3 × £150 + 1/3 × £450

Therefore, as the ENPV of A_2 is the highest, it should be chosen.

Assigning equal probabilities involves making an assumption about the real world on the basis of no sound reason, evidence or information. Accordingly, Pearce and Nash (1991) state that the Laplace criterion is "a dangerous rule to utilise".

Which Criterion to Use

Pearce and Nash (1991) suggest that the views of stakeholders should be taken into consideration when one of the above decision-support tools is selected. Their argument is that if stakeholders are cautious with respect to a particular course of action then a cautious criterion should be utilised. The opposite applies if the outlook of stakeholders is judged to be optimistic. For example, if the cost of being 'wrong' in the context of a particular decision problem is judged to be significant by stakeholders, the decision-maker is advised to use a 'pessimistic' rule, such as the maximin criterion. (Indeed, the Green Book considers the maximin criterion as the most important to consider in this context, since it represents the most risk-averse method.) In contrast, if the cost of being 'wrong' is judged to be relatively small, a more 'optimistic' rule is more suitable, such as the maximax criterion. This is another way of saying that the Hurwicz α-criterion should be used with a value for α which reflects the attitudes of stakeholders to the decision problem in question.

5.7.5 Assessing the Effect of Future Uncertainty on the Outcome Estimates

An analyst does not simply take a set of quantified climate change impacts and economic unit values out of a convenient file, combine them, and crank out NPV estimates. Since these estimates essentially determine the choice of the ‘best’ option, *the decision-maker may want to know how sensitive the future estimates are to the input data and modelling approach used by the analyst, as well as the key assumptions adopted*. Several techniques exist for coming to grips with the key factors that underpin the estimated outcomes in a decision problem, including:

- ♦ sensitivity analysis
- ♦ (Monte Carlo) simulation and
- ♦ interval analysis.

The latter two are examined briefly below; sensitivity analysis is considered in separate Guideline (see Section 5.8).

Monte Carlo Simulation

As mentioned in the guideline on Benefit Transfer, **Monte Carlo** simulation (or **simulation** for short) provides a rigorous approach to the treatment of uncertainty. Indeed, it is probably the most common approach used to evaluate the impact of future uncertainty on inputs to quantitative modelling.

In Monte Carlo simulation, three stages are generally followed to produce the desired results:[147]

- ♦ Establish equations to model the outcomes of each option/state-of-nature combination. These must reflect any interdependencies among variables.
- ♦ Specify probability density functions (PDFs) for each variable/parameter and assign random number ranges to each.
- ♦ Sample outcomes (typically computers are used to draw a large number of random samples from each of the underlying PDFs), calculate outcome descriptors, and record them. This is repeated a large number of times until an accurate picture of the distribution of

[147] A discussion of Monte Carlo simulation techniques is beyond the scope of these guidelines; the interested reader is referred to Fishman (1996).

possible outcomes has been built up.[148] This procedure is illustrated in Figure 5.7 below. Each curve in the figure represents a PDF for each of the inputs to the mortality cost calculation.

The resulting frequency distribution provides information about both:

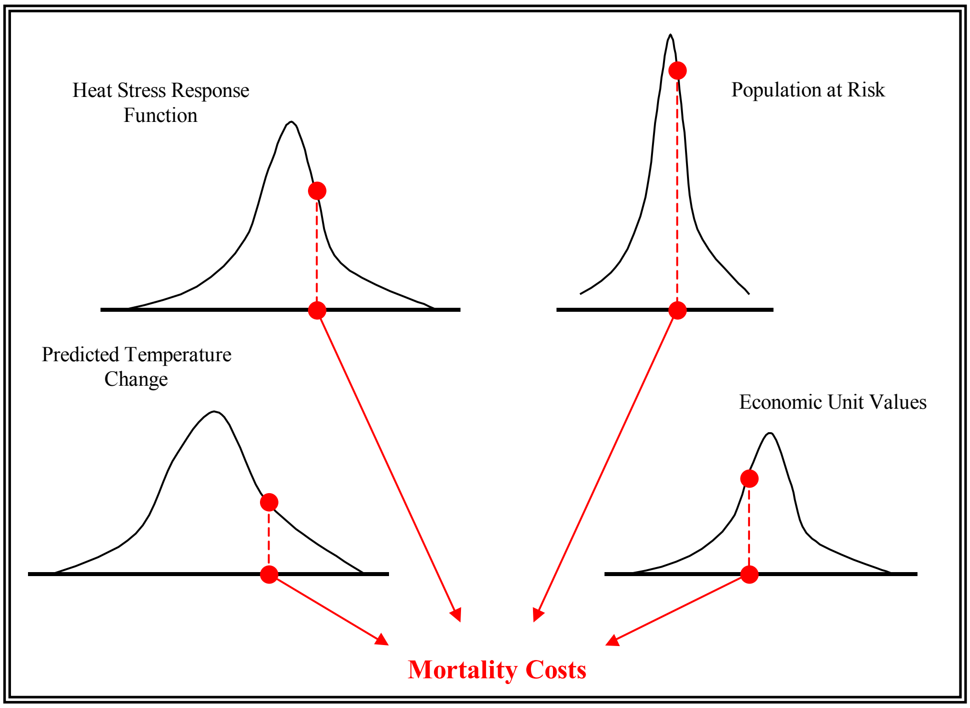
- the expected outcome (i.e. the **mean** value for the outcome descriptor) and
- how far it is likely to deviate from the mean (i.e. the **standard deviation**).

These two measures can be used to make statistical inferences, e.g. to identify the probability that the outcome will fall below some value. Monte Carlo simulation thus provides a robust indication of the overall level of uncertainty in the final results.

On the positive, side simulation forces explicit specification of interdependencies. However, in order to model these interdependencies they are often simplified, which can lead to an underestimation of the uncertainties. To simulate realistic scenarios it is therefore necessary to build complex models, which requires large amounts of data, effort and computer time. Add-ins to standard spreadsheet packages now exist which make Monte Carlo simulation more accessible.

[148] The precision of the constructed distribution increases with the number of draws made, but in most cases several hundred is sufficient to produce an acceptable approximation of the mean distribution (Desvousges, Johnson and Banzhaf, 1998).

Figure 5.7: Illustration of Monte Carlo Simulation Using Heat Stress - Related Mortality as an Example



Adapted from Desvousges, Johnson and Banzhaf (1998)

Box 5.13: Example of Monte Carlo Simulation: Heat Stress Related Mortality

Recall the example given in the Benefit Transfer Guideline (Section 4.11), where it is assumed that the impact of heat stress on the elderly is predicted by the following (hypothetical) relationship:

cases of premature death in 65 + year olds = exp (0.036 × change in ambient temperature) × base cases.

The (dose-response) coefficient 0.036 is the mean value derived from available data. Suppose that the mean change in ambient temperature is +1.5 ^{0}C in the study region and the mean number of base cases (deaths in the population at risk) is 360. The number of deaths resulting from the increase in temperature is thus given as:

exp (0.036 × +1.5) × 360 - 360 = 20 cases.

If the mean WTP to avoid a case in the affected population is, say

£120,000 per case, then the mortality cost is £2.4 million.

The above calculations used *mean* values for each of the model inputs. In Monte Carlo simulation, each of the model inputs is allowed to vary over its underlying PDF. In any given draw – as illustrated in Figure 5.7 above - the computer might select a dose-response coefficient of 0.040 instead of 0.036, a change in ambient temperature of +2.0 ^{0}C, an estimate of 400 base cases, and a WTP of £75,000 per case. For this draw the mortality cost is given as:

$$\exp(0.04 \times +2.0) \times 400 - 400 = 33 \times £75{,}000 = £4.5 \text{ million.}$$

This process is repeated large number of times until an accurate picture of the distribution of possible outcomes has been built up, from which the mean of the combined values can be determined with an acceptable level of confidence.

Adapted from Desvousges, Johnson and Banzhaf (1998)

Interval Analysis

As with simulation, interval analysis was introduced in the Benefit Transfer Guideline as a means of evaluating the effect of uncertainties on the final outcomes. **Interval analysis** simply involves taking the (absolute) lower value of the range of estimates for each model input, and combining them to define the *lower bound* of the final result; likewise, the (absolute) upper value of the range of estimates for each model input can be combined to define the *upper bound* of the final result. (An example is provided in Box 5.14 below.) In other words, interval analysis identifies the extreme lower and upper estimated outcomes for a given set of input variables, modelling assumptions, etc.

Since the probability of all the lower (upper) values occurring simultaneously is relatively small, the confidence interval for the final result is wider than those corresponding to the individual inputs.[149] While interval analysis produces very wide bounds to the final outcome, it is fair to say that the 'true' outcome will definitely fall somewhere within these bounds.

In general, interval analysis is less demanding than simulation: the data requirements are simple in that only the extreme values of each input are required, and no data are required on the PDFs of each model input. Care is required, however, when combining the extreme (lower/upper) values for model inputs to ensure that they are combined in such a way as to

[149] Chances are that some individual values will be high at the same time as others are low.

produce the lowest and highest possible combined outcome; this is not always as straightforward as it may appear.

Box 5.14: Example of Interval Analysis: Heat Stress Related Mortality

In the previous box, the following four elements were combined to estimate the mortality cost associated with heat stress in the elderly: (1) dose-response coefficient; (2) change in ambient temperature; (3) base cases and; (4) WTP to avoid a case. **Interval analysis** involves identifying the lowest (highest) value of the range of estimates for each of these variables, and combining them to define the lower (upper) bounds of the final result – the estimated mortality costs in this case. Suppose the lowest possible and highest possible value that each model input can assume is given by:

Model Input	Lowest Value	Highest Value
dose-response coefficient	0.00	0.103
change in ambient temperature	+0.5 ^{0}C	+2.5 ^{0}C
base cases	240	480
WTP to avoid a case	£35,000	£205,000

These values can be combined to yield, respectively, the extreme lower and upper estimated mortality cost:

$$\exp(0.00 \times +0.5) \times 240 - 240 = 0 \times £35{,}000 = £0.0 \text{ million}$$

$$\exp(0.103 \times +2.5) \times 480 - 480 = 141 \times £205{,}000 = £28.9 \text{ million}$$

If the uncertainties are properly represented, the ‘true’ mortality cost is guaranteed to fall somewhere within these bounds.

5.7.6 Assessing the effect of learning on future uncertainty: Quasi-option values

The analyst should consider that the optimal timing (and nature) of adaptation options might be dependent on whether new information about likely climate change impacts becomes available in the future. The value of this new information is known as quasi-option value (see e.g. Dixit and

Pindyck (1993) and Ulph and Ulph (1997) for further details of its use and in the climate change context, specifically). For example, new information in the future might suggest that climate change impacts are likely to be lower than was previously thought and that lower expenditure on adaptation options was therefore necessary. Conversely, the new information might suggest that higher, irreversible, climate change impacts are to occur now that adaptation expenditures have been delayed, and that future adaptation costs will therefore have to be higher. In these two cases the quasi-option value is positive and negative, respectively.

In the reverse – when this option value is not realized because the adaptation is undertaken without waiting for the new information – then the high, irreversible climate change impacts might be avoided, in which case the option value would be negative. Alternatively, the climate change impacts could be low, in which case expenditure on adaptation options would have been needlessly high, and the option value would be positive.

The size of these option values will be determined by the degree to which adaptation responses are flexible over time, relative to the degree of irreversibility of the climate change impact. For example, if the former is greater than the latter then the option value is more likely to be negative and so the adaptation response should be brought forward. These values are therefore - to a degree at least - likely to be sectoral-specific. Empirical estimates relevant to the UK climate change impacts context are not currently available, though the Tyndall Centre has recently commissioned work on this.

5.8 Sensitivity Analysis

5.8.1 Context of Guideline

The cost-benefit of climate change impacts on a single good or service, a particular sector or a collection of sensitive sectors, or of individual or portfolios of adaptation options, are typically calculated using the most likely (or **base case**) forecast values of costs/benefits. However, the stream of anticipated costs and benefits used to derive the final outcome(s) is influenced by a wide variety of factors (e.g. the input data and modelling approach used by the analyst) that may vary from the base case assumptions. Since the estimated final outcome(s) essentially determines the selection of the 'best' option, the decision-maker may want to know how sensitive the estimates are to these factors. Several techniques exist for coming to grips with the key factors that underpin the estimated outcomes in a decision problem, including:

- Monte Carlo simulation;
- Interval analysis; and
- Sensitivity analysis.

The former two methods are examined in Section 5.7.5. The focal point of this guideline is sensitivity analysis.

Sensitivity analysis focuses on alternative assumptions that have a significant effect on the study's results – the estimated outcome descriptor (e.g. NPV). It should be applied in all cases in which anticipated costs and benefits are quantified. The purpose of sensitivity analysis is to identify actions that can mitigate the effects of uncertainty, or to redesign the institutional structure of adaptation project to ensure maximum effectiveness.

Note that one form of bias in cost benefit analysis – optimism bias – requires sensitivity analysis to correct for it. Optimism bias is the tendency for project appraisers to be overly optimistic - tending to overstate benefits, and understate timings and costs, both capital and operational. The Treasury Green Book[150] states that "to redress this tendency, appraisers should make explicit adjustments for this bias. These will take the form of increasing estimates of the costs and decreasing, and delaying the receipt of, estimated benefits. Sensitivity analysis should be used to test assumptions about operating costs and expected benefits".

[150] http://greenbook.treasury.gov.uk/chapter05.htm#adjusting

5.8.2 Methodology

General

Sensitivity analysis involves recalculating the NPV for different values of major variables, where they are varied one at a time. Combinations of changes in values can also be investigated, in which case we are really referring to **scenario analysis**.

Sensitivity analysis involves four steps:

- Selecting those variables to which the estimated NPV may be sensitive.
- Determining the extent to which the value of such variables may differ from the base case – i.e. the values used in the costing study.
- Calculating the effect of different values on the estimated NPV by recalculating the NPV.
- Interpreting the results and designing mitigating actions, where necessary.

Some of the variables entering into cost and benefit streams will be, one, predictable, and two, small in value relative to total costs and benefits. In general, it is not necessary to investigate the sensitivity of the estimated NPV to such variables. Other variables however, will be relatively larger and less predictable. Post-completion audits of adaptation options and/or previous experience with similar economic studies may provide insights into both the type of variable that is less predictable (relatively more uncertain) and the likely extent of divergence from the base case value. There are also some types of variable in every economic study that are likely to affect the study's results, and are therefore consistently subjected to sensitivity analysis. Some likely candidates for sensitivity analysis include:

- Quantities of goods and services included in the economic analysis can be affected by changes in technical and/or market conditions. It is recommended that quantities be broken down into their underlying components, if possible - for example, agricultural output into yields and affected area - and the sensitivity of the estimated NPV to each of the constituent components assessed.
- Changes in the cost of affected goods and services may also occur because of changes in the price of any of the constituent components. The price of, for example, specific agricultural

commodities can fluctuate considerably from year to year. The influence of the future price assumptions adopted in the analysis (on the estimated NPV) should be tested by varying the base case forecasts.

- The actual timing and coordination of certain activities – e.g. the implementation of adaptation options - may differ from the base case. For instance, the timing of investment expenditures, whether they are earlier, or later than the base case, can affect considerably the estimated NPV.

Procedure

In conducting sensitivity analysis, the following procedure should be followed (adapted from ADB, 1999):

- Variables to which the estimated NPV is likely to be sensitive should be listed. Alternative values should be assumed, based on previous experience/data, where available. The change in the value of the variable may be calculated and expressed as a percentage of the original value, where possible. In cases where a percentage change in the variable is meaningless, e.g. the timing of activities, the absolute magnitude of the change may be recorded.

- The NPV (or other measure of economic performance) should then be recalculated for the stated changes in each of the listed variables - one at a time.

- A **sensitivity indicator** (SI) - summarizing the effect of the change in a variable on the estimated NPV - should be calculated, where possible. The SI is calculated as the ratio of the percentage change in the NPV to the percentage change in the selected variable (see Box 5.15 below). The interpretation of the calculated SI is simple: a high value for the SI indicates that the NPV is sensitive to the variable.

- A **switching value** (SV) may also be calculated. If, under base case assumptions, a positive NPV is calculated, the SV shows the percentage increase in a specific cost item (or equally, the percentage decline in a specific benefit item) required for the NPV to become zero. The SV is itself a percentage – basically, the percentage change in a variable required for the estimated NPV to change sign. If the SV is relatively high, a very substantial change in the variable is required before the NPV changes sign. Conversely, if the SV is relatively low, a small change in the variable is required to change the NPV sign, indicating there may be a significant risk for the base case estimate.

- The change in the NPV may also be calculated for combinations of variables, for example, an increase in price together with a lower quantity change.

- The results of the sensitivity analysis should, at least, be presented in a table showing the base case results, the change in each variable considered, the sensitivity indicator, the switching value if relevant, and the change in the estimated NPV for cases where these indicators cannot be calculated (see Box 5.15 below).

Box 5.15: Determining Sensitivity Indicators and Switching Values

A **sensitivity indicator** (SI) is given by

$$SI = \frac{(NPV_b - NPV_s)}{NPV_b} \div \frac{(V_b - V_s)}{V_b}$$

where

NPV_b	=	The NPV under the base case assumptions.
NPV_s	=	The NPV with the sensitivity test.
V_b	=	The value of the variable under the base case assumptions.
V_s	=	The value of the variable selected for the sensitivity text.

A **switching value** (SV) is given by

$$SV\ (\%) = 100 \times \frac{NPV_b}{(NPV_b - NPV_s)} \times \frac{(V_b - V_s)}{V_b}$$

where the variables are as defined above.

Interpretation of Results

In reviewing the results of the foregoing sensitivity analysis, the following questions should be considered:

- Which variables have high sensitivity indicators?
- Are the calculations based on the most likely range of values for these variables?
- Where relevant, do the likely range of values come close to, or exceed, the switching values that will change the sign of the base case NPV?
- What is the chance that the combinations of variables investigated will actually occur?

Answering these questions as one considers the results of the sensitivity analysis will help identify those variables that are key to the realisation of the base case results. For these key variables, a statement can be made of the likelihood of the variation tested actually occurring. In turn, this should also facilitate the identification of measures, which could be taken to mitigate or reduce the likelihood of such variations from the base case.

Box 5.16: Sensitivity Analysis - A Worked Example

Consider an irrigation rehabilitation project as part of an adaptation strategy. The project involves a predicted increase in cropped area for irrigated vegetables, in growing intensity, and in yield, with a compensating decline in cereal cropped area. The base case results are as follows (see Table 5.10 below): the NPV is positive £1.44 million at a 6 percent real discount rate. In other words, the present value benefits of the project exceed the present value costs.

On the basis of previous, similar irrigation projects, there is uncertainty over the farmer response to improved irrigation. Post-audit studies indicate the possibility of lower values for cropped vegetable area, growing intensity and yield by 9, 10 and 6 percent respectively, than those assumed under the base case. There is also uncertainty over the levels of cropping intensity and yield of both vegetables and cereal, without the irrigation project. Increases in these variables of 10 percent have been included in the sensitivity tests.

The forecast price of vegetables should also be key variables in the project analysis, as the project will increase the quantity of vegetable output. In the sensitivity analysis, the forecast price of vegetables, which declines over the first ten years of the project anyway, is predicted to follow the same pattern, but to be at the level of the lower range of the distribution given together with the base case price forecasts. This is equivalent to a price, which is 39 percent lower than in the base case.

The sensitivity of the estimated NPV to an increase in investment costs (+10 percent), and a shortening in operating life (a reduction of five years), is also investigated.

The results of these sensitivity tests on the underlying and specific cost and benefit factors are given in Table 5.10. There are three variables to which the irrigation project is most sensitive and, in turn, to which the most attention should be paid. These include the price of vegetables, the growing intensity, and the assumed yield of vegetables with the project. The forecast (base case) values for these variables need only be less favourable by 20 and 14 percent for the sign of the NPV to change.

Table 5.10: Example – Results of Sensitivity Analysis

Variable	Change (%)	NPV (£ million)	Sensitivity Indicator	Switching Value (%)
Base Case	N/A	+1.44	N/A	N/A
Costs				
Investment costs	+10.0	+1.29	1.03	+97
Project Life			Net PVC declines by 13 per cent	
Reduced by five years	N/A	+1.25		
Benefits				
Vegetable price	-39.0	-1.43	5.12	-20
With irrigation:				
Vegetable area	-9	+1.30	1.10	-91
Growing intensity	-10	+0.45	6.90	-14
Vegetable yield	-6	+0.84	6.90	-14
Without irrigation:				
Growing intensity	+10	+0.87	3.94	+25
Vegetable yield	+10	+0.87	3.94	+25
Cereal yield	+10	+1.16	1.93	+52

Adapted from ADB (1999)

5.9 Treatment of Unvalued Impacts

5.9.1 Context of Guideline

To the extent that the impacts of climate change, and adaptation responses to those impacts, can be expressed in the same terms – pounds – the difference between them (i.e. the **net cost** or **benefit** of the adaptation option) provides a valid measure of the aggregate 'worth' of that option. Reducing the outcome descriptor to a single dimension is useful in that it simplifies the selection of the 'best' option. However, as is stressed in Section II, it is highly likely that, for many of the impacts of climate change on receptors in the UK, there will be many situations where appropriate quantitative data are simply not available, thereby making economic valuation extremely difficult, if not impossible. It is also likely, given state of the art economic valuation, that it will not be possible to 'price' certain impacts even where quantitative data are available. Nevertheless, **the lack of a monetary estimate for specific climate change impacts does not mean that those impacts can be overlooked in any decision-making process.**

The first step in ensuring these impacts are not overlooked is the construction of a simple checklist, which can be used to identify all potential impacts relevant to the decision problem at hand, and to indicate whether or not they can be valued. An example of such a checklist was shown in Section 3.2.3, for the case of a user interested in estimating the benefits that could result from alternative strategies to adapt to sea level rise in a sensitive coastal area. The idea of the checklist is that its construction forces the explicit recognition of *all* the climate change impacts anticipated to occur in the context of a particular decision problem, regardless of whether they have or have not been valued. This should ensure that we do not omit any relevant impacts from the decision-making process.

We now need alternative options appraisal (decision-support) tool(s), which allows us to bring both valued and unvalued impacts into common stages of analysis. One possibility is to use a variation of **sensitivity analysis**. A second, more rigorous option is to use **multi-criteria analysis** (MCA). MCA also allows other decision criteria – in addition to economic efficiency (or economic value) - to influence the decision-making process (e.g. flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity, etc).[151]

Both these alternative options appraisal tools are presented in this

[151] More recent extensions of CBA expressively allow for more than one objective to be addressed. For example, it is possible to explicitly account for risk and uncertainty, and distributional effects within a CBA framework.

Guideline.

5.9.2 Sensitivity Analysis

In Section 5.8 we present **sensitivity analysis** as a technique for assessing the vulnerability of options to future uncertainties.

A variation on sensitivity analysis, which allows us to take the unvalued impacts into account, albeit subjectively, is to calculate the magnitude of the unvalued impacts necessary to make (see Box 5.22 below for further details):

- an 'unfavourable' NPV 'favourable'; or
- a 'favourable' NPV 'unfavourable'.

Once we have determined the magnitude of the unvalued impacts necessary to switch the estimated NPV from positive to negative, or vice versa, we can then make a judgement as to whether the unvalued impacts are likely to not amount to this value. An example is also given in Box 5.22 below.

Clearly this approach is not appropriate for assessing **mutually exclusive** alternatives (this is best done using MCA), since it only allows for *inter*-option trade-offs involving two attributes. For **independent** options, it can only provide a benchmark for contrast against the unvalued impacts, so we can assess their likely influence on the selection decision.

Box 5.17: Qualitative Analysis Based on Switching Values

General Procedure:

In Section 2.2.3 we defined the social cost-benefit criteria (in the context of adaptation to a specific climate change risk) to be tested as given by:

$$\text{Is } \left(D_j^B - D_j^{RA}\right) - \left(C_j^A\right) > 0 ? \tag{5.13}$$

where

D_j^B	=	The baseline damage associated with climate change impact j.
D_j^{RA}	=	The residual damage associated with climate change impact j following the implementation of adaptation measures.
C_j^A	=	The incremental cost of the adaptation response(s) to climate change impact j.

A NPV is '**unfavourable**' if:

$$\left(D_j^B - D_j^{RA}\right) < C_j^A \tag{5.14}$$

That is, the incremental benefits of adaptation are *less* than the associated costs. In contrast, a NPV is '**favourable**' if:

$$\left(D_j^B - D_j^{RA}\right) > C_j^A \tag{5.15}$$

In this case, the incremental benefits of adaptation are *greater* than the associated costs.

In both cases, we want to determine the net value that the unvalued impacts would have to be in order to *equate* the incremental benefits of climate change (the forgone impacts which have been valued) and the incremental cost of the adaptation measures required to realise those benefits, that is:

$$\left[\left(D_j^B - D_j^{RA}\right) + \left(NM_j^B - NM_j^{RA}\right)\right] = C_j^A \tag{5.16}$$

where

NM_j^B = The baseline *unvalued* impacts associated with climate change impact j.

NM_j^{RA} = The residual *unvalued* impacts associated with climate change impact j following the implementation of adaptation measures.

Numerical Example:

One consequence of the predicted increase in frequency of storms and flash flooding in the UK is the expected short-term disruption to transport infrastructure. Suppose, at a local level, we are interested in determining whether the gross benefit of mitigating these impacts is greater than the total cost of the adaptation measures. A simple checklist corresponding to this policy question is shown in Table 5.11. As you can see from the table, we have been able to derive monetary estimates for three of the four climate change impacts of interest.

Table 5.11: Checklist for the Identification of all Impacts of Relevance: Example of Short-term Disruption to Transport Infrastructure

3rd Order Impact	Valuation		4th Order Impact	Valuation	
	NO	YES		NO	YES
Short-term disruption (local transport infrastructure)	√		Change in travel time (productive)		√
			Change in travel time (non-productive)		√
			Change in demand for alternative modes/routes		√
			Change in external cost of transport	√	

Suppose the measures to mitigate flash flooding disruption in the local area have a present value cost of £750,000, i.e. $C_j^A = £750{,}000$. Further assume that the present value benefits associated with work and non-work time savings are estimated to be £550,000, i.e. $\left(D_j^B - D_j^{RA}\right) = £550{,}000$. In this example the impact of changes in demand for alternative modes/routes in assumed to be negligible. Based solely on this information we have a situation in which the incremental benefits of adaptation are *less* than the associated costs; hence, the NPV is 'unfavourable'. However, the adaptation measures will also reduce congestion (improve traffic flows) relative to the reference case, which in turn will reduce congestion related externalities, e.g. improve local air quality.

We need to determine the magnitude that these foregone externalities must be in order to switch the estimated NPV from negative to positive, i.e. make the 'unfavourable' NPV 'favourable'. This is accomplished by solving equation 4.16 for $\left(NM_j^B - NM_j^{RA}\right)$, as follows:

$$£550{,}000 + \left(NM_j^B - NM_j^{RA}\right) = £750{,}000$$

$$\left(NM_j^B - NM_j^{RA}\right) = £750{,}000 - £550{,}000 = £200{,}000$$

Thus, if the present value of the foregone externalities was expected to be greater than £200,000, then investment in the adaptation measures could be justified on economic grounds. A way to assess the likelihood of this being the case, which is often easier, is to convert the present value measure of the unvalued item(s) into an annual value, which is more readily understood than present values. This is done by multiplying the present value of the unvalued item(s) by an appropriate capital recovery factor (see Section 5.6.2 for full details). It is then a matter of deciding whether the impact in question is likely to approach the estimated annual value.

5.9.3 Multi-criteria Analysis

Introduction

Economic efficiency (or value) is not the sole criterion for making climate adaptation decisions. As mentioned above and in Section 1, other decision criteria (or desired states-of-affairs) including flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity etc., may also be important to the decision-maker. Furthermore, while some of these objectives and associated decision criteria are readily measured in money terms others are not, and can only be expressed through quantitative (physical) or qualitative indicators. **Multi-criteria analysis** (MCA) (sometimes referred to as 'weighting and scoring') allows for the appraisal of these different decision criteria and unvalued items, which are often expressed in differing units of measurement, in a common analytical method.

Multi-criteria analysis (MCA) provides an analytical method for the evaluation of project/policy alternatives in situations where decisions must be made taking into account more than one decision criterion, which are expressed in differing units of measurement.

MCA differs from conventional economic analysis in three ways:

a) it does not restrict the decision-making process to economic efficiency criterion;

b) it allows climate change impacts to be measured in units other than monetary ones; and

c) it does require the use of economic valuation to accommodate climate change impacts in the decision-making process.

Adapted from WBI (1999)

Methodology

At the outset it is worth stressing that the purpose of this section is only to provide the reader with a general overview of the 'workings' of MCA. MCA embodies a vast array of analytical techniques, which cannot possibly be given due coverage in this guideline. Detailed guidance on MCA is available at is available from the Office of the Deputy Prime Minister website (www.odpm.gov.uk) (see the DTLR archive).

In general, MCA proceeds in four steps:

1. Problem definition, which involves specifying overall **objectives** and feasible **alternative courses of action** (adaptation options).

2. Selecting **decision criteria** and assessing alternative options, in which qualitative and/or quantitative information on each option is summarised by using the assignment of a **rank**, **rating** or **scale value** relative to each decision criterion.[152]

3. Specifying stakeholder preferences, which involves the **weighting** of decision criteria relative to one another.

4. Aggregation, where an overall **composite index** or **total score** is calculated for each option. The total score of an option is given by the product of the importance weighting assigned to each decision criterion and the ranking, rating, or scale of each alternative with respect to that decision criterion, summed over all decision

[152] **Ranking** involves ordering alternatives, from best to worst, in terms of their likely impact on each identified decision factor. **Rating** involves the use of a pre-defined rating scheme. **Scaling** refers to the assignment of algebraic scales or letter scales to the impact of each alternative being assessed on each identified decision factor.

criteria.[153] Composite indices of this type take the general form:

$$\text{Index}_j = \sum_{i=1}^{n} W_i \cdot R_{ji} \qquad (5.17)$$

where

Index_j = composite index or total score for the *j*th option;

W_i = importance weight assigned to the *i*th decision criterion;

R_{ji} = ranking, rating, or scale assigned to the *j*th option with respect to the *i*th decision criterion; and

n = the total number of decision criteria.

We will now briefly look at these four steps in turn.

Problem Definition

Problem definition is covered in Section 2. Briefly, a decision-maker is dissatisfied with the prospect of a future state of affairs (climate change risks), and possesses the desire and authority to initiate actions designed to alter this state. The decision-maker's desire to achieve a new state of affairs derives from a need to achieve some broad objectives, which are compromised, in this case, by climate change. To attain the desired state of affairs, the decision-maker can undertake adaptation measures.

The specification of objectives often exhibits a hierarchical structure, with the highest level representing broad, vaguely stated objectives (e.g. economic efficiency or value), which are not very operational. These broad objectives usually need to be broken down in to lower-level, more specific operational objectives (or decision criteria), so that the extent to which they are achieved by the adaptation option can be more readily assessed (see step 2).

Specifying objectives is typically accomplished by holding a workshop for individuals or groups of individuals who are positively or negatively affected by the proposed option, and using participatory methods to reach a consensus on decision criteria. (To some extent this has already been done regarding the impacts of climate change, since the impact matrices presented in Section 3 embody the concerns of stakeholders captured

[153] **Weighting-scaling** or **weighting-rating** methodologies embody the assignment of relative importance weights to decision factors, and impact scales or ratings for each alternative relative to each factor. **Weighting-ranking** approaches involve the assignment of importance weights, and the relative ranking of all alternatives from best to worst in terms of their impact on each decision factor.

during the sub-UK studies.)

Selecting Decision Criteria and Scoring Alternatives

The next step is to identify appropriate criteria to assess the ability of the adaptation option(s) to achieve the set of specified higher-level objectives. **Decision criteria** define the scale (or index) used to measure progress in meeting objectives, and the range of possible consequences (typically from 'worst' to 'best'). Criteria are generally of two types:

- **Quantitative** – e.g. present value costs (£), present value benefits (£), net present value (£), numbers of tree lost per year, number of hectares of sand dunes lost per year etc. (The first three criteria measure the degree to which the economic efficiency objective is achieved.)

- **Qualitative** – e.g. no impact, minimal impact, limited impact, moderate impact, significant impact.

It is best to base the selection of decision criteria on the consensus of stakeholders, particularly with respect to qualitative criteria, since their selection would otherwise require considerable value judgement on the part of the analyst. Qualitative criteria can be expressed in the form of subjective indices, typically based on an '**ordinal**' scale.[154] An example is shown in Box 5.18 below.

In general, when specifying decision criteria it is important to ensure that they are both 'measurable' and 'comprehensive' (Keeney and Raiffa, 1976). A decision criterion is '**measurable**' if it is reasonable:

- to assign a point value to each option over all possible levels of the decision criterion;[155] and

- to assess the decision maker's preferences for different levels of the decision criterion.[156]

A decision criterion is said to be '**comprehensive**' if the decision-maker has a clear understanding of the extent to which it is achieved when (s)he knows the level of that decision criterion in a particular situation.

In addition, any MCA decision problem requires that the set of decision criteria are:

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[154] **Ordinal scales** simply rank alternatives or decision factors in order; they do not convey how much 'better' one alternative or decision factor is to another, but simply indicate relative order.

[155] Or obtain a probability distribution in the event of uncertainty.

[156] Moreover, it is important that these tasks can be accomplished without expending an excess amount of resources, e.g. time, cost or effort.

- **Complete** - i.e. do they cover all the important aspects of the problem?
- **Operational** - i.e. can they be meaningfully used in the analysis?
- **Decomposable** - i.e. do they facilitate the simplification of the evaluation process by permitting it to be broken down into smaller parts?
- **Non-redundant** - i.e. are they defined in such a way so as to avoid double-counting?
- **Mutually independent** - i.e. are the preferences held for criterion *A* not affected, in any way, by the preferences held for other criteria.
- **Minimal** (**number of criterion**) - i.e. subject to the above, do they keep the problem dimension as small as possible?

These requirements need to be fully considered when identifying the set of decision criteria.

Box 5.18: Example of a Qualitative Index

An example of a **qualitative** (subjective) **index** for aggregate biological impacts is shown in Table 5.12 below. This index, which was developed by two experienced ecologists, was used by Woodward-Clyde Consultants (1975) as part of a MCA to identify potential sites for power stations in Washington State. (In this case, the 'best' consequence is assigned a scale value of zero and the 'worse' consequence a scale value of eight.)

Table 5.12: Example of a Qualitative (Subjective) Index for Biological Impacts

Scale Value	Level of Impact
0	Complete loss of 1.0 square mile of land that is entirely in agricultural use or is entirely urbanised; no loss of any 'biological' communities.
1	Complete loss of 1.0 square mile of land that is primarily (75%) agricultural habitat with loss of 25% second growth; no measured loss of wetlands or endangered species habitat.
2	Complete loss of 1.0 square mile of land that is 50% farmed and 50% disturbed in some other way (logged or new second growth); no measured loss of wetlands or endangered species habitat.
3	Complete loss of 1.0 square mile of recently disturbed land (logged or plowed), plus disturbance of surrounding previously disturbed habitat within 1 mile of site border; or 15% loss of wetlands or endangered species habitat.
4	Complete loss of 1.0 square mile of land that is 50% farmed (or otherwise disturbed) and 50% mature second growth or other community; or 15% loss of wetlands or endangered species habitat.
5	Complete loss of 1 square mile of land that is primarily (75%) undisturbed mature 'desert' community; or 15% loss of wetlands or endangered species habitat.
6	Complete loss of 1.0 square mile of mature, second growth (but not virgin) forest community; or 50% loss of big game and upland game birds; or 50% loss of wetlands or endangered species habitat.
7	Complete loss of 1 square mile of mature community or 90% loss of local productive wetlands and local endangered species habitat.
8	Complete loss of 1 square mile of mature, virgin forest or local wetlands or local endangered species habitat.

Source: Woodward-Clyde Consultants (1975)

Notes:

This is a qualitative scale of potential short- and long-term impacts that could result from the construction and operation of a power station on a site. The impacts range from '0' for no impact to '8' for maximum impact. Site visits showed that the biologically important characteristics (aside from aquatic resources) of the State are: (1) virgin or large, mature, second growth stands of timber or 'undisturbed' sagebrush communities; (2) known or potential habitat of endangered species; and (3) wetland areas.

It is also important to ensure that the decision criteria chosen do not measure achievement of the same higher-level objective. If they do, then the weight accorded this objective in the final result will be upwardly biased. Finally, in the context of climate change the time profile of risks is particularly important. This may necessitate different decision criteria being defined for impacts that occur at various points in time.

Decision criteria are then combined with adaptation options to form a **trade-off matrix** – a variation of the outcome array introduced in Section 1. Such matrices serve as the conceptual method for MCA. For example, suppose that three alternative adaptation options (A_1, A_2 and A_3) are being considered for a coastal town at risk from sea level rise. For simplicity let us assume that four decision criteria have been selected: DC_1 – net present value, inclusive of valued climate change impacts avoided (£); DC_2 – rare bird sanctuary protected (number nesting sites); DC_3 – alleviation of anxiety in local population (subjective index 1-worst to 5-best); and DC_4 – net employment effect (number of additional man-days). Suppose the trade-off matrix corresponding to this situation is given in Table 5.13. Note that the cells in the matrix are incremental to the reference (with climate change) case. Furthermore, it is assumed that only one future state-of-nature will occur.

Table 5.13: Trade-off Matrix – an Example of a Coastal Area at Risk to Sea Level Rise

Decision Criteria	**Adaptation Options**		
	A_1	**A_2**	**A_3**
DC_1 (£ NPV)	+105,000	+130,000	+113,000
DC_2 (# of nesting sites)	2,700	2,000	3,200
DC_3 (subjective index)	2	3	5
DC_4 (# of man-days)	264	150	150

Once a trade-off matrix like Table 5.13 has been constructed for the specific problem, it should be analysed to see whether it is possible to identify a **dominant option**. If one option outperforms the others with respect to some decision criteria, and is not itself outperformed with respect to all other criteria, then that option is said to dominate the set of feasible options. **The decision rule in this case is to select the dominant option**. In the example provided in Table 5.13 there is no single dominant option.

Where there is no single dominant option, then you may assign a **rank**, **rating** or **scale value** to each decision criterion. This will allow you to assess the performance of individual options relative to each decision factor. Several different techniques have been developed for this purpose, including: a) un/ranked paired-comparisons; b) functional relationships; or c) predefined impact-rating schemes.

Paired-comparison techniques, ranked or unranked, basically involve a series of comparisons between options relative to each decision factor.

The results of the comparisons are then systematically tabulated. Dean and Nishry (1965) developed one of the more useful paired-comparison techniques The unranked approach they describe consists of considering each option relative to every other option for each decision factor, and assigning a value of 1 to the 'more desirable' option, and a value of zero to the 'less desirable' option.[157] If two options in a pair are 'equally desirable', then a value of 0.5 is assigned to both. This technique can be implemented by an individual, or a group. The use of the paired-comparison technique for the three adaptation options and four decision criteria shown in Table 5.13 is illustrated in Box 5.19.

Box 5.19: An Example of the Unranked Paired-comparison Technique

A trade-off matrix corresponding to an example policy context is given in Table 5.13 above. The application and tabulated results of Dean and Nishry's unranked paired-comparison technique for the three adaptation options and four decision criteria displayed in Table 5.13 are shown in Table 5.14 through Table 5.17, respectively.

Note that a dummy option, A_4, is included in each table. The purpose of this dummy option is to serve as a 'place keeper' – i.e. to ensure that no option (A_1 through A_4) is assigned a net value of zero.

Following the assignment of relative desirability to each option pair, a process which may involve several iterations, the individual desirability assignments are summed. For example, the sum of the desirability assignments for A_1 relative to the other options relative to DC_1 is 3 (see Table 5.14). The next step is to compute the **option choice coefficient** (OCC), which is equal to the sum of the individual desirability assignments divided by the total of the Sum column. These calculations are shown in the final columns in Table 5.14 through Table 5.17. With respect to DC_1 for example, the OCC column in Table 5.14 indicates that A_1 is the most desirable, followed by A_3 and A_2.[158]

[157] The assignment of zero to an option *only* signifies that, in the pair considered, that option is of 'less' importance; it *does not* signify 'no' importance.

[158] Since the ACC rates the quantitative degree of difference between the alternatives and permits you to rank the alternatives in order, this technique involves both **interval** and **ordinal** scaling, respectively.

Table 5.14: Scaling of Options Relative to Decision Factor 1

Adaptation Options	Tabulation of Relative Desirability						Sum	OCC
A_1	1	1	1				3	3÷ 6=0.50
A_2	0			0	1		1	1÷ 6=0.17
A_3		0		1		1	2	2÷ 6=0.33
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5.15: Scaling of Options Relative to Decision Factor 2

Adaptation Options	Tabulation of Relative Desirability						Sum	OCC
A_1	1	0	1				2	2÷ 6=0.33
A_2	0			0	1		1	1÷ 6=0.17
A_3		1		1		1	3	3÷ 6=0.50
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5.16: Scaling of Options Relative to Decision Factor 3

Adaptation Options	Tabulation of Relative Desirability						Sum	OCC
A_1	0	0	1				1	1÷ 6=0.17
A_2	1			0	1		2	2÷ 6=0.33
A_3		1		1		1	3	3÷ 6=0.50
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5.17: Scaling of Options Relative to Decision Factor 4

Adaptation Options	Tabulation of Relative Desirability						Sum	OCC
A_1	0	0	1				1	1÷ 6=0.17
A_2	1			0.5	1		2.5	2.5÷ 6=0.42
A_3		1		0.5		1	2.5	2.5÷ 6=0.42
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Adapted from Canter (1996)

As you will see in Table 5-31 below, the OCC fractions can be weighted, and then used to construct a **composite index** or **total score** for each option over all decision criteria. Even if this is not done, the OCC fractions facilitate the rank ordering of the desirability of options with respect to each decision criterion. It is also possible to apply a simple decision rule at this point, namely the **worst score technique**. This decision rule is appropriate if one of the main objectives is to minimise the risk that undesirable and/or irreversible project consequences will be realised. The technique consists of two main steps:

1. identify the worst OCC fraction for each option; and

2. select the alternative that performs the best amongst the worst fractions – i.e. choose the alternative with the highest OCC fraction.

Based on the OCC fractions presented in Table 5.14 through Table 5.17, an example of ranking options using the worst score technique is summarised in Table 5.18. In this example A_1 would be selected, followed by A_2 and A_3. Since this approach does not require the specification of weights, it is relatively straightforward to apply. For the same reason, it is only suitable in situations were objectives are given equal weight (i.e. have the same importance).

Table 5.18: Ranking Options Based on the Worst Score Technique

Adaptation Options	OCC Values for Each alternative Relative to Each Decision Factor				Worst OCC Value	Ranking
	DC_1	DC_2	DC_3	DC_4		
A_1	0.50	0.33	0.17	0.16	0.16	1st
A_2	0.17	0.17	0.33	0.42	0.17	2nd
A_3	0.33	0.50	0.50	0.42	0.33	3rd

Functional relationships[159] can also be used for scaling, ranking or rating options relative to decision factors. These functions essentially relate the objective (physical) measurement of a decision criterion to a subjective judgement regarding its 'quality', based on a scale of designator indicators which are typically calibrated from 0 ('low quality/less desirable') to 1 ('high quality/more desirable').[160] Expressing the physical relationships in terms of a quality scale between 0 and 1 is sometimes called **normalisation**, whereby differing units of measurement are translated into dimensionless units. An example functional relationship for water quality is shown in Figure 5.8 below. Dee *et al.* (1972) describe a seven-step procedure for constructing such functional relationships. Curves like the one shown in Figure 5.8 can then be used to complete matrices similar to that shown in Box 5.19 above.

Rating options relative to decision criteria can also be done with the aid of **predefined rating schemes**. With this approach, numerical values are taken from the predefined scale and assigned to each option relative to each decision criterion. An example of a predefined rating scale from Wilson (1991),[161] which delineates five reference scales, is shown in Table 5-32. The descriptions corresponding to each reference scale are to aid in the assignment of numerical values to each option. Again, predefined rating schemes like Table 5.19 can be used to complete matrices similar to that shown in Box 5.19 above.

[159] These are also called 'functional curves', 'value functions' or 'parameter function graphs'.

[160] In this sense, it constitutes **ratio scaling**, in that it indicates the quantitative degree of difference between alternatives relative to some defined starting point.

[161] Wilson (1991) personal communication to Canter (1996), Sante Fe, New Mexico.

Figure 5.8: Example of a Functional Relationship – Water Quality

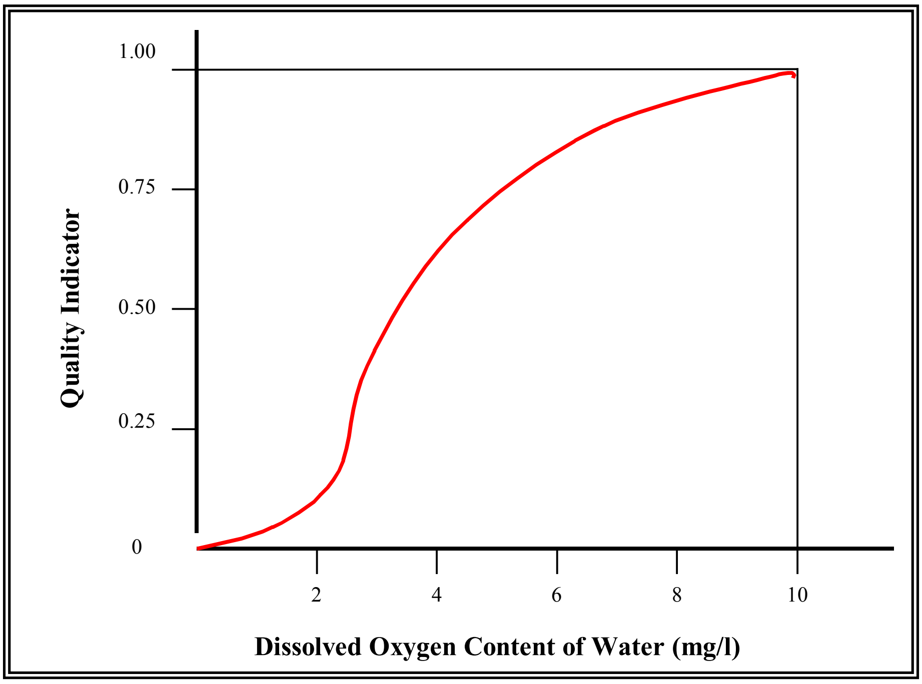

Table 5.19: Example of a Predefined Rating Scale: Ecological Impact

Rating Scale	Assignment Criteria
5	No potential impact to important species or habitats; no existing habitats (vegetation and/or soil) poor in quality and diversity or severely damaged.
4	The potential negative impact to important species or habitat would be minimal.
3	The potential negative impact to important species or habitat would be limited.
2	The potential negative impact to important species or habitat would be substantial.
1	The potential negative impact to important species or habitat would be only marginally acceptable.
0	The potential negative impact to important species or habitat would be excessive and unacceptable. Affected area contains critical habitat for endangered or threatened species.

Adapted from Wilson (1991) in Canter (1996)

The Weighting of Decision Criteria

In this step a 'value' or 'weight' is allocated to each of the decision criteria - that is, the decision criteria are weighted relative to one another.[162] (The weighting of decision factors is necessary if ultimately we wish to combine them.) Typically experts, decision-makers or stakeholders set this 'weight' in accordance with their interpretation of society's preferences. For example, if experts assume that society places more importance on economic value than equity, then they will assign a higher weight to economic value. This step in the MCA process is the most complex; not only must you know the preferences of society for the various decision factors, but you must also be able to translate these preferences into *relative* weights. Examples of techniques usually employed to establish importance weights include: a) the Delphi Method; b) un/ranked paired comparisons, and c) rating from predefined scales.

With the **Delphi Method** the weights are formed by a group, which typically comprises decision-makers, representatives of the stakeholder community and relevant experts (e.g. scientists, economists, engineers, agronomists etc.). The method generally consists of (collectively) developing a questionnaire, which is then submitted to the 'group' in order to elicit their preferences independently. The results of the questionnaires are then analysed, and a second questionnaire is prepared (often containing selected information on the 'group' weights). The purpose of this second questionnaire is to obtain more precise information from the respondents. Further iterations can occur until responses to the questions are constant and consistent. You can then use the importance weights taken from the final iteration, or average the weights over several iterations.

The **paired-comparison technique** for importance weighting is identical to that described in Box 5.19 above, except now the comparisons are made between decision criteria, as opposed to between options relative to a given decision factor. As was the case previously, the weights are estimated on the basis of a simple procedure which takes into account three possibilities: 1) assigning a valuing of 1 to the decision criterion considered to be *more* important in a pair-wise comparison; 2) assigning a valuing of 0 to the decision criterion considered to be *less* important in a pair-wise comparison; and 3) assigning a valuing of 0.5 to both decision criteria if they are considered to be of *equal* importance. An example is provided in Box 5.20 below. Again, this technique can be implemented by an individual or a group.

[162] The 'value' or 'weight' assigned to a decision factor reflects: (a) the magnitude of difference between decision factors; and (b) the relative importance of this difference.

Box 5.20: An Example of the Unranked Paired-comparison Technique for Importance Weighting

The application and (assumed) tabulated results of the unranked paired-comparison technique to our case study are shown in Table 5.20. For the same reasons given in Box 5.19 a dummy decision criterion (DC_5) is included in the table.

Following the assignment of relative importance weights to the decision criteria – which again may involve several iterations – the individual weight assignments are summed. For example, the sum of the weight assignments for DC_1 relative to the other decision criteria is 4 (see Table 5.20). The next step is to compute the **criteria importance coefficient** (CIC), which is equal to the sum of the individual weight assignments divided by the total of the Sum column. These calculations are shown in the final columns in Table 5.20. The CIC column in Table 5.20 indicates that DC_1 is the most important decision criterion, followed by DC_4, DC_2 and finally DC_3. This technique thus allows the rank ordering of decision criteria from *most* important to *least* important.

Table 5.20: Using Paired-comparisons for Weighting Decision Criteria

Decision Criteria	Importance Weight Assignment										Sum	CIC
DC_1	1	1	1	1							4	4 ÷ 10=0.40
DC_2	0				1	0	1				2	2 ÷ 10=0.20
DC_3		0			0			0	1		1	1 ÷ 10=0.10
DC_4			0			1		1		1	3	3 ÷ 10=0.30
DC_5 (dummy)				0			0		0	0	0	0÷ 10=0.00
Total											∑= 10	∑= 1.00

Adapted from Canter (1996)

Importance weighting can also be done with the use of a **predefined importance scale**. These scales are analogous to the predefined rating scales discussed above. An example of a predefined importance scale from Linstone and Turoff (1975), which delineates five reference scales, is shown in Table 5.21. The description corresponding to each reference scale is to aid in the assignment of numerical values to the decision factors. Individuals or a group can undertake the assignment of values.

Table 5.21: Example of a Predefined Importance Weighting Scale

Scale Reference		Description
1.	Very important	A most relevant point; first-order priority; has direct bearing on major issues; must be resolved, dealt with, or treated
2.	Important	Is relevant to the issue; second-order priority; has significant impact, but not until other items are treated; does not have to be fully resolved
3.	Moderately important	May be relevant to the issue; third-order priority; may have impact; may be determining factor to major issue
4.	Unimportant	Insignificantly relevant; low priority; has little impact; not a determining factor to a major issue
5.	Most unimportant	No priority; no relevance; no measurable effect; should be dropped as an item to consider

Source: Linstone and Turoff (1975) in Canter (1996)

Aggregation

In general, the final step in MCA is to calculate an overall **composite index** or **total score** for each option. This can take the form of a **decision matrix**, which displays the products of the option scales, ratings or ranks, and the importance weights or ranks. The development of a decision matrix from our previous example based on the paired-comparisons is shown in Box 5.21.

Since the purpose of this section is solely to provide the reader with a general overview of the 'workings' of MCA, we have presented only the more 'simplistic' analytical techniques employed in MCA. More sophisticated techniques exist however, including a) outranking techniques such as ELECTRE and PROMETHEE;[163] b) multi-attribute utility analysis;[164] and c) the Analytical Hierarchy Process (AHP).[165] Each of these techniques has the same basic structure as outlined above, but employs slightly more complex mathematical procedures for ranking,

[163] See, for example, Roy (1971) or Roy (1976).

[164] See, for example, Keeney (1972); Keeney (1974); Keeney and Raiffa (1976).

[165] See, for example, Saaty (1980).

scaling, rating and weighting.

Finally, the use of MCA does not remove the need for uncertainty analysis. In Section 5.10 we looked at how sensitivity analysis is used to focus our attention on alternative assumptions that could have a significant effect on the final cost estimates. The output of the sensitivity analysis is then used to identify actions that can mitigate the effects of uncertainty, or to redesign the institutional structure of adaptation projects to ensure maximum effectiveness. Sensitivity analysis can equally be used within MCA to identify those assumptions - such as the decision factors, scoring and weighting systems used in the analysis - that potentially could have a significant effect on the final results.

It is also possible to explicitly incorporate the analysis of uncertainty into MCA. For example, the preferences of decision-makers for uncertain outcomes can be built into the (expected) utility functions that underpin multi-attribute utility analysis.

Box 5.21: Example of Decision Matrix Based on Paired-Comparisons

The CIC values for our four decision criteria, and the OCC values for the three adaptation options are summarised in Table 5.22. The decision matrix presenting the overall **composite index** or **total score** for each option is shown in Table 5.23. Based on the total score for each adaptation option displayed in Table 5.23, adaptation option 3 represents the 'best' choice, followed by option 1 and then option 3.

Table 5.22: Summary of FIC and ACC Values

Decision Criteria		**OCC Values for Each Option**		
	CIC Values	A_1	A_2	A_3
DC_1	0.40	0.50	0.17	0.33
DC_2	0.20	0.33	0.17	0.50
DC_3	0.10	0.17	0.33	0.50
DC_4	0.30	0.16	0.42	0.42

Table 5.23: Decision Matrix

Decision Criteria	Total Score for Each Option		
	A_1	A_2	A_3
DC_1	0.50*0.40=0.200	0.17*0.40=0.068	0.33*0.40=0.132
DC_2	0.33*0.20=0.066	0.17*0.20=0.034	0.50*0.20=0.100
DC_3	0.17*0.10=0.017	0.33*0.10=0.033	0.50*0.10=0.050
DC_4	0.16*0.30=0.051	0.42*0.30=0.124	0.42*0.30=0.124
Total Score	$\sum$= 0.334	$\sum$= 0.259	$\sum$= 0.406
Ranking	**2nd**	**3rd**	**1st**

Adapted from Canter (1996)

5.10 Treatment of Non-monetised Impacts

5.10.1 Context of Guideline

To the extent that the impacts of climate change, and adaptation responses to those impacts, can be expressed in the same terms – pounds – the difference between them (i.e. the **net cost** or **benefit** of the adaptation option) provides a valid measure of the aggregate 'worth' of that option. Reducing the outcome descriptions to a single dimension is useful in that it simplifies the selection of the 'best' option. However, as is stressed in Section II, it is highly likely that for all of the key sectors in the UK, there will be many situations where appropriate quantitative data are simply not available, thereby making economic valuation extremely difficult, if not impossible. It is also likely, given state of the art economic valuation, that it will not be possible to cost certain impacts even where quantitative data are available. Nevertheless, **the lack of a monetary estimate for specific climate change impacts does not mean that those impacts can be overlooked in any decision-making process.**

In order to ensure these impacts are not overlooked, we recommended as a first step, constructing a simple checklist which serves to identify all potential impacts relevant to the decision problem at hand, and indicate whether or not each impact would be monetised. An example of such a checklist was shown in Section 3.2.3, for the case of a user interested in estimating the benefits that could result from alternative strategies to adapt to sea level rise in a sensitive coastal area. The idea of the checklist is that its construction forces the explicit recognition of *all* the climate change impacts anticipated to occur in the context of a particular decision problem, regardless of whether they have or have not been valued. This should ensure that we do not omit any relevant impacts from the decision-making process.

We now need alternative options appraisal (decision-support) tool(s), which allows us to bring both monetised and non-monetised impacts into a common method of analysis. One possibility is to use a variation of **sensitivity analysis**. A second more rigorous option, is to use **multi-criteria analysis** (MCA). MCA also allows other objectives – in addition to economic efficiency (or economic value) - to influence the decision-making process (e.g. flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity, etc).[166]

Both these alternative options appraisal tools are presented in this guideline.

5.10.2 Sensitivity Analysis

In Section 5.8 we present **sensitivity analysis** as a technique for assessing option risk. It works by identifying those variables that most influence the estimated costs of climate change and quantifying the extent of their influence. By testing the effects of variations in selected cost and benefit variables one at a time, sensitivity analysis identifies alternative assumptions that have a significant effect on the study's results.

A variation on sensitivity analysis, which allows us to take the non-monetised impacts into account, albeit subjectively, is to calculate the magnitude of the non-monetised impacts necessary to make (see Box 5.22 below for further details):

- an 'unfavourable' net cost[167] 'favourable'; or
- a 'favourable' net cost 'unfavourable'.

Once we have determined the magnitude of the non-monetised impacts necessary to switch the estimated net cost from positive to negative, or vice versa, we can then make a judgement as to whether the non-monetised impacts are likely to not amount to this value. An example is

[166] More recent extensions of CBA expressively allow for more than one objective to be addressed. For example, it is possible to explicitly account for risk and uncertainty, and distributional effects within a CBA framework.

[167] You will recall that a net cost is 'unfavourable' if it is *positive*, since the costs of adaptation exceed the value of the forgone climate change impacts. Conversely, a net cost is 'favourable' if it is *negative*, since the costs of adaptation are less than the value of the forgone climate change impacts.

also given in Box 5.22 below.

Clearly this approach is not appropriate for assessing **mutually exclusive** alternatives (this is best done using MCA), since it only allows for *inter*-option trade-offs involving two attributes. For **independent** options, it can only provide a benchmark for contrast against the non-monetised impacts, so we can assess their likely influence on the selection decision.

Box 5.22: Qualitative Analysis Based on Switching Values

General Procedure:

In Section 2.2.3 we defined the social cost-benefit criteria (in the context of adaptation to a specific climate change impact) to be tested as given by:

$$\text{Is } \left(D_j^B - D_j^{RA}\right) - \left(C_j^A\right) > 0 ? \qquad (5.13)$$

where

D_j^B = The baseline damage associated with climate change impact j.

D_j^{RA} = The residual damage associated with climate change impact j following the implementation of adaptation measures.

C_j^A = The cost of the adaptation response(s) to climate change impact j.

A net cost is '**unfavourable**' if:

$$\left(D_j^B - D_j^{RA}\right) < C_j^A \qquad (5.14)$$

That is, the gross benefits of adaptation are *less* than the associated costs. In contrast, a net cost is '**favourable**' if:

$$\left(D_j^B - D_j^{RA}\right) > C_j^A \qquad (5.15)$$

In this case, the gross benefits of adaptation are *greater* than the associated costs.

In both cases, we want to determine the net value that the non-monetised impacts would have to be in order to *equate* the benefits of climate change (the forgone impacts which have been valued) and the cost of the adaptation measures required to realise those benefits, that is:

$$\left[\left(D_j^B - D_j^{RA}\right) + \left(NM_j^B - NM_j^{RA}\right)\right] = C_j^A \quad (5.16)$$

where

NM_j^B = The baseline *non-monetised* impacts associated with climate change impact j.

NM_j^{RA} = The residual *non-monetised* impacts associated with climate change impact j following the implementation of adaptation measures.

Numerical Example:

One consequence of the predicted increase in frequency of storms and flash flooding in the UK is the expected short-term disruption to transport infrastructure. Suppose, at a local level, we are interested in determining whether the gross benefit of mitigating these impacts is greater than the total cost of the adaptation measures. A simple checklist corresponding to this policy question is shown in Table 5-24. As you can see from the table, we have been able to derive monetary estimates for 3 of the four climate change impacts of interest.

Table 5-24: Checklist for the Identification of all Impacts of Relevance: Example of Short-term Disruption to Transport Infrastructure

3rd Order Impact	Valuation		4th Order Impact	Valuation	
	NO	YES		NO	YES
Short-term disruption (local transport infrastructure)	√		Change in travel time (productive)		√
			Change in travel time (non-productive)		√
			Change in demand for alternative modes/routes		√
			Change in external cost of transport	√	

Suppose the measures to mitigate flash flooding disruption in the local area have a present value cost of £750,000, i.e. $C_j^A = £750{,}000$. Further assume that the present value benefits associated with work and non-work time savings are estimated to be £550,000, i.e. $\left(D_j^B - D_j^{RA}\right) = £550{,}000$. In this example the impact of changes in demand for alternative modes/routes in assumed to be negligible. Based solely on this information we have a situation in which the gross benefits of adaptation are *less* than the associated costs; hence, the net cost is 'unfavourable'.

However, the mitigation measures will also reduce congestion (improve traffic flows) relative to the baseline, which in turn will reduce congestion related externalities, e.g. improve local air quality.

We need to determine the magnitude that these foregone externalities must be in order to switch the estimated net cost from positive to negative, i.e. make the 'unfavourable' net cost 'favourable'. This is accomplished by solving equation 4.16 for $\left(NM_j^B - NM_j^{RA}\right)$, as follows:

$$£550{,}000 + \left(NM_j^B - NM_j^{RA}\right) = £750{,}000$$

$$\left(NM_j^B - NM_j^{RA}\right) = £750{,}000 - £550{,}000 = £200{,}000$$

Thus, if the present value of the foregone externalities was expected to be greater than £200,000, then investment in the adaptation measures could be justified on economic grounds. A way to assess the likelihood of this being the case, which is often easier, is to convert the present value cost into an annual value, which is more readily understood than present values. This is done by multiplying the present value cost by an appropriate capital recovery factor (see Section 5.6.2 for full details). It is then a matter of deciding whether the impact in question is likely to approach the estimated annual value.

5.10.3 Multi-criteria Analysis

Introduction

Economic efficiency (or value) is not the sole criterion for making decisions about allocating investment resources. As mentioned above and in Section 1, other objectives (or desired states-of-affairs) including flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity etc., may also be important to the decision-maker. Furthermore, while some of these objectives and associated decision criteria are readily measured in money terms others are not, and can only be expressed through quantitative (physical) or qualitative indicators. **Multi-criteria analysis** (MCA) allows for the appraisal of these different objectives, which are often expressed in differing units of measurement, in a common analytical method.

Multi-criteria analysis (MCA) provides an analytical method for the evaluation of project/policy alternatives in situations where decisions must be made taking into account more than one objective, which are expressed in differing units of measurement.

MCA differs from conventional economic analysis in three ways:a) it does not restrict the decision-making process to economic efficiency criterion; b) it allows climate change impacts to be measured in units other than monetary ones; andc) it does require the use of economic valuation to accommodate climate change impacts in the decision-making process.

Adapted from WBI (1999)

Methodology

At the outset it is worth stressing that the purpose of this section is only to provide the reader with a general overview of the 'workings' of MCA. MCA embodies a vast array of analytical techniques, which cannot possibly be given due coverage in this guideline. Detailed guidance on MCA is available at (http://www.environment.detr.gov.uk/multicriteria/).

In general, MCA proceeds in four steps:

1) Problem definition, which involves specifying overall **objectives** and feasible **alternative courses of action** (adaptation options).

2) Selecting **decision criteria** and assessing alternatives, in which qualitative and/or quantitative information on each alternative is summarised by using the assignment of a **rank**, **rating** or **scale value** relative to each decision criterion.[168]

3) Specifying stakeholder preferences, which involves the **weighting** of decision criteria relative to one another.

4) Aggregation, where an overall **composite index** or **total score** is calculated for each alternative. The total score of an alternative is given by the product of the importance weighting assigned to each

[168] **Ranking** involves ordering alternatives, from best to worst, in terms of their likely impact on each identified decision factor. **Rating** involves the use of a pre-defined rating scheme. **Scaling** refers to the assignment of algebraic scales or letter scales to the impact of each alternative being assessed on each identified decision factor.

decision criterion and the ranking, rating, or scale of each alternative with respect to that decision criterion, summed over all decision criteria.[169] Composite indices of this type take the general form:

$$\text{Index}_j = \sum_{i=1}^{n} \text{W}_i \cdot \text{R}_{ji} \qquad (5.17)$$

where

Index_j = composite index or total score for the *j*th alternative;

W_i = importance weight assigned to the *i*th decision criterion;

R_{ji} = ranking, rating, or scale assigned to the *j*th alternative with respect to the *i*th decision criterion; and

n = the total number of decision criteria.

We will now briefly look at these four steps in turn.

<u>Problem Definition</u>

Problem definition is covered in Section 2. Briefly, a decision-maker is dissatisfied with the prospect of a future state of affairs (climate change impacts), and possesses the desire and authority to initiate actions designed to alter this state. The decision-maker's desire to achieve a new state of affairs derives from a need to achieve some broad objectives, which are compromised, in this case, by climate change. To attain the desired state of affairs, the decision-maker can undertake adaptation measures.

The specification of objectives often exhibits a hierarchical structure, with the highest level representing broad, vaguely stated objectives, (e.g. economic efficiency or value) which are not very operational. These broad objectives usually need to be broken down in to lower-level, more specific operational objectives (or decision factors), so that the extent to which they are achieved by the adaptation option can be more readily assessed (see step 2).

Specifying objectives is typically accomplished by holding a workshop for individuals or groups of individuals who are positively or negatively

[169] **Weighting-scaling** or **weighting-rating** methodologies embody the assignment of relative importance weights to decision factors, and impact scales or ratings for each alternative relative to each factor. **Weighting-ranking** approaches involve the assignment of importance weights, and the relative ranking of all alternatives from best to worst in terms of their impact on each decision factor.

affected by the proposed option, and using participatory methods to reach a consensus on decision factors. To some extent this has already been done regarding the impacts of climate change, since the impact matrices presented in Section 3 embody the concerns of stakeholders captured during the sub-UK studies.

Selecting Decision Criteria and Scoring Alternatives

The next step is to identify appropriate criteria to assess the ability of the adaptation alternative(s) to achieve the set of specified higher-level objectives. **Decision criteria** define the scale (or index) used to measure progress in meeting objectives, and the range of possible consequences (typically from 'worst' to 'best'). Criteria are generally of two types:

- **Quantitative** – e.g. present value costs (£), present value benefits (£), net present value (£), numbers of tree lost per year, number of hectares of sand dunes lost per year etc. (The first three criteria measure the degree to which the economic efficiency objective is achieved.)

- **Qualitative** – e.g. no impact, minimal impact, limited impact, moderate impact, significant impact, major impact.

As with the specification of decision factors, it is best to base the selection of decision criteria on the consensus of stakeholders, particularly with respect to qualitative criteria, since their selection would otherwise require considerable value judgement on the part of the analyst. Qualitative criteria can be expressed in the form of subjective indices, typically based on an '**ordinal**' scale.[170] An example is shown in Box 5.23 below.

In general, when specifying decision criteria it is important to ensure that they are both 'measurable' and 'comprehensive' (Keeney and Raiffa, 1976). A decision criterion is '**measurable**' if it is reasonable:

- to assign a point value to each alternative over all possible levels of the decision criterion;[171] and

- to assess the decision maker's preferences for different levels of the decision criterion.[172]

A decision criterion is said to be '**comprehensive**' if the decision-maker has a clear understanding of the extent to which it is achieved when (s)he

[170] **Ordinal scales** simply rank alternatives or decision factors in order; they do not convey how much 'better' one alternative or decision factor is to another, but simply indicate relative order.

[171] Or obtain a probability distribution in the event of uncertainty.

[172] Moreover, it is important that these tasks can be accomplished without expending an excess amount of resources, e.g. time, cost or effort.

knows the level of that decision criterion in a particular situation.

In addition any MCA decision problem requires that the set of decision criteria are:

- **Complete** - i.e. do they cover all the important aspects of the problem?
- **Operational** - i.e. can they be meaningfully used in the analysis?
- **Decomposable** - i.e. do they facilitate the simplification of the evaluation process by permitting it to be broken down into smaller parts?
- **Non-redundant** - i.e. are they defined in such a way so as to avoid double-counting?
- **Mutually independent** - i.e. are the preferences held for criterion A not affected, in any way, by the preferences held for other criteria.
- **Minimal** (**number of criterion**) - i.e. subject to the above, do they keep the problem dimension as small as possible?

These requirements need to be fully considered when identifying the set of decision criteria.

Box 5.23: Example of a Qualitative Index

An example of a **qualitative** (subjective) **index** for aggregate biological impacts is shown in Table 5-25 below. This index, which was developed by two experienced ecologists, was used by Woodward-Clyde Consultants (1975) as part of a MCA to identify potential sites for power stations in Washington State. (In this case, the 'best' consequence is assigned a scale value of zero and the 'worse' consequence a scale value of eight.)

Table 5-25: Example of a Qualitative (Subjective) Index for Biological Impacts

Scale Value	Level of Impact
0	Complete loss of 1.0 square mile of land that is entirely in agricultural use or is entirely urbanised; no loss of any 'biological' communities.
1	Complete loss of 1.0 square mile of land that is primarily (75%) agricultural habitat with loss of 25% second growth; no measured loss of wetlands or endangered species habitat.
2	Complete loss of 1.0 square mile of land that is 50% farmed and 50% disturbed in some other way (logged or new second growth); no measured loss of wetlands or endangered species habitat.
3	Complete loss of 1.0 square mile of recently disturbed land (logged or plowed), plus disturbance of surrounding previously disturbed habitat within 1 mile of site border; or 15% loss of wetlands or endangered species habitat.
4	Complete loss of 1.0 square mile of land that is 50% farmed (or otherwise disturbed) and 50% mature second growth or other community; or 15% loss of wetlands or endangered species habitat.
5	Complete loss of 1 square mile of land that is primarily (75%) undisturbed mature 'desert' community; or 15% loss of wetlands or endangered species habitat.
6	Complete loss of 1.0 square mile of mature, second growth (but not virgin) forest community; or 50% loss of big game and upland game birds; or 50% loss of wetlands or endangered species habitat.
7	Complete loss of 1 square mile of mature community or 90% loss of local productive wetlands and local endangered species habitat.
8	Complete loss of 1 square mile of mature, virgin forest or local wetlands or local endangered species habitat.

Source: Woodward-Clyde Consultants (1975)

Notes:

This is a qualitative scale of potential short- and long-term impacts that could result from the construction and operation of a power station on a site. The impacts range from '0' for no impact to '8' for maximum impact. Site visits showed that the biologically important characteristics (aside from aquatic resources) of the State are: (1) virgin or large, mature, second growth stands of timber or 'undisturbed' sagebrush communities; (2) known or potential habitat of endangered species; and (3) wetland areas.

It is also important to ensure that the decision criteria chosen do not measure achievement of the same higher-level objective. If they do, then the weight accorded this objective in the final result will be upwardly bias. Finally, in the context of climate change the time profile of impacts is particularly important. This may necessitate different decision factors being defined for impacts that occur at various points in time.

Decision criteria are then combined with adaptation options to form a **trade-off matrix** – a variation of the outcome array introduced in Section 1. Such matrices serve as the conceptual method for MCA. For example, suppose that three alternative adaptation options (A_1, A_2 and A_3) are being considered by a coastal town at risk from sea level rise. For simplicity let us assume that four decision criteria have been selected: DC_1 – net present value costs, inclusive of monetised climate change impacts avoided (£); DC_2 – rare bird sanctuary protected (number nesting sites); DC_3 – alleviation of anxiety in local population (subjective index 1-worst to 5-best); and DC_4 – net employment effect (number of additional man-days). Suppose the trade-off matrix corresponding to this situation is given in Table 5-26. Note that the cells in the matrix are incremental to the baseline (with climate change) scenario. Furthermore, it is assumed that only one future state-of-nature will occur.

Table 5-26: Trade-off Matrix – an Example of a Coastal Area at Risk to Sea Level Rise

Decision Criteria	Adaptation Alternative		
	A_1	A_2	A_3
DC_1 (£ PVC)	+105,000	+130,000	+113,000
DC_2 (# of nesting sites)	2,700	2,000	3,200
DC_3 (subjective index)	2	3	5
DC_4 (# of man-days)	264	150	150

Once a trade-off matrix like Table 5-26 has been constructed for the specific problem, it should be analysed to see whether it is possible to identify a **dominant alterative**. If one alternative outperforms the others with respect to some decision criteria, and is not itself outperformed with respect to all other criteria, then that alternative is said to dominate the set of feasible alternatives. **The decision rule in this case is to select the dominant alternative**. In the example provided in Table 5-26 there is no single dominant alternative.

Where there is no single dominant alternative, then you may assign a **rank**, **rating** or **scale value** to each decision criterion. This will allow you to assess the performance of individual alternatives relative to each decision factor. Several different techniques have been developed for this purpose, including: a) un/ranked paired-comparisons; b) functional relationships; or c) predefined impact-rating schemes.

Paired-comparison techniques, ranked or unranked, basically involve a series of comparisons between alternatives relative to each decision factor.

The results of the comparisons are then systematically tabulated. One of the more useful paired-comparison techniques was developed by Dean and Nishry (1965). The unranked approach they describe consists of considering each alternative relative to every other alternative for each decision factor, and assigning a value of 1 to the 'more desirable' alternative, and a value of zero to the 'less desirable' alternative.[173] If two alternatives in a pair are 'equally desirable', then a value of 0.5 is assigned to both. This technique can be implemented by an individual or a group of individuals. The use of the paired-comparison technique for the three adaptation alternatives and four decision criteria shown in Table 5-26 is illustrated in Box 5.24.

Box 5.24: An Example of the Unranked Paired-comparison Technique

A trade-off matrix corresponding to an example policy context is given in Table 5-26 above. The application and tabulated results of Dean and Nishry's unranked paired-comparison technique for the three adaptation alternatives and four decision criteria displayed in Table 5-26 are shown in Table 5-27 through Table 5-30, respectively.

Note that a dummy alternative, A_4, is included in each table. The purpose of this dummy alternative is to serve as a 'place keeper' – i.e. to ensure that no alternative (A_1 through A_4) is assigned a net value of zero.

Following the assignment of relative desirability to each alternative pair, a process which may involve several iterations, the individual desirability assignments are summed. For example, the sum of the desirability assignments for A_1 relative to the other alternatives relative to DC_1 is 3 (see Table 5-27). The next step is to compute the **alternative choice coefficient** (ACC) which is equal to the sum of the individual desirability assignments divided by the total of the Sum column. These calculations are shown in the final columns in Table 5-27 through Table 5-30. With respect to DC_1 for example, the ACC column in Table 5-27 indicates that A_1 is the most desirable, followed by A_3 and A_2.[174]

Table 5-27: Scaling of Alternatives Relative to Decision Factor 1

[173] The assignment of zero to an alternative *only* signifies that, in the pair considered, that alternative is of 'less' importance; it *does not* signify 'no' importance.

[174] Since the ACC rates the quantitative degree of difference between the alternatives and permits you to rank the alternatives in order, this technique involves both **interval** and **ordinal** scaling, respectively.

Adaptation Alternatives	Tabulation of Relative Desirability						Sum	ACC
A_1	1	1	1				3	3÷ 6=0.50
A_2	0			0	1		1	1÷ 6=0.17
A_3		0		1		1	2	2÷ 6=0.33
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5-28: Scaling of Alternatives Relative to Decision Factor 2

Adaptation Alternatives	Tabulation of Relative Desirability						Sum	ACC
A_1	1	0	1				2	2÷ 6=0.33
A_2	0			0	1		1	1÷ 6=0.17
A_3		1		1		1	3	3÷ 6=0.50
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5-29: Scaling of Alternatives Relative to Decision Factor 3

Adaptation Alternatives	Tabulation of Relative Desirability						Sum	ACC
A_1	0	0	1				1	1÷ 6=0.17
A_2	1			0	1		2	2÷ 6=0.33
A_3		1		1		1	3	3÷ 6=0.50
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Table 5-30: Scaling of Alternatives Relative to Decision Factor 4

Adaptation Alternatives	Tabulation of Relative Desirability						Sum	ACC
A_1	0	0	1				1	1÷ 6=0.17
A_2	1			0.5	1		2.5	2.5÷ 6=0.42
A_3		1		0.5		1	2.5	2.5÷ 6=0.42
A_4 (dummy)			0		0	0	0	0÷ 6=0.00
Total							∑= 6	∑= 1.00

Adapted from Canter (1996)

As you will see in Table 5-31 below, the ACC fractions can be weighted, and then used to construct a **composite index** or **total score** for each alternative over all decision criteria. Even if this is not done, the ACC fractions facilitate the rank ordering of the desirability of alternatives with respect to each decision criterion. It is also possible to apply a simple decision rule at this point, namely the **worst score technique**. This decision rule is appropriate if one of the main objectives is to minimise the risk that undesirable and/or irreversible project consequences will be realised. The technique consists of two main steps:

3. identify the worst ACC fraction for each alternative; and

4. select the alternative that performs the best amongst the worst fractions – i.e. choose the alternative with the highest ACC fraction.

Based on the ACC fractions presented in Table 5-27 through Table 5-30, an example of ranking alternatives using the worst score technique is summarised in Table 5-31. In this example A_1 would be selected, followed by A_2 and A_3. Since this approach does not require the specification of weights, it is relatively straightforward to apply. For the same reason, it is only suitable in situations were objectives are given equal weight (i.e. have the same importance).

Table 5-31: Ranking Alternatives Based on the Worst Score Technique

Adaptation Alternatives	ACC Values for Each alternative Relative to Each Decision Factor				Worst ACC Value	Ranking
	DC_1	DC_2	DC_3	DC_4		
A_1	0.50	0.33	0.17	0.16	0.16	**1st**
A_2	0.17	0.17	0.33	0.42	0.17	**2nd**
A_3	0.33	0.50	0.50	0.42	0.33	**3rd**

Functional relationships[175] can also be used for scaling, ranking or rating alternatives relative to decision factors. These functions essentially relate the objective (physical) measurement of a decision criterion to a subjective judgement regarding its 'quality', based on a scale of designator indicators which are typically calibrated from 0 ('low quality/less desirable') to 1 ('high quality/more desirable').[176] Expressing the physical relationships in terms of a quality scale between 0 and 1 is sometimes called **normalisation**, whereby differing units of measurement are translated into dimensionless units. An example functional relationship for water quality is shown in Figure 5.9 below. Dee *et al* (1972) describe a seven-step procedure for constructing such functional relationships. Curves like the one shown in Figure 5.9 can then be used to complete matrices similar to that shown in Box 5.24 above.

Rating alternatives relative to decision criteria can also be done with the aid of **predefined rating schemes**. With this approach, numerical values are taken from the predefined scale and assigned to each alternative relative to each decision criterion. An example of a predefined rating scale from Wilson (1991)[177] which delineates five reference scales, is shown in Table 5-32. The descriptions corresponding to each reference scale are to aid in the assignment of numerical values to each alternative. Again, predefined rating schemes like Table 5-32 can be used to complete matrices similar to that shown in Box 5.24 above.

[175] These are also called 'functional curves', 'value functions' or 'parameter function graphs'.

[176] In this sense, it constitutes **ratio scaling**, in that it indicates the quantitative degree of difference between alternatives relative to some defined starting point.

[177] Wilson (1991) personal communication to Canter (1996), Sante Fe, New Mexico.

Figure 5.9: Example of a Functional Relationship – Water Quality

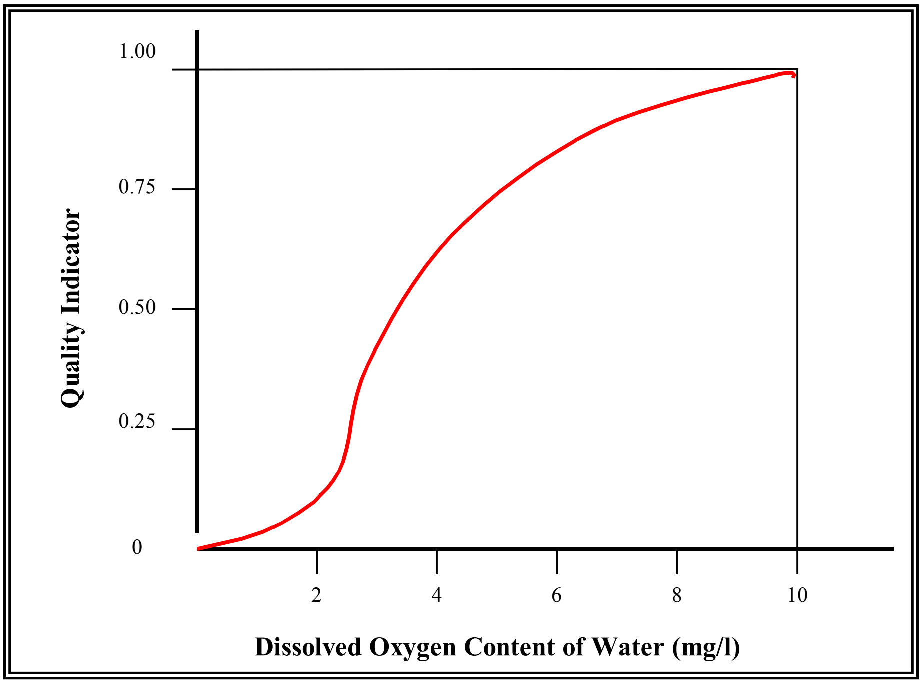

Table 5-32: Example of a Predefined Rating Scale: Ecological Impact

Rating Scale	Assignment Criteria
5	No potential impact to important species or habitats; no existing habitats (vegetation and/or soil) poor in quality and diversity or severely damaged.
4	The potential negative impact to important species or habitat would be minimal.
3	The potential negative impact to important species or habitat would be limited.
2	The potential negative impact to important species or habitat would be substantial.
1	The potential negative impact to important species or habitat would be only marginally acceptable.
0	The potential negative impact to important species or habitat would be excessive and unacceptable. Affected area contains critical habitat for endangered or threatened species.

Adapted from Wilson (1991) in Canter (1996)

The Weighting of Decision Criteria

In this step a 'value' or 'weight' is allocated to each of the decision criteria - that is, the decision criteria are weighted relative to one another.[178] (The weighting of decision factors is necessary if ultimately we wish to combine them.) Typically experts, decision-makers or stakeholders set this 'weight' in accordance with their interpretation of society’s preferences. For example, if experts assume that society places more importance on economic value than equity, then they will assign a higher weight to economic value. This step in the MCA process is the most complex; not only must you know the preferences of society for the various decision factors, but you must also be able to translate these preferences into *relative* weights. Examples of techniques usually employed to establish importance weights include: a) the Delphi Method; b) un/ranked paired comparisons; and c) rating from predefined scales.

With the **Delphi Method** the weights are formed by a group, which typically comprises decision-makers, representatives of the stakeholder community and relevant experts (e.g. scientists, economists, engineers, agronomists etc.). The method generally consists of (collectively) developing a questionnaire, which is then submitted to the ‘group’ in order to elicit their preferences independently. The results of the questionnaires are then analysed, and a second questionnaire is prepared (often containing selected information on the ‘group’ weights). The purpose of this second questionnaire is to obtain more precise information from the respondents. Further iterations can occur until responses to the questions are constant and consistent. You can then use the importance weights taken from the final iteration, or average the weights over several iterations.

The **paired-comparison technique** for importance weighting is identical to that described in above, except now the comparisons are made between decision criteria, as opposed to between alternatives relative to a given decision factor. As was the case previously, the weights are estimated on the basis of a simple procedure which takes into account three possibilities: 1) assigning a valuing of 1 to the decision criterion considered to be *more* important in a pair-wise comparison; 2) assigning a valuing of 0 to the decision criterion considered to be *less* important in a pair-wise comparison; and 3) assigning a valuing of 0.5 to both decision criteria if they are considered to be of *equal* importance. An example is provided in Box 5.25. Again, this technique can be implemented by an individual or a group of individuals.

[178] The 'value' or 'weight' assigned to a decision factor reflects: (a) the magnitude of difference between decision factors; and (b) the relative importance of this difference.

Box 5.25: An Example of the Unranked Paired-comparison Technique for Importance Weighting

The application and (assumed) tabulated results of the unranked paired-comparison technique to our case study are shown in Table 5-33. For the same reasons given in Box 5.24, a dummy decision criterion (DC_5) is included in the table.

Following the assignment of relative importance weights to the decision criteria – which again may involve several iterations – the individual weight assignments are summed. For example, the sum of the weight assignments for DC_1 relative to the other decision criteria is 4 (see Table 5-33). The next step is to compute the **criteria importance coefficient** (CIC), which is equal to the sum of the individual weight assignments divided by the total of the Sum column. These calculations are shown in the final columns in Table 5-33. The CIC column in Table 5-33 indicates that DC_1 is the most important decision criterion, followed by DC_4, DC_2 and finally DC_3. This technique thus allows the rank ordering of decision criteria from *most* important to *least* important.

Table 5-33: Using Paired-comparisons for Weighting Decision Criteria

Decision Criteria	Importance Weight Assignment										Sum	CIC
DC_1	1	1	1	1							4	4 ÷ 10=0.40
DC_2	0				1	0	1				2	2 ÷ 10=0.20
DC_3		0			0			0	1		1	1 ÷ 10=0.10
DC_4			0			1		1		1	3	3 ÷ 10=0.30
DC_5 (dummy)				0			0		0	0	0	0÷ 10=0.00
Total											Σ= 10	Σ= 1.00

Adapted from Canter (1996)

Importance weighting can also be done with the use of a **predefined importance scale**. These scales are analogous to the predefined rating scales discussed above. An example of a predefined importance scale from Linstone and Turoff (1975) which delineates five reference scales, is shown in Table 5-34. The description corresponding to each reference scale is to aid in the assignment of numerical values to the decision factors. The assignment of values can be undertaken by individuals or a group.

Table 5-34: Example of a Predefined Importance Weighting Scale

Scale Reference		Description
1.	Very important	A most relevant point; first-order priority; has direct bearing on major issues; must be resolved, dealt with, or treated
2.	Important	Is relevant to the issue; second-order priority; has significant impact, but not until other items are treated; does not have to be fully resolved
3.	Moderately important	May be relevant to the issue; third-order priority; may have impact; may be determining factor to major issue
4.	Unimportant	Insignificantly relevant; low priority; has little impact; not a determining factor to a major issue
5.	Most unimportant	No priority; no relevance; no measurable effect; should be dropped as an item to consider

Source: Linstone and Turoff (1975) in Canter (1996)

Aggregation

In general, the final step in MCA is to calculate an overall **composite index** or **total score** for each alternative. This can take the form of a **decision matrix**, which displays the products of the alternative scales, ratings or ranks, and the importance weights or ranks. The development of a decision matrix from our previous example based on the paired-comparisons is shown in Box 5.26.

Since the purpose of this section is solely to provide the reader with a general overview of the 'workings' of MCA, we have presented only the more 'simplistic' analytical techniques employed in MCA. More sophisticated techniques exist however, including a) outranking techniques such as ELECTRE and PROMETHEE;[179] b) multi-attribute utility analysis;[180] and c) the Analytical Hierarchy Process (AHP).[181] Each of these techniques has the same basic structure as outlined above, but employs slightly more complex mathematical procedures for ranking,

[179] See, for example, Roy (1971) or Roy (1976).

[180] See, for example, Keeney (1972); Keeney (1974); Keeney and Raiffa (1976).

[181] See, for example, Saaty (1980).

scaling, rating and weighting.

Finally, the use of MCA does not remove the need for uncertainty analysis. In Section 5.10 we looked at how sensitivity analysis is used to focus our attention on alternative assumptions that could have a significant effect on the final cost estimates. The output of the sensitivity analysis is then used to identify actions that can mitigate the effects of uncertainty, or to redesign the institutional structure of adaptation projects to ensure maximum effectiveness. Sensitivity analysis can equally be used within MCA to identify those assumptions - such as the decision factors, scoring and weighting systems used in the analysis - that potentially could have a significant effect on the final results.

It is also possible to explicitly incorporate the analysis of uncertainty into MCA. For example, the preferences of decision-makers for uncertain outcomes can be built into the (expected) utility functions that underpin multi-attribute utility analysis.

Box 5.26: Example of Decision Matrix Based on Paired-Comparisons

The CIC values for our four decision criteria, and the ACC values for the three adaptation alternatives are summarised in Table 5-35. The decision matrix presenting the overall **composite index** or **total score** for each alternative is shown in Table 5-36. Based on the total score for each adaptation alternative displayed in Table 5-36, adaptation alternative 3 represents the 'best' choice, followed by alternative 1 and then alternative 3.

Table 5-35: Summary of FIC and ACC Values

Decision Criteria	CIC Values	ACC Values for Each Alternative		
		A_1	A_2	A_3
DC_1	0.40	0.50	0.17	0.33
DC_2	0.20	0.33	0.17	0.50
DC_3	0.10	0.17	0.33	0.50
DC_4	0.30	0.16	0.42	0.42

Table 5-36: Decision Matrix

Decision Criteria	**Total Score for Each Alternative**		
	A_1	**A_2**	**A_3**
DC_1	0.50*0.40=0.200	0.17*0.40=0.068	0.33*0.40=0.132
DC_2	0.33*0.20=0.066	0.17*0.20=0.034	0.50*0.20=0.100
DC_3	0.17*0.10=0.017	0.33*0.10=0.033	0.50*0.10=0.050
DC_4	0.16*0.30=0.051	0.42*0.30=0.124	0.42*0.30=0.124
Total Score	∑= 0.334	∑= 0.259	∑= 0.406
Ranking	**2nd**	**3rd**	**1st**

Adapted from Canter (1996)

5.11 Assessing Distributional Effects

5.11.1 Context of Guideline

The distributional effects of climate change impacts and adaptation options are important because they may affect the achievement of equity-related social objectives that a public decision-maker may have. They are also important because the burden of the benefits and costs on different groups within society may well determine the acceptability of alternative options, and in this sense are of importance to private sector agents. For example, if the analysis fails to identify groups who would lose as a result of a particular adaptation option, but who have the power to block it or to thwart its effective implementation, the whole analytical exercise may be wasted since no compensatory or compromise solutions can be developed. The costing analysis therefore needs to consider: (1) how equity - and particularly the effect of impacts and adaptation on e.g. income distribution - is incorporated, and; (2) what procedure is adopted that allows us to identify affected groups more generally. Possible approaches to these problems are identified below. Public sector analysis of distributional issues is supported by the information provided in the Treasury's Green Book.[182] The focus of attention regarding distributional issues in the Green Book is on income distribution. Guidance relating to gender, race, age, health, skill or location is also provided though it is noted in the Green Book that generally these distributional issues are correlated with income. This focus is reflected in this section.

5.11.2 Treatment of Equity

The equity concern in this context is that there is the potential for climate change impacts to be borne disproportionately by poorer sections of society. Similarly, there may be the possibility that the net costs of adaptation may also be disproportionately borne by low income groups. For example, it may be the case that increased winter rainfall results in increased flooding incidence in lower income residential areas so that these lower income groups bear the majority of the impact cost, and increases the welfare disparity that already exists between high and low income groups. It is also likely, as a consequence, that the impact cost estimated will be lower, given the lower income constraint on willingness to pay valuation measures.

In order to incorporate this issue in the costing analysis it is necessary, for

[182] see http://greenbook.treasury.gov.uk/annex05.htm#six

any given impact or adaptation option, to:

1. Collect information on which income groups are affected by the measures proposed. This is likely to be an approximate exercise. One possibility, if the impact has a specific geographical distribution, is to use micro-level census data that provides information on socio-economic data at the post-code level. From this, the deviation from the national average income level can be calculated.[183] The Green Book states that, at a minimum, any distributional effects identified from such an exercise should be explicitly stated in the appraisal report. Defra Flood Management unit has more formally incorporated local area socio-economic data, that comprises an index of social deprivation, into a Priority Score Calculation that explicitly and separately presents the economic, social and environmental impacts of a flood defence scheme. Details of this calculator are given at:

http://www.defra.gov.uk/environ/fcd/policy/PSCALC.htm

2. Estimate the impact cost using the appropriate valuation technique. In the example of the flooding in low-lying areas of low-income housing, the technique may be based on differences in land/property values from areas that do not have a flood risk.

In principle, two possible approaches can then be used to incorporate distributional concerns: (1) income weighting; and (2) the formulation of a distributional matrix.

Estimates of Income Distribution Weights

The costs of different climate change impacts, as well as any related benefits, belong to individuals from different income classes. Economic theory has developed a method of weighting the benefits and costs according to who is impacted. This is based on converting changes in income into changes in welfare, and assuming that an addition to the welfare of a lower income person is worth more than that of a richer person. More specifically, a special form can be taken for the social welfare function, and a common one that has been adopted is that of Atkinson (1970). He assumes that social welfare is given by the function:

$$W = \sum_{i=1}^{N} \frac{AY_i^{1-\varepsilon}}{1-\varepsilon} \qquad (5.18)$$

where *W* is the social welfare function; Y_i is the income of individual *i*; ε is the elasticity of the social marginal utility of income (or inequality

[183] The required income data is available from the National Statistics website (http://www.statistics.go.uk).

aversion parameter); and *A* is a constant.

The social marginal utility of income is defined as:

$$\frac{\partial W}{\partial Y_i} = AY_i^{-\varepsilon} \tag{5.19}$$

Taking per capita national income, $\bar{Y}$ as the numeraire, and giving it a value of one, we have:

$$\frac{\partial W}{\partial Y_i} = A\overline{Y}_i^{-\varepsilon} = 1 \tag{5.20}$$

and

$$\frac{\partial W}{\partial Y_i} = SMU_i = \left[\frac{\overline{Y}}{Y_i}\right]^{\varepsilon} \tag{5.21}$$

Where SMU_i is the social marginal utility of a small amount of income going to group *i* relative to income going to a person with the average *per capita income*. The values of SMU_i are therefore the weights to be attached to costs and benefits to groups *i* relative to costs and benefits to a person with average income.

In order to apply the method estimates of $\bar{Y}$ and ε are required. Average income levels can be found in the UK Office of National Statistics Blue Book.[184] A recent survey of the literature by Cowell and Gardiner (1999) suggests that values of around 1 for the inequality aversion parameter, ε, are generally found. . A value of 1 would be implied if: decision-makers decided to value environmental damages to all individuals at the value associated with the average income individual; and the 'income elasticity' of environmental damage with respect to income is one.[185] On this basis, the Treasury Green Book states that a value of 1 is defensible in such analysis.

Given these parameters, by way of illustration, if the average income is £15,000 and the mean income of the individuals impacted negatively by climate change is £10,000, then the weight to attach to the impact costs would be 1.5 (assuming a value of 1 for ε). The estimated impact costs would then be multiplied by 1.5. The effect of this weighting would be

[184] http://www.statistics.gov.uk/downloads/ theme_economy/BB_2001.pdf

[185] This is the same adjustment that is made when the mortality costs of climate change are valued at a single figure for all deaths, based on average world income, irrespective of where they occur. See, for example, Fankhauser *et al.* (1997).

that the effect of the lower income constraint would be counteracted.

The Green Book notes that, whilst in principle, costs and benefits should consider such a weighting exercise, the reality may be that cost restrictions may limit data availability. It therefore suggests that a decision as to whether such an adjustment is warranted will be informed by the scale of the impact, the likely robustness of any such calculation, and the type of project being assessed, though where an adjustment is not made justification should be provided.

Distribution Matrix

The paragraphs above suggest that at minimum the analyst should document the distribution of costs of a particular impact. One form of documentation that has been used to present different cost burdens within society is the distributional matrix. This typically takes the form of Table 5-27 below.

The decision-maker may consider the results of this matrix and decide, in a cost-effectiveness decision method where all three adaptation options achieve the same reduction in climate change impacts, that whilst option 2 is the most cost-effective option, those costs are borne disproportionately by lower income groups. Option 1 may then be preferred in order to meet the equity objectives of the decision-maker. Further examples of this type of matrix are presented in the Green Book at: http://greenbook.treasury.gov.uk/annex05.htm#six.

Table 5-37: Distributional Matrix for an Adaptation Decision Problem

	Adaptation Option					
	Option 1		**Option 2**		**Option 3**	
Income Quintile	(£'000)	(% of total)	(£'000)	(% of total)	(£'000)	(% of total)
> £50,000	12,000	19	6,000	10	10,000	9
£28,000 - £49,999	14,000	22	8,000	14	18,000	16
£16,000 - £27,999	15,000	23	12,000	21	25,000	22
£8,000 - £15,999	13,000	20	14,000	24	28,000	25
< £8,000	10,000	16	18,000	31	30,000	27
Total Net Cost	**64,000**	**100**	**58,000**	**100**	**113,000**	**100**

5.11.3 Stakeholder Analysis

Distributional analysis also needs to incorporate the fact that the acceptability of a project/policy, e.g. an adaptation option, may be dependent on the relative influence of the different stakeholder groups who are bearing the benefits and costs of such an action. A method of assessing this - **stakeholder analysis** - is briefly outlined below.

The aim of a stakeholder analysis is to identify those organisations or individuals whose interests will be, or are being, affected by the planned option, and to assess the potential influence they may have on the decision problem. The techniques used to identify the stakeholders can range from the formal to the informal. Option formulators and implementers should be expected to be aware of who the cast of stakeholders are likely to be, though this can be supplemented by the use of group consultations, etc.

Once a cast of stakeholders has been identified it is helpful to have systems of categorisation. The UK Government (DFID, 1995) categorise stakeholders as:

- ♦ **Primary:** those ultimately affected by the option, positively or negatively.
- ♦ **Secondary:** those involved in the delivering of the option, including those involved in the decision-making and those excluded.
- ♦ **Key:** those who may be indirectly affected by the option, but who may exercise a large degree of influence which can affect the intervention.

In the example given above regarding flooding of low-lying areas, an obvious adaptation is to improve the flood defence system along that stretch of river. The primary stakeholders are the residents presently at risk from flooding, and businesses located in that area. The secondary stakeholders might include the local planning authority, Defra and the Environment Agency. The key stakeholders might include house insurance companies, local conservation groups and anglers.

Having identified and categorised stakeholders the next step is to assess their interest in, and potential impact on, the option. Once again, a range of formal and informal research techniques may be used to gather information on the ways in which different stakeholders have an interest in the option and the ways in which they might influence an option. The importance of the different stakeholders in the policy objectives of the decision-maker, and the amount of influence that different stakeholders can bring to bear on an option, are therefore assessed. A matrix can then be constructed to locate stakeholders. The stakeholders identified in the example above are plotted in the matrix below (see Table 5.10). Importance on the vertical axis means the extent to which the needs and interests of a particular group of stakeholders are regarded as a priority by the decision-maker. The horizontal axis ranks the amount of influence they may bring to bear.

Figure 5.10: Example of a Stakeholder Matrix

	Low Influence	**High Influence**
High Importance	**A** 2	**B** 1, 3, 4
Low Importance	**C** 6, 7	**D** 5

Notes:

Primary stakeholders: 1 = residents; 2 = businesses

Secondary stakeholders: 3 = local planning authority; 4 = Defra/Environment Agency

Key stakeholders: 5 = house insurance companies; 6 = local conservation groups; 7 = anglers.

The matrix is used as an impressionistic tool to rank the importance and influence of stakeholders in relation to each other. Those stakeholders in quadrant B, e.g. Defra/Environment Agency, have both high influence and high importance and are therefore crucial to the decision problem. In quadrant D, the stakeholders (e.g. insurers) have high influence, even though they are of no particular importance to the option. Stakeholders in quadrant A, (e.g. businesses), are regarded as important to the option, but have low influence.

An analysis of the relationships between the stakeholders' views and the intervention objective(s) is the key output of a stakeholder analysis. In particular, it is necessary to assess the risks posed by the stakeholder views to the possibility of the option achieving its objective(s). Where stakeholders are identified as having considerable potential influence on the option, then they represent a considerable risk to its implementation. This then leads to consideration of how such risks should be managed. The second dimension of the analysis is to identify what assumptions need to be made about how stakeholders should act for as option to achieve its objective(s). If the assumption is too ambitious, then it may be that it should be regarded as what is sometimes known as a 'killer-assumption' and the option specification should be revisited. The conclusion as to the merit of stakeholder analysis lies in the simple observation that options seldom succeed despite the people they are intending to benefit.

SECTION VI

CONCEPTUAL BASIS:

- The Economic Concepts of Cost and Benefit -

6 CONCEPTUAL BASIS FOR THE COSTING GUIDELINES

6.1 Introduction

The conceptual basis of the costing guidelines is grounded in the economic concepts of cost and benefit. The purpose of this section is to provide those users unfamiliar with these concepts, or their application to environmental problems, with a basic understanding.

The section is structured as follows. First, the main cost concepts that underpin the assessment of the impacts of climate change and adaptation responses to those impacts are defined – with distinctions being drawn between private and social cost, and between financial and economic cost. The basic principles of benefit valuation are then considered. This includes definition of what *values* to quantify, and explanation of how such values are *measured*.

6.2 Conceptual Basis for Costing Analysis

6.2.1 Introduction

This guideline outlines the principal concepts that apply to the costs associated with climate change impacts and adaptation measures. We work from the basic premise of cost analysis that the term, '**cost**' expresses the idea of **scarce resources**[186] that are used in satisfying people's material wants and needs. It is important to allow for the fact that some adaptation measures may generate 'benefits' and these benefits are part of a unified method of cost assessment. When speaking about costs we normally think of a positive number, reflecting a payment that has to be made in return for some goods or services. In the wider context in which the cost concept is being used here, however, it is necessary, in some cases, to allow for negative costs - i.e. cost savings. It is essential that any cost assessment consider all changes in resources demanded and supplied which will result from adoption of a given adaptation measure.

6.2.2 Cost, Value and Welfare

The conceptual foundation of all cost estimation is the value of the scarce resources to individuals. Thus, values are based on individual preferences, and the total value of any resource is the sum of the values of the different individuals involved in the use of the resource. This distinguishes this system of values from one based on 'expert' preferences, or on the preferences of political leaders.

Individual preferences are expressed in two, theoretically equivalent, ways. These are:

- the minimum payment the owner of the resource is **willing to accept** (WTA) for its use, or;
- the maximum amount a consumer of the resource is **willing to pay** (WTP) for its use.[187]

In the context of the UKCIP, for example, the WTP measure of value reflects the maximum people would be willing to pay to avoid a particular climate change impact; WTA is the minimum compensation people would accept to live with the impact. The concept of WTP and WTA therefore

[186] Resources include natural resources, labour and capital. Clearly, there are only limited quantities in the world available to be used by society and thus they can be said to be scarce.

[187] The concepts of WTP and WTA are also central to the valuation of benefits in economic analysis.

plays a critical part in defining our cost methodology. Indeed, this is consistent with the Treasury Green Book where the emphasis is firmly on the use of WTP to value non-market impacts generally in project and policy appraisal.[188]

Actions taken to adapt to climate change divert resources from other alternative uses. Similarly, a climate change impact such as crop damage from increased storm frequency results in lost production from given resources – resources that may otherwise have been put to more productive use elsewhere in the economy. The theoretically precise measure of the costs of climate change, therefore, is the total value that society places on the goods and services foregone as a result of the diversion of resources from alternative uses. A cost assessment should ideally consider all value, or **welfare**, changes in resources demanded and supplied by a given adaptation option or climate change impact.

A criticism of this costing method, based on individuals' willingness to pay which is itself constrained by their income, is that it is inequitable, as it gives greater weight to the 'well off'. We acknowledge the validity of this criticism, and we also note that there is no coherent and consistent method of valuation that can replace the existing one in its entirety. Concerns about equity outlined in a separate guideline (see Section 5.10). It should be noted in addition that the estimated costs are one piece of information in the decision-making process for climate change that can be supplemented with other information on other social objectives.

6.2.3 Social, Private and External Cost

It is not always the case that individuals' WTP is fully reflected in the allocation of scarce resources mentioned above. A basic distinction that needs to be made in our cost analysis is between the **social cost** of an activity or intervention and the **private cost**.

Private Costs

Private cost is the more easily understood concept, and refers to those costs which people take into account when making every day decisions, buying or selling in **markets**. Typically, **private costs** are taken from the market price of the resource inputs – e.g. land, materials, labour and equipment. Such costs are private in the sense that they are internal to the decision making process of the individual consumer or producer.

To illustrate: a farmer's decision on how much and what sort of a fertiliser to use as a response to growing different crops as a result of climate change mainly depends upon the relative prices and effectiveness of the

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188 See http://greenbook.treasury.gov.uk/annex02.htm

fertilisers. In this case the price of a fertiliser and the cost of labour used to apply it form the private cost, which is the main factor in the farmer's decision.

External and Social Costs

The private costs of a decision, (e.g. whether to undertake an adaptation project), do not necessarily reflect all the costs that this decision imposes on society. Many projects have **external effects**, which may not be accounted for in the decision-making process. In the example of the farmer's actions given above, the use of a fertiliser may have negative impacts on the water quality in the local area as a result of run-off from the field to water-courses. Moreover, these impacts may vary for the different types of fertiliser between which the farmer has a choice. However the additional costs (e.g. increased treatment costs) imposed on down-stream users of the contaminated water do not play a part in the farmer's decision as to whether to use the fertiliser.

Another example of external costs arise when considering an adaptation project in the transport sector such as the creation of an alternative highway in the coastal zone that is less likely to get damaged by sea storm surges than the existing highway. Such a project will be associated with a number of adverse impacts on the area of transit, including the impairment of human health from the air pollution that results from fuel combustion, and ecological functions, congestion, noise pollution, the obstruction of views, etc. None of these costs are borne by the highway construction company and are therefore not included in their private cost calculations.

When, as in these examples, environmental impacts are not taken into account in the decision making process they are referred to as **externalities**. Therefore, the cost of such effects is an **external cost** to the private decision-making process but remains a real cost from society's viewpoint.

To emphasise this point, external costs arise when markets fail to provide a link between the person creating the 'externality' and the person being affected by it. Economists describe this situation as occurring when property, or ownership, rights for the relevant resources are not well defined. If such rights were to be defined, market forces and/or bargaining arrangements would ensure that the benefits and costs of generating the external effect were properly taken into account in market transactions. In other words, the external effect would be **internalised**. In assessing the costs of climate change external effects are important because:

- There may be impacts that are external to the market and are therefore not included in a financial costing of the impact - e.g. the pain and suffering from losing a limb over and above out-of-pocket medical costs and foregone earnings; the emotional distress of property damage over and above values reflected in restoration costs. (Methods for estimating these so-called 'non-market' values are presented in Section 6 of these guidelines.)

- There may be external effects of adaptation options or strategies, as in the example of the coastal zone highway given above.

- External effects may have an impact on policy goals unrelated to climate change policy. These are called ancillary impacts and are special cases of the first two categories. The estimation of ancillary impacts are described in more detail in the Annex to this section.

When there are external costs to the decision-making process, scarce resources will not be allocated efficiently among the portfolio of available climate change adaptation programs/projects – that is, they will not be allocated to yield the greatest benefit – as reflected in individuals' WTP/WTA.

Therefore, the full cost of an activity to society comprises both the **external cost** and the **private cost**, collectively defined as the **social cost**. If society's scarce resources are to be used to maximum effect, then decisions governing resource allocation should, as far as possible, be based on social costs.

Social Cost = External Cost + Private Cost

In summary, when conducting a cost analysis in the context of climate change impacts and adaptation policies, the analyst has the option of working with private costs or social costs, or with some combination of the two. However, in order to ensure that the impacts are fully accounted for and that scarce resources are allocated efficiently among the portfolio of available adaptation projects (i.e. to yield the greatest benefit in terms of climate change impacts foregone), the analyst should, as far as possible, work with social costs.

6.2.4 Economic (Opportunity) Cost versus Financial Cost

Description of Cost Concept

In addition to the distinction between private cost and social cost, it is often necessary in economic analysis to make a further distinction between the **economic cost** of any activity or intervention, and the **financial cost**. The discussion outlined above emphasises the fact that scarcity of resources necessitates trade-offs between alternative resource uses. The trade-offs are made on the basis of values that are expressed to some extent at least in market prices – themselves an expression of WTP. The economic cost of a good is therefore the full value of the scarce resources that have been used in producing it. These resources, in turn, are measured in terms of the value of the next best alternative, which could have been produced with the same resources (i.e. the value of the opportunity foregone). Hence, the term **opportunity cost**. This notion of cost may differ greatly from the common, accounting (financial), notion of cost expressed through market prices.

Example of Opportunity Cost Concept

Take the cost of establishing a new protected area that has been designated in response to a perceived loss of habitat brought about by climate change. In estimating the costs of such an enterprise, what should the analyst take as the cost of the land? In some cases a zero 'cost' is attached, if the land is not rented out and no money actually flows from the implementing agency to the owner. This, however, is incorrect from society's perspective. In economic analysis the cost of the land is measured in terms of the value of the output that would have been received from that land, had it not been used for the protected area. Such output may be a market good or service (e.g. agricultural output), and/or a non-market good or service (e.g. recreational use[189]). When valued in this way, the cost of the land is given by its opportunity cost.

6.2.5 Summary of Discussion

The key points of note with regard to the cost concepts discussed so far, therefore, are the following:

- The **opportunity cost** of a good or service is measured in terms of the value of the best alternative use to which resources used could be put. That in turn is given by the WTP/WTA for releasing the resource for its present use by the individuals who own the resources.

- The **social cost** of a good or service is given by the opportunity cost of all the resources that go into producing it. Some of these may not involve financial payments (e.g. use of own labour). Hence the financial cost may not be equal to the social cost. The **financial cost** is equal to the **private cost** if all resources provided by the party responsible for the good or service are paid for in money.

- The financial cost or private cost can differ from the social cost

[189] In some cases recreation benefits may be marketed. Other examples of non-marketed services include soil erosion control and biodiversity conservation.

for a number of reasons. The most important of these is the presence of **external effects**. These arise when the welfare of individuals is affected by the production and/or consumption of something but full account is not taken of that effect.

- From the public policy perspective of the UKCIP, **social cost estimates are essential in determining the economically efficient policy response from society's point of view**. However, it is also necessary for the financial costs to be known by the policy maker since if, for example, it is discovered that an adaptation measure is profitable to the private entrepreneur there will be no need for the policy maker to intervene, apart from, perhaps, bearing the implementation costs (see below).

6.2.6 Further Cost Categories

Project Costs

As noted above, the total social cost of a project or intervention includes the private costs of all resources used by the provider(s) of the project over some pre-defined time horizon (usually the useful life of the project), plus any costs imposed on third parties (i.e. the externalities). The private cost category is commonly broken down into two elements: **investment expenditures** and **recurring costs**. (These are sometimes known as fixed and variable costs, respectively – see, for example, the Treasury Green Book Chapter five).

- **Investment expenditures** are incurred towards the start of a project, and do not tend to recur throughout the project's life, hence they are also known as **non-recurring costs**. This category of costs typically includes land and property costs, infrastructure expenditures, plant and equipment, plus associated installation ('set-up') costs.

- The operation and maintenance of a project or intervention usually, but not always, incurs expenses. As these expenses tend to be incurred annually throughout the life of the project, they are termed **recurring costs**. Private recurring costs tend to be grouped into three broad categories: energy costs, labour costs, and material costs. These concepts can be demonstrated by the use of a numerical example of a (hypothetical) scheme - an adaptation measure to ensure continued reliability of water supply in the context of changing precipitation patterns - see Box 6.1.

Box 6.1: Types of Project Costs: an example of an interconnection to a new public water supply

Investment Expenditures:	
Construction of link pipe (Year 1)	£2,000,000
Recurring Costs:	
Energy costs (per annum for years 2-25)	£15000/annum
Annual labour costs: (per annum for years 2-25)	£80,000/annum
Material costs: (per annum for years 2-25)	£6000/annum

There are two further types of financial costs that may be incurred in the introduction of an adaptation option but may be neglected in an analysis of the financial costs incurred by the directly responsible agency only. These costs are categorised as **administration costs** and **barrier removal** costs, under the general heading of **implementation costs**.

Implementation (or 'hidden') Costs

All climate change adaptation policies necessitate some costs of implementation, i.e. of changes in existing rules and regulations, ensuring that the necessary infrastructure is available, training and educating for those implementing the policy as well those affected by the measures, etc. These cost elements need to be quantified so that the reported figures are a complete representation of the true costs that will be incurred if the programmes are actually implemented.

Sources of **implementation costs** include:

- Institutional and human changes needed to implement the measure, including monitoring capacity and skills development.
- Information requirements that may be necessary for, the up-take of an adaptation technology measure to be maximised for example.
- Market size and opportunities for technology gain and learning.
- Economic incentives needed (grants, subsidies and taxes).

These costs can be divided into **administration costs** and **barrier removal costs**.

Administration costs are the costs of activities that are directly related and limited to short-term implementation of the project or intervention. They include the costs of planning, training, administration, monitoring etc. The implementation of adaptation strategies in the coastal areas, for example, would necessitate the co-ordination of the measures between different sectors and coastal units, together with the extra training of the local management personnel.

Barrier removal costs are the costs of activities aimed at reducing the so-called 'transactions costs'[190] in the public and/or private sector. These activities should support processes related to project implementation. Examples of barrier removal include the costs of improving institutional capacity, reducing risk and uncertainty, facilitating market transactions by, for example, information provision, and enforcing regulatory policies. The incorporation of improved standards in existing buildings and infrastructure as a result of climate change impacts, for example, would necessitate some increase in institutional capacity to publicise and enforce the new regulations.

Typically, implementation costs will have a dynamic aspect - that is, they will be incurred over time, and the effectiveness of the policies associated with them will, likewise, change over time.

Stages for assessing implementation costs will then include: costs of the project or policy design, institutional and human capacity costs (management and training), information costs and monitoring costs. The costs of resources involved should, in each case, be based on economic opportunity costs.

In **summary**, the scope of the cost categories considered in these guidelines is a wide one. **<u>All</u>** changes in the use of resources resulting from the project or policy intervention under consideration should be valued. These values form the basis of the costs of the project or policy. Project costs include the obvious resources, such as land, labour, energy and physical capital, which may comprise a **recurring** and/or a **non-recurring** element. They may also include changes in less obvious societal resources, such as clean air, water etc (i.e. **external costs**). Finally they may include the 'hidden' resources required to achieve changes in policies – **the costs of barrier removal and implementation.**

The final set of cost concepts that are particularly relevant to the UKCIP

190 **Transactions costs** are those costs that are incurred in facilitating any exchange of goods and services. In the context of climate change adaptation, an example would be the time spent (and therefore cost incurred) by a builder searching for new suppliers that could supply climate-resistant fabrics to him or her. In this example, the transaction costs could be lowered by an advertising campaign.

context are those that relate to the aggregation or division of costs i.e. total, average or marginal costs. These can be related to any of the cost categories defined above.

6.2.7 Average, Marginal and Total Cost

The **total cost** (TC) of a climate change impact or an adaptation measure is the sum of all cost components over time. Note that since impacts may be valued differently, depending on which point of time they occur at, the cost items cannot be simply added together. As explained below, where costs are spread across different time periods, it is common practice to use a procedure known as **discounting** (see Section 5.4) in order to compute the value in today's terms of the total cost stream. As long as both private and some external costs are included, and if future costs have been appropriately discounted, we can refer to the sum as approximating the **present value**[191] **total social cost** of the climate change impact or an adaptation measure.

Total costs are clearly important in order to assess the full extent of the damages (or benefits) brought about by climate change and to evaluate adaptation measures in the context of minimising the **present value of total** (social) **costs** relative to achieving a certain level of impact reduction i.e. to conduct cost-effectiveness analysis (see Section 5.6).

The **average**, or **unit**, **cost** (AC) is defined as the total cost (TC) divided by the number of units of the item (Q) whose cost is being assessed – that is,

$$AC = TC/Q \tag{6.1}$$

Average costs are also relevant when comparing the effectiveness of adaptation options with one another. For example, a project analyst may have a number of options to address a specific climate change impact, each of which has a different total cost and reduces the targeted climate change impact by varying amounts. A comparison between the options could be made on the basis of the cost per pound of damage avoided, which is essentially a form of cost-effectiveness analysis based on average costs.

The **marginal cost** (MC) is defined as the change in total cost resulting from the provision of one more unit of the good in question. In a climate change adaptation context, MC is the change in total cost from avoiding an additional unit of climate change related damage. That is, MC can be defined as the rate of change of total cost with respect to the level of damage avoidance, given by:

[191] The term **present value** (PV) is defined in the Guideline on discounting.

$$MC = d\,TC/d\,Q \qquad (6.2)$$

Decisions about the level of adaptation to be pursued will need to consider **marginal costs** since the marginal costs need to be set against the marginal benefits of undertaking the extra unit of adaptation. If the marginal social benefit (MSB) is greater than the marginal social cost (MSC) then there will be a net social benefit. This indicates that the adaptation activity should be increased by incremental, or marginal, units to the point where MSC = MSB since up to this level of output each additional unit will add a net gain to welfare. The marginal cost concept is additionally important because most of the disaggregated higher order effects are measured by estimating changes in markets that are assumed not to be large enough to change market prices. Where this is not the case the guideline on non-marginal impacts (Section 5.5) should be referred to.

Let us demonstrate these concepts using a hypothetical example of the private costs associated with an adaptation project in agriculture, e.g. implementation of a drainage system. A number of systems are available, each with different capacities, investment expenditure and recurring cost requirements (see Table 6-1).

Table 6-1: Illustration of Average and Marginal Cost Concepts

Drainage System	Annual Capacity	Annualised Investment	Recurring Costs	Total Annual Cost	Average Cost	Marginal Cost
	(ML per yr)	(£ per yr)	(£ per yr)	(£ per yr)	(£ per ML)	(£ per ML)
	Q	I	R	TC=I+R	AC=TC/Q	MC=∂TC/∂Q
I	100	200	29	229	2.29	
II	101	201	31.5	232.5	2.30	3.5
III	102	201.5	33.8	235.3	2.31	2.8
IV	103	202	36.2	238.2	2.31	2.9

To highlight some of the distinctions implied by the cost concepts described above, a hypothetical example of a climate change adaptation measure is outlined in Box 6.2.

Box 6.2: Example of Cost Concepts

An increased occurrence of high summer temperatures in the UK, as a result of climate change, has resulted in the installation, and subsequent use, of 100,000 air conditioners by private individuals in their properties. The costs involved in this measure are outlined in subsequent paragraphs. Note that:

- ♦ The autonomous measures undertaken by the private households have been supported by a government public awareness campaign.
- ♦ Costs are averaged on a per unit basis

The relevant costs to be considered are:

1. Private financial costs

a. *Financial costs incurred by households*

Within the investment expenditure and recurring cost categories the individual cost items are:

i. Investment expenditures

Purchase of conditioners – 100,000 units at a price of £500/unit = £50 million.

Installation costs - 100,000 installations at a price of £100/installation = £10 million.

Hence, total investment expenditures are £60 million (or £7.16 million per year[192]).

ii. Recurring costs

Maintenance - 100,000 units per year at a price of £20/unit = £2 million per year.

Electricity - 100,000 units per year at a price of £100/unit = £10 million per year.

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[192] In order to compare (non-recurring) investment expenditures with (recurring) annual operating and maintenance costs, the investment expenditures need to be converted in to so-called '**annualised capital costs**'. This is accomplished by multiplying the initial investment outlay by a **capital recovery factor** (this process is explained in more detail in the Guideline on cost-effectiveness analysis). In this example we have assumed that the air conditioning units have a useful life of 12 years and the appropriate discount rate is 6% - the corresponding capital recovery factor is 0.1193. Hence, the annualised capital cost is equal to £60 million *x* 0.1193 = 7.16 million per year.

Total recurring costs are thus £12 million per year.

Hence, the total annual household financial cost is £7.16 million/yr + £12 million/yr = £19.16 million/yr.

b. *Non-financial private costs*

In addition to these financial costs that are incurred by the households, they have additional welfare costs associated with the adaptation measure. These are in the form of disruption costs from building work entailed in the installation process. These costs are assumed to have been estimated by the use of the contingent valuation, or survey based, method that would, in this context, ask individuals how much, for example, they would be prepared to pay to avoid the disturbances.[193] The individual average willingness to pay to avoid these disturbances is £8 per installation.

The total for non-financial private costs is therefore: 100,000 installations at a disturbance cost of £8/installation = a non-recurring expenditure of £0.8 million (or £0.095 million per year).

2. Financial costs incurred by public, and other, bodies to promote adaptation measure

a. *Barrier removal or hidden costs*

Background costs on information, education and, etc. that has been expended to encourage households to use conditioners = a non-recurring expenditure of £500,000 (or £0.06 million per year).

b. *Administration costs*

The costs of setting up a promotion scheme and the costs of management = a non-recurring expenditure of £500,000 (or £0.06 million per year).

Total annual financial costs[194] = £7.16 million/yr + £0.06 million/yr + £0.06 million/yr = £7.28 million/yr.

Total annual private costs = £7.28 million/yr + £0.095 million/yr = £7.375 million/yr.

3. External costs

The use of the installed air conditioners necessitates energy

[193] See Section IV for a description of the contingent valuation method.

[194] Note that total financial costs of implementing an adaptation measure are also known as total implementation costs.

consumption. This is assumed to be derived from mains electricity supplies generated by fossil fuel consumption. Fossil fuel consumption is known to result in pollution emissions to air that cause respiratory illnesses in humans as well as, paradoxically, further climate change impacts. These third party effects - or externalities – have welfare costs. They are estimated using the non-market valuation techniques outlined in these Guidelines. Note that these external costs are also ancillary impacts, (here, ancillary costs), derived from the adaptation measures.

A value for external costs in this project context has been estimated to be £0.2 million per year.

4. Total social cost

To derive the total social costs of the adaptation measure, we need to add the private costs and the external costs together.

Total annual social cost = £7.375 million/yr + £0.2 million/yr = £7.575 million/yr.

We assume in this example that no further adjustment needs to be made to the cost elements in order to give the opportunity cost of the measure - i.e. financial cost and economic costs are equivalent. Therefore, the opportunity cost equals the total social cost.

6.3 Basic Principles of Benefit Valuation

6.3.1 Introduction

Any empirical analysis requires some decisions to be made regarding the scope of the work. Concerning the economic valuation of climate change impacts this means defining what *value* to quantify, and deciding how to *measure* such values. The purpose of this section is therefore twofold: (1) to develop a taxonomy of economic values; and (2) to explain how these values are measured.

While the discussion is in terms of the benefits an individual accrues from a resource - environmental or otherwise - if climate change adversely affects that resource, then the resulting decrement in benefits (or value) is a measure of the impact (damages) of climate change.

6.3.2 Total Economic Value

For some goods and services (e.g. buildings, timber, land, livestock), the market provides prices that reasonably reflect the value society places on that good or service. For other goods and services however, market prices either only partially reflect the value society places on them or they do not exist at all (e.g. cultural objects, a wetland, a species of bird). To simplify the task of valuation, economists like to disaggregate environmental impacts into individual components of value. The most commonly used approach is based on the concept of **Total Economic Value** (TEV). With this approach an impact on an environmental resource – e.g. the permanent loss of territory resulting from sea level rise - is broken down into a number of categories of (foregone) value. The logic behind the approach is that a good or service comprises various attributes, some of which are *tangible* and readily measured, while others are less tangible and thus more difficult to quantify. The total value of the good or service however, is given by the all 'relevant' categories of value, and not simply those that are easy to measure. It should noted however, that not every good/service provides all components of TEV; hence the use of the term 'relevant'.[195]

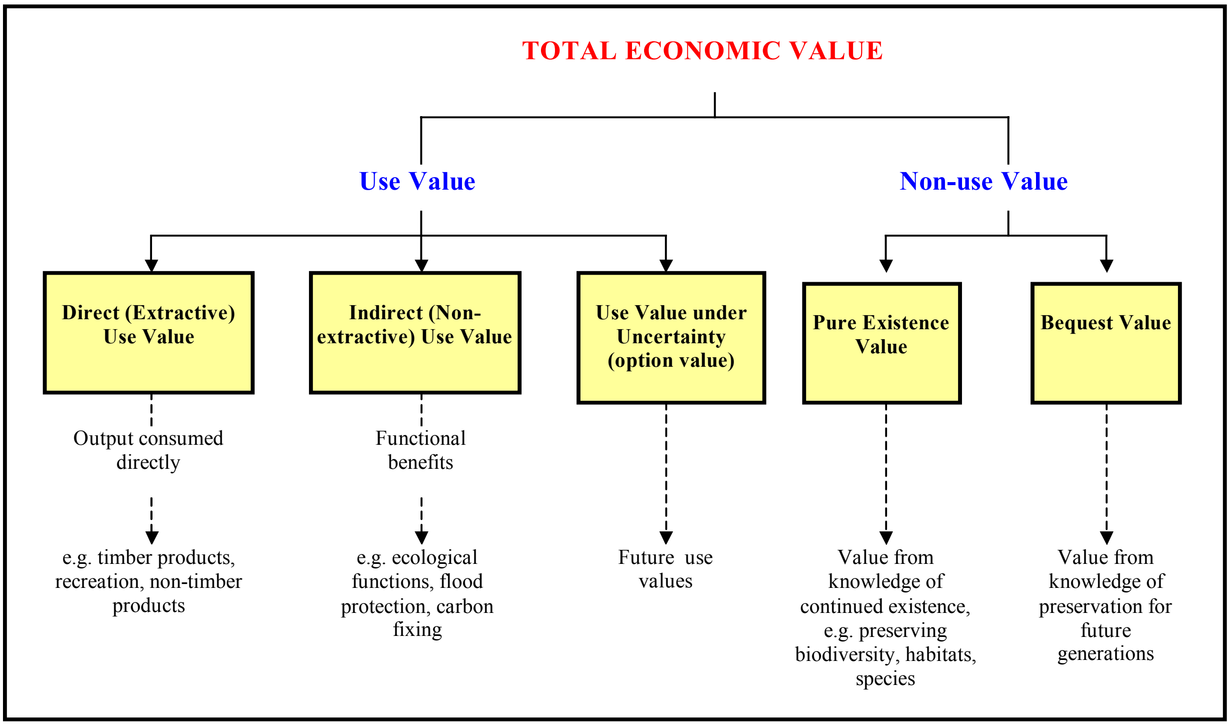
There is as yet no fully agreed taxonomy of the individual categories of value comprising TEV. Nonetheless, TEV is generally divided into three categories: (1) direct use value; (2) indirect use value; and (3) non-use value. The former two categories are sometimes collectively referred to as 'use value'. Further subdivision of these categories is also possible (see Figure 6.1 below).

[195] Some good examples of such commodities are provided in Garrod and Willis (1999).

Use Values

Direct use value derives from the *use* of goods, which can be directly extracted, consumed or enjoyed.[196] In the context of a forest, for example, direct use value derives from the harvesting of timber. In general, direct use values are real, can be measured, and have values. Furthermore, since direct use of a resource involves observable quantities of goods, the price of which is also observable, direct use values are usually relatively straightforward to value.

Figure 6.1: Components of Total Economic Value (examples from a forest)



Indirect use value, also referred to as non-extractive use value, derives from the services that a environmental resource provides. A wetland, for example, acts as a water filter, often improving water quality for downstream users. This service is valued by downstream users, but does not require any good to be extracted/consumed. In terms of measurement, indirect use values differ from direct use values in two ways: (1) the 'quantity' of the service provided is often hard to define; and (2) the types of services in question are often not traded in established markets, and

[196] It is therefore also known as **extractive** or **consumptive** use value

therefore have no observable 'prices'. For these reasons, measuring indirect use value is relatively more difficult than measuring direct use value.

If you are unsure whether you will use an environmental service or not, you might be willing to pay a positive sum to guarantee that the service will still be available in case you desire to use it at a later date. That is, you may value the 'option' to use the resource in the future. Such values, appropriately known as **option values**, arise when you are *uncertain* about whether you will demand a commodity in some future time period and are faced with *uncertainty* concerning the future supply or availability of that commodity. It is distinct from a current use value in that it arises not from the use of the resource itself, but from uncertainty over the resource's availability to meet future demands. In this way option value is akin to an insurance policy against future uncertainty.

Non-use Values

Non-use values are defined as those welfare gains/losses to individuals that arise from environmental changes *independently* of any direct or indirect use of the environment. Non-use values can be defined in various ways. Most definitions however contain two main components: (1) pure existence values; and (2) bequest values.

A **pure existence value** relates to the worth associated with an environmental good or service, which is completely unrelated to current or future use of that commodity, by yourself, your descendants, or others. These values are *intrinsic* in nature - i.e. they represent a value that resides in something.[197] A number of pure existence values are related to ecological attributes. Support for the protection of endangered species and the protection of critical habitats for those species represents an intrinsic valuation process.

Bequest value derives from our desire to preserve the environment for relatives and friends, and also for all other people living today and future generations, so that they may benefit from conservation of the environment.

Since in most cases non-use value is not, by definition, reflected in individual's behaviour and is thus not observable, it is the most difficult component of TEV to measure.

It is important to assess the change in the TEV arising from climate change-induced impacts on exposure units. It may be the case that the 'true' cost (reduction in TEV) of climate change on a particular exposure

[197] Some possible motivations or rationales for the presence of such values include the preservation of, concern for, sympathy with, respect for the rights of, any other altruistic motives with respect to non-human beings.

unit will be greater than the direct use value foregone, but the direct use value foregone may be less than the cost of potential adaptation responses. In order to build an accurate argument for (or against) specific adaptation responses, it is important to measure as many components of TEV as possible, when costing climate change impacts.

6.3.3 Measures of Economic Benefit

The economic analysis of climate change impacts aims to value the effects of climatic change as they would be valued in money terms by the individuals affected. The maximum amount of money an individual is willing to pay to obtain a benefit reflects that individual's intensity of preferences for the benefit. Hence, the value of a good or service can be expressed in money terms by identifying the individual's **maximum willingness to pay**[198] (WTP) for that good or service. Alternatively, we could seek to identify the minimum amount of money an individual is **willing-to-accept** (WTA) as compensation for foregoing a benefit or for tolerating something they do not like. Both concepts provide a monetary measure of the intensity of an individual's preferences for a good or service.

As mentioned previously, a frequent criticism of this basis of valuation if that it is inequitable (see Section 5.10).

Box 6.3 below provides an illustration of how the concept of WTP (or WTA) is used to measure the cost (foregone benefits) of climate change-induced impacts. The idea of WTP is investigated in a little more detail in the Annex to this section.

Box 6.3: The Cost of Climate Change Impacts as Measured by WTP or WTA – an Example of a Deterioration in Water Quality

Climate change-induced water pollution can affect individuals in many ways – e.g. pollution can adversely affect health directly, it can limit outdoor recreation (and possibly tourism) or reduce aesthetics by degrading canals, lakes, rivers and estuaries. The costs of degraded water quality may be defined by the difference between individuals' well-being before water quality changes, and individuals' level of well-being after the change in water quality.[199] Assuming that individuals are aware of the impacts of the pollution, a change in water quality can be expressed in

[198] WTP is a measure of the economic value, in terms of income or other goods, an individual is willing and able to forgo to gain or maintain a resource, good, or service.

[199] Or, conversely, the benefits of improved water quality are given by the difference between individuals' well-being before water quality changes and individuals' level of happiness after the change.

money terms by identifying the amount of income an individual would be **willing to pay** (WTP) to avoid the deterioration in water quality, or **willing-to-accept** (WTA) payment as compensation for the water quality deterioration. The WTP payments should leave the individuals indifferent[200] between the state-of-the-world before the change ('cleaner' water), but with less income, and the state-of-the-world after the change, but with the original income. The WTA payment leaves the individuals indifferent between the state-of-the-world before the change, with the original income and the state-of-the-world after the change ('degraded' water), but with higher income.

6.4 Annex: Measuring Economic Benefits

The concept of economic benefits can be illustrated with the aid of a simple graph. Consider Figure 6.2 below, which shows a supply and demand curve for a hypothetical good *X*.[201] The net economic benefits derived from the consumption and production of this good comprise two parts - these are known as consumer surplus and producer surplus. The area, *A*, above the price line and bounded by the demand curve measures the **consumer surplus**. The consumer surplus is essentially the *net* benefit accruing to the consumer, given the existing price.[202] **Producer surplus**, formally defined as the excess of price (or producer revenues – equal to the sum of area *B* and *C*) over production costs (area *C*), is given by the area, *B*, below the prevailing price and above the supply curve. The **net benefits** to society from the production and consumption of this hypothetical good is given by the sum of areas *A* and *B*.

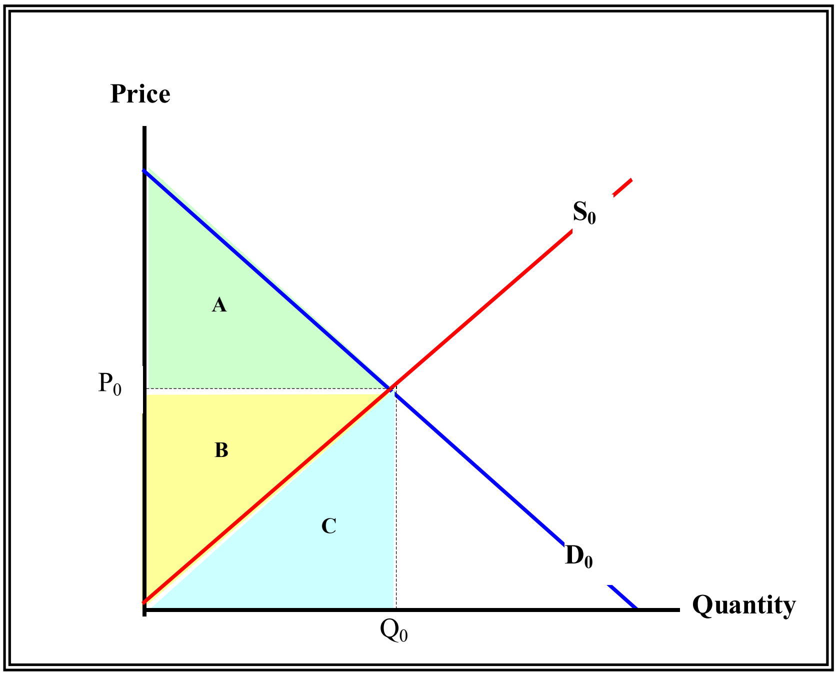
In the broadest sense, the costing of climate change impacts is the process of identifying and measuring changes in consumer demand and producer supply arising from the climate change-induced impact.

[200] That is, one state-of-the-world is not preferred to the other.

[201] We can think of the demand curve as a **marginal willingness to pay curve** – that is, any one point on the curve shows the maximum amount individuals are WTP for an additional unit of *X*. We can also think of the supply curve as showing the minimum amount producers are **willing-to-accept** as payment for providing an additional unit of *X*.

[202] Formally, **consumer surplus** is defined as the difference between individuals' maximum WTP (as given by the demand curve) and the actual expenditure at the prevailing price (equal to the sum of area *B* and *C*). In other words, the maximum amount individuals are willing to pay for a good or service is given by the sum of the price of the good or service and the individuals' consumer surplus.

Figure 6.2: Market for Hypothetical Good *X*



SECTION VII

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7 REFERENCES

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GLOSSARY OF TERMS

Term	Definition
Abatement cost	The cost of abating, or reducing, environmental pollution.
Adaptation	Measures taken to reduce harm, or risk of harm, associated with climate change. Examples include the building of sea walls to prevent damages from sea level rise and the installation of air conditioning in the case of increased mean temperatures.
Amenity	Benefit derived from living near a certain (environmental) attribute. May be positive, e.g. in the case of woodland, or negative, e.g. in the case of a landfill site.
Ancillary impacts	External effects, which have an impact on policy goals unrelated to climate change policy
Benefit transfer	Benefit transfer is not a *valuation* method *per se*, but involves the use of existing estimates of non-market values derived in one context/location to estimate values in a different context/location. The site for which the original estimates were obtained is often referred to as the study site; and the site to which the original estimates are now to be applied, is known as the policy site. Benefit transfer is therefore the practice of adapting available estimates of the economic value of changes in the quality or provision of a *non-marketed* good/service at a study site(s), to evaluate a change in quality or provision of a 'similar' resource at a policy site(s).
Benefit-cost ratio	The ratio of an option's present value benefit to its present value costs.
Bequest value	Bequest value refers to the value that an individual places on having an environmental resource or general environmental quality available for his or her descendants to experience. Bequest values are considered as a *use value* of a resource, even though the value derived results from future rather than present use of the resource.
Built heritage	All types of man-made structures and remains that are thought to have value in addition to any functional worth, due to historical, artistic or other cultural factors.
Cause-effect chain	Links climatic variation to *lower-order impacts* through to specific *higher-order impacts*
Certainty	When the decision-maker has complete knowledge of every element of the decision problem and thus can predict which state-of-nature will occur, in which case the decision-maker is certain of the outcome associated with each alternative action.
Change-in-productivity technique	Market prices can often be used to value the output from a productive process, and environmental conditions often affect such processes. In these circumstances, values for a change in the environment can be derived from the associated change in productivity. An increase in output due to the change is a measure of an increase in benefit, and a decrease in output is a measure of an increase in cost.
Confidence interval	A quantitative estimate of the degree of uncertainty associated with a statistic or other estimate. For example, the range of

	values within which some percentage, say, 95 percent of repeated estimates would fall. In other words, a confidence interval provides a range of values within which the 'true' value would actually fall with 95 percent certainty.
Constant (real) price	Real or constant price variables adjust *current price* variables for changes in the general level of prices – that is, they are *inflation*-adjusted prices.
Constructed market	A hypothetical situation in which individuals are asked to assume that they can exchange money for an environmental benefit or to avoid an environmental loss. This technique is used to estimate the value of non-market costs and benefits in the *Contingent valuation method*.
Consumer surplus	The consumer surplus is essentially the *net benefit* accruing to the consumer from consuming a good, given the good's current price. Formally, consumer surplus is the excess that consumers would be willing to pay over actual expenditure at the current price.
Contingent valuation method (CVM)	CVM directly elicits the values that respondents place on some, usually *non-marketed*, goods and services. This is done by either employing an experimental approach, based upon simulations or game analysis, or, more commonly, by using data derived from questionnaire or survey techniques. It derives people's preferences for public goods by asking them how much they would be willing to pay for specified improvements or to avoid specified deterioration or losses. Alternatively, respondents to CV surveys might be asked what level of compensation they would be *willing to accept (WTA)* to take a loss, or for not getting an improvement in environmental quality.
Cost-benefit analysis (CBA)	Analysis which quantifies in monetary terms as many of the costs and benefits of a project as possible, CBA is designed to show whether the total advantages (benefits) of a project or policy intervention exceed the disadvantages (costs). This essentially involves listing all parties affected by the policy intervention and then valuing the effect of the intervention on their well-being as it would be valued in money terms by them. It may include items for which the market does not provide a satisfactory measure of economic value
Cost-Effectiveness Analysis (CEA)	A tool with which to minimise the cost of achieving a specified environmental or economic objective. For example, in the acid deposition field the objective might be to meet a target loading of sulphur at minimum cost over a large region, taking into account that control costs vary from industry to industry, and that the cost of control increases with increasing severity of control. Cost effectiveness analysis ignores benefit side of *cost benefit analysis* but concentrates on the cost side
Cost of illness	An objective *valuation* approach, which places an economic value on illness caused by environmental damage. The *financial costs* of illness caused by e.g. air pollution can be calculated by adding the costs of treating an illness to the costs of lost work-time. The full cost of the illness would then require a measure of the value that the individual places on the suffering that it causes, but this must be measured using a technique such as the *contingent valuation method*, which is not an objective valuation approach.
Decision-maker	A person or institution dissatisfied with the prospect of a future state, and who possess the desire and authority to initiate actions designed to alter this state.
Demand curve	The relationship between the demand for a good and its market price. For most goods, more will be demanded at lower prices.

Direct impact	See *Lower-order impact*.
Direct use value	Value that derives from the *use* of goods, which can be directly extracted, consumed or enjoyed. This includes consumption value, altruistic value *bequest value*.
Discount rate	The rate at which, when *Discounting*, costs and benefits are valued in present terms, as the time at which they occur moves further into the future.
Discounting	Discounting is the technique used to add and compare environmental costs and benefits that occur at different points in time. It is the practice of placing lower numerical values on future benefits and costs as compared to present benefits and costs. It arises because individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now.
Distributional effects	The way in which a decision/ policy affects different income groups, and thus effects the distribution of income or welfare.
Economic efficiency	An allocation of resources in production and consumption so as to achieve the maximum total benefit. This means that no person could be made better off without making someone else worse off. A condition for economic efficiency is that the environmental costs of production should be accounted for, and included in the total costs of production.
Economic (opportunity) cost	The economic cost of a good is the full value of the *scarce resources* that have been used in producing it. These resources, in turn, are measured in terms of the value of the next best alternative, which could have been produced with the same resources (i.e. the value of the opportunity foregone).
Environmental externality	Where an activity affects a third party (either positively or negatively) without this effect being accounted for by the agent responsible for the activity.
Expected monetary value decision rule	A rule that leads to the selection of options so as to maximise the expected monetary value (EMV), where the EMV is the weighted average of all possible values of a variable, where the weights are the probabilities.
Expected utility decision rule	Select adaptation options so as to maximise expected *utility* – choose the option with the highest expected utility.
Externality	See Environmental Externality
Extreme events	Events such as hurricanes, storms and other naturally occurring phenomena. The likelihood of such events is expected to increase with climate change.
Financial cost	The common, accounting, notion of cost expressed through market prices.
Fixed baseline	Within the fixed *baseline* approach current climatological, environmental and socio-economic conditions are assumed to prevail in the study region into the future. Therefore, a fixed baseline is usually a horizontal curve.
General price level	The general price level is given by the weighted average price of a representative 'basket' of consumer goods and services traded in the economy, relative to the price of that 'basket' at some fixed date in the past. As such, the general price level shows what is happening to consumer prices on average, and not what is happening to the price of individual consumer goods and services. Consequently, increases in the price of a specific good or service over time do not necessarily imply that the general price level has changed. For example, subject to the weights assigned to two items in the 'basket' of consumer goods and services, increases in the price of one item may be offset by decreases in the price of another item, to the extent that the average price level remains unchanged. Therefore, for the

	general price level to move upwards, the prices of a majority of items in the 'basket' must increase.
Gross benefit	The total benefit of a project or other activity. Deducting the costs of the project from the gross benefits gives a measure of *Net benefit*.
Hedonic techniques	Hedonic pricing is a market-based *valuation* method that is used to value non-market, often environmental, assets. The method can be used to infer the value of *non-marketed* goods by analysing the prices of marketed goods to which the non-marketed goods are related. Houses are often used in hedonic pricing studies to infer the values of environmental characteristics, using the *hedonic property price function*.
Hedonic wage differential	The hedonic wage-differential (or *wage-risk*) approach estimates relation between the wage rate in each occupation and qualifications of worker, job attributes (unionisation, desirability, etc.) and workplace risk (e.g. risk of death). This is one of the most commonly used *hedonic valuation techniques*.
Higher-order impact	An indirect climate change impact that results from a *lower order* (or direct) impact of climate change. For instance, loss of habitat may result from the lower-order impact of sea level rise. Also known as indirect impact.
Hurwicz α-rule	Decision-support criterion under conditions of uncertainty in which the decision-maker should select the alternative option with the largest α-index.
Impact assessment process	The process of identifying all parties affected by a policy intervention, and quantifying the 'incremental' impact of the intervention on these parties.
Indifference curves	Curves that link combinations of two commodities, for instance *Expected Monetary Value* and *risk*, among which a person (e.g. a decision-maker) is indifferent. If both commodities are desirable, then for a decision-maker to be indifferent between any two combinations, less of one commodity must be compensated by more of the other, and vice versa.
Indirect use value	Indirect use value, also referred to as non-extractive use value, derives from the services that an environmental resource provides. Its definition lies between those of use value and *non-use value*, and can be used to refer to two main types of situation. The first is where a person makes direct use of an environmental resource, for example a fishery, but where that fishery benefits from the services of another environmental resource such as a freshwater spawning ground. In this case, the person derives indirect use value from the freshwater spawning ground. The nature and extent of this type of indirect use values is clearly very uncertain, since scientific knowledge of the complex relationships within and between ecosystems is incomplete. The second situation in which indirect use values accrue is where a resource is used in a way that does not involve depleting the resource, for example recreation.
Indirect impact	See *Higher-order impact*.
Inferential statistics	Analysis that uses information on a sample in order to infer information about the attributes of a general population.
Inflation	Inflation refers to increases in the *general price level* over time. The inflation rate defines the rate at which the general price increases over a specified time period – e.g. monthly or yearly.
Internal rate of return	Internal rate of return is the discounted cash flow rate of return or yield. It is usually defined as the discount rate that would make the present value of a project's profit stream equal to the initial investment expenditure.
Interval analysis	Identifies the extreme lower and upper estimated outcomes for a

	given set of input variables, modelling assumptions, etc.
Irreversibility	Where a decision, e.g. to convert a natural habitat into farmland, cannot be reversed. This is usually when a decision involves the loss of an irreplaceable asset that might subsequently be preferred for a more important later use.
Lower-order impact	A direct impact of climate change, such as sea level rise, which results in *higher-order impact* (or indirect impact) such as loss of natural habitat.
Marketed impacts	Marketed impacts refer to damages/benefits to goods and services that traded in markets – e.g. infrastructure, buildings – and have an observable price.
Marginal cost	The contribution to total cost of the last unit of a good produced.
Marginal productivity	The marginal productivity of a factor of production, e.g. labour or capital, is the contribution to total output of the last unit of the factor used.
Maximax rule	An optimistic decision-support criterion under conditions of uncertainty in which the decision-maker should opt for the option with the highest possible outcome.
Maximin rule	A pessimistic decision-support criterion under conditions of uncertainty in which the decision-maker should maximise the minimum outcome.
Mean	The average outcome.
Meta-analysis	A meta analysis is a study that estimates the value of an environmental cost or benefit by analysing statistically the information gathered from all previous studies on similar costs or benefits.
Minimax regret rule	A cautious approach to decision-support criterion under conditions of uncertainty in which the decision-maker should minimise the maximum regret.
Monte Carlo Analysis	A way to estimate of the likely outcome of an uncertain event, it can be used to analyse risk. It involved simulating the possible outcomes of an uncertain event by varying the factors that affect the outcome, thus gaining a picture of the distribution of possible outcomes.
Net benefit	Net benefit is the difference between total benefits and *total costs*.
Net present value (NPV)	The net present value of a project is the difference between the discounted benefit (or impacts cost avoided) stream and the required investment and annual costs.
Non-marginal impacts	Impacts where adaptation measures lead to changes in the market conditions, meaning that partial or general equilibrium analysis may need to be applied to assess the total impacts of a given climate change impact or adaptation strategy.
Non-marketed impacts	Refer to damages/benefits to goods and services for which no market exists – e.g. most environmental resources – and which therefore have no observable price.
Non-monetised impacts	Impacts of climate change for which it is not possible to estimate a monetary value. This may be because physical data on the impact is not available, or because existing environmental valuation techniques cannot value a particular impact.
Non-use value	Non-use value is defined as those welfare gains/losses to individuals that arise from environmental changes independently of any direct or indirect use of the environment.
Options appraisal	Comparing the costs and benefits of possible decision options using criteria such as *economic efficiency*.
Opportunity cost	The *economic cost* of using a resource as represented by the benefit it could have generated in its most efficient alternative use.

Outcome array	A matrix that shows the outcomes (or consequences) associated with *particular combinations* of specific options and specific states of nature.
Policy site	In the context of *benefit transfer*, the policy site is the location to which the original estimates are now to be applied.
Preventative expenditure	These are expenditures aimed at averting the damages associated with pollution and other externalities. Estimates for these are sometimes used as measures of the lower bound of the costs of the environmental damages. Expenditures to mitigate damages to the environment can be seen as a *surrogate* demand for environmental protection.
Price elasticity of demand	Measures the percentage change in quantity demanded associated with a percentage change in price.
Primary studies	Valuation studies (e.g. CVM, TCM) that require primary research, as opposed to those using techniques such as benefit transfer to derive values for environmental attributes and assets.
Production cost technique	Values the cost (benefit) of deterioration (improvement) in environmental quality by valuing increases (decreases) in the resource costs of production.
Production function	A mathematical relation showing the maximum output that can be produced by each combination of inputs.
Projected baseline	Projected *baseline* is based on estimated predictions of future climatological, environmental and socio-economic conditions in the study region in the absence of climate change. It is then used as a reference case against climate change mitigation and adaptation policies. This is a more realistic approach than application of a *fixed baseline*.
Property value approach	A type of a *hedonic pricing technique* where analysis is conducted on housing data. It measures the welfare effects of changes in environmental goods or services by estimating the influence of environmental attributes on the value (or price) of properties.
Pure existence value	Relates to the value that people attach to an environmental good or service, which is completely unrelated to current or future use of that commodity by themselves, their descendants, or by others. These values are intrinsic in nature.
Pure time preference	The preference for consumption now rather than later.
Relative price	As the term implies, this defines the price of a particular good or service relative to other goods and services in general. If the price of any good or service is expected to change relative to the *general price level*, then it is said to have changed in *real* terms.
Relocation cost	The relocation cost technique is a variant of the *replacement cost* technique. Here, the actual costs of relocating a physical facility - because of changes in the quality of the environment – are used to evaluate the potential benefits of preventing the environmental change.
Replacement cost	The replacement cost technique assumes that the costs incurred in replacing productive environmental assets that have been damaged through climate change can be measured and interpreted as an estimate of the benefits presumed to flow from the assets. Expenditure actually incurred on replacement is a measure of the minimum *willingness to pay* to continue to receive a particular benefit. It gives only a minimum estimate because more may have been spent had it been seen to be necessary to do so. This technique is closely-related to the *preventative expenditure* technique.
Risk	When the decision-maker does not know which state-of-nature will occur, but is reasonable confident of the proportion of the total number of occasions on which each state-of-nature will

	occur if the situation frequently recurs.
Risk-averse	A person (or decision-maker) who would pay to avoid risk, as represented by an *actuarially fair gambles*.
Risk-lover	A person (or decision-maker) who would pay to participate in a risky decision, as represented by an *actuarially fair gamble*.
Risk-neutral	A decision-maker who is indifferent to all *actuarially fair gambles*.
Sensitivity analysis	Sensitivity analysis shows the extent to which changes for different values of the major variables affects an appraisal.
Shadow project	The shadow project *valuation* measure can be seen as a particular type of *replacement cost*. It attempts to estimate the cost of replacing the entire range of environmental goods and services that are threatened by climate change by examining the costs of a real or hypothetical project that would provide substitutes.
Social cost	The total social cost of a project or intervention includes the *private cost*s of all resources used by the provider(s) of the project over some pre-defined time horizon (usually the useful life of the project), plus any costs imposed on third parties (i.e. the *externalities*).
Stakeholder analysis	This form of analysis identifies those whose interests will be or are being affected by the planned project/policy, and to assess the potential influence they may have on the project.
Standard error	Is used to construct a *confidence interval* that reflects the variability of an observed response relative to the variability of the explanatory variable(s).
States of nature	Variable factors that are beyond the control of decision-makers, but which will affect the outcome of a decision problem, for example the climate change impacts that will actually occur.
Study site	In the context of *benefit transfer*, the study site is the location in which the original estimates were obtained.
Supply curve	A function that shows the amount of a good which producers are willing to supply for each level of the good's price. Producers are generally willing to supply more of a good the higher is its price.
Surrogate market	A market for a good that is associated with a non-marketed cost or benefit. Such markets, an example being the market for housing, can be analysed using *Hedonic techniques*.
Top-down approach	This is a modelling approach widely used in the analysis of climate change. Top-down models evaluate a system using aggregate economic variables. Modellers using this technique apply macroeconomic theory and econometric techniques to historical data on consumption, prices, incomes and factor costs to model final demand for goods and services. Supply is modelled using data from major sectors like the energy sector, transportation, agriculture and industry. Critics of this technique suggest that aggregate models applied to climate policy do not contain adequate detail, and they recommend the use of *bottom-up modelling* techniques.
Total cost	Total cost of a climate change impact or an adaptation measure is the sum of all cost components over time.
Total economic value	The economic concept of value has been broadly defined as any net change in the welfare of society. The total economic value approach breaks down an impact on an environmental resource into a number of categories of (foregone) value, some of which are *tangible* and readily measured, while others are less tangible and thus more difficult to quantify. The total value of the good or service however, is given by the sum of all categories of value, and not simply those that are easy to measure. TEV is

	generally divided into three categories: (1) *direct use value*; (2) *indirect use value*; and (3) *non-use value*.
Travel cost	Travel cost technique attempts to deduce values from observed behaviour in *surrogate markets*. Information on visitors' total expenditure to visit a site is used to derive their demand curve for the services provided by the site.
Uncertainty	When the decision-maker has poor knowledge of the likelihood with which each state-of-nature will occur and so cannot attach probabilities to each possible outcome.
Unit cost	The total economic cost of producing a unit of output.
Unit value	Value placed on a unit change in the level of an environmental attribute.
Utility	The benefit that consumers derive from consuming marketed goods, from enjoying non-marketed goods such as environmental benefits, and from other factors that contribute to their overall wellbeing. In most economic analysis, consumers are assumed to be 'utility maximisers'.
Valuation	The process of attaching an appropriate 'price tag' to all economically relevant impacts. The effects of potential projects should, as far as possible, be expressed in monetary terms.
Value of a prevented fatality (VPF)	This is a measure of the value that people place on a small change in the *risk* of dying. Such measures are often used as an estimate of the amount that people are willing to spend to increase safety and are therefore used in decisions on public spending on safety.
Wage-risk approach	See *hedonic wage differential*.
Willingness-to-accept (WTA)	The minimum amount of money that an individual is willing to accept as compensation for suffering a loss, or forgoing a benefit. It can also be the maximum payment that the owner of a resource is willing to accept to allow its use by others.
Willingness to pay (WTP)	The maximum amount of money an individual is willing to pay to obtain a benefit or to avoid a loss.