
Costing the Local and Regional Impacts of Climate Change Using the UKCIP Costing Methodology

July 2006

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Introduction

In 2004 the UK Climate Impacts Programme (UKCIP) published a standard methodology and set of guidelines to estimate the cost of climate change risks, both with and without adaptation². The Costing Methodology, as it is known, is designed to enable decision-makers in the public and private sector to calculate order-of-magnitude estimates of the costs (or benefits) of climate change and so help identify priority climate-related risks and to select appropriate adaptation responses. The methodology can be applied across a range of climate-sensitive sectors, and at a local, regional and national scale.

Since its publication the Costing Methodology has been applied extensively by Metroeconomica to value the impacts of climate change on a variety of sectors, under a range of climate scenarios. The purpose of this paper is to outline how these cost assessments have been undertaken, and thus illustrate how the Costing Methodology has been used in practice.

Context and Purpose of Cost Assessments

Broadly speaking, society can respond to the potential risks posed by climate change in one of two ways: (1) **mitigation** – taking action to limit the emission of greenhouse gases or enhancing their sinks or (2) **adaptation** – taking action to avoid, prepare for, or otherwise respond to observed or anticipated damages. Given that both courses of action essentially represent two different ways of reducing damages they can be thought of as substitutes, at least in the purely economic sense that if one becomes more expensive, more use should be made of the other.

There are a range of contexts in which policy-makers involved in mitigation and adaptation decisions at the global, national and sub-national levels need information about the benefits and costs of avoiding the risks of climate change. Quantitative information on the regional, local and sectoral costs of climate change impacts in the UK is likely to be useful in determining where, and in what form, adaptation initiatives should be focused, particularly for planners in climate sensitive sectors. The formulation of policy on climate change at a national level requires information on the costs and benefits of both adaptation and mitigation, and may involve making the trade-off between mitigation and adaptation alluded to above. These trade-offs are possible at a national or sub-national level, since the costs of adaptation and the costs of mitigation are both local (at most national) in nature. While the global benefits of limiting greenhouse gas emissions by one tonne are the same no matter where mitigation takes place - for the reasons set out in Box 1 - local climate risks (and thus local mitigation benefits) will not be uniform across countries, regions or sectors. As a result, the benefits of adaptation will also be local in nature, and adaptation assessments are most likely to be conducted at a local, regional or national level.

² Metroeconomica (2004) *Costing the Impacts of Climate Change in the UK: Implementation Report*, UK Climate Impacts Programme, Oxford, UK; and Metroeconomica (2004) *Costing the Impacts of Climate Change in the UK: Overview Guidelines*, UK Climate Impacts Programme, Oxford, UK.

Domestic policy-makers, especially those in climate-sensitive sectors, thus have limited needs for global information vis-à-vis national, regional or local information; except, possibly, when it comes to taking a position on burden sharing arrangements in the context of the UNFCCC³.

Indeed, regional and sectoral stakeholders who have been involved in the UK Climate Impacts Programme (UKCIP) have expressed a strong desire to better understand where the cost burden of climate change risks is likely to fall. As well as identifying regional and sectoral cost burdens there is a need to predict better the degree to which the cost burden (or benefit) falls on private enterprise or public administration operations. Prediction of these cost burdens will raise awareness of the financial threat (or opportunities) of climate change to these sectors, and may provide the necessary stimulus to develop adaptive capacity, so allowing adaptation responses to be better tailored.

Box 1: Why the Costs and Benefits of Adaptation are Location Specific

In the IPCC Third Assessment Report the vulnerability of a group or sector to climate change was described as: “*a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity*”. While many groups and sectors in society are vulnerable to climate change, different groups and sectors are more vulnerable than others, for the following reasons:

1. First (related to **exposure**): climate (stimuli) hazards will vary according to location. Climate models predict greater warming in some regions than others. Likewise, predicted precipitation patterns show some regions experiencing more intense rainfall, others seeing more prolonged dry periods, with other regions experiencing both. Furthermore, sea-level rise will not be uniform globally.
2. Second (related to **sensitivity**): there are differences between regions and between groups and sectors in society that mediate their relative sensitivity to climate hazards. For instance, heat stress is more likely to be fatal to the over 75s than younger age groups. Similarly, intense rainfall in some catchments may lead to severely damaging flooding, while in other catchments it may result in only minor damage.
3. Third (related to **adaptive capacity**): there are differences in the extent to which regions, groups and sectors are able to adjust to climate hazards, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. When faced with the prospect of more frequent and intense heat waves, some households will be able to invest in air-conditioning units; others may not be able to afford such units, lack the skills to operate them or have insufficient facts to make an informed decision.

In general, the vulnerability of a system to climate change is therefore not uniform across a country, region or sector, or across time and differs according to geography, demographics and socio-economic factors.

Against this background, assessments using the UKCIP Costing Methodology serve to advance our knowledge of the costs of climate change risks to the UK (and thus the benefits of taking action to avoid those risks), by generating initial estimates of the welfare impacts associated with specific climate hazards occurring under a range of climate change and socio-economic scenarios within the UK. A primarily bottom-up approach based on local, regional and national case studies in a range of key impact

³ At a global level, information on the distribution of the benefits of mitigation and adaptation across sectors, regions and countries may be more important than global totals.

sectors has been adopted. The rationale for this approach is further justified by the fact that for the results of such assessments to be acceptable to relevant regional stakeholder communities the impact identification, measurement and costing exercises need to be based on data derived in specific local and regional contexts, as far as is possible.

The UKCIP Costing Methodology provides a consistent set of tools and methods which, when implemented systematically across a sufficient number of sectors and representative climate risks facing the UK, will facilitate the generation of national benefit estimates for adaptation and mitigation.

Overall Methodological Approach

Figure 1 below graphically summaries the Costing Methodology, as it has been used in practice. The main elements are discussed in the following section.

Sectoral and Regional Coverage

Climate-sensitive sectors that have been the subject of costing studies are shown in Table 1. These sectors have been identified in the UKCIP regional studies as being most important to stakeholders.

Table 1: Summary of Sectoral and Spatial Coverage of Costing Studies

Sensitive Sector	Sub-regional	Regional	National
Health		ET	ET; (AR)
Transport	ET	ET; MT	ET; MT
Built Environment & Cultural Heritage	MP; EP	ET; MP; EP	ET; MP; EP; (AR)
Agriculture	MT; MP	MT; MP; (ASR)	MT; MP; (AR)
Biodiversity		MT	MT
Water Resources	MT; MP	MT; MP; (ASR)	
Tourism		MT	MT; (AR)
Energy			MT

Notes: Climate hazards considered: MT = mean temperature; MP = mean precipitation; ET = extreme temperatures; EP = extreme precipitation. Aggregation over spatial scales: AR = national estimate derived from regional cost estimates; ASR = regional estimates derived from sub-regional (local) cost estimates; DR = regional cost estimates disaggregated from national cost estimates.

As stated above, the cost assessments typically start with case studies conducted at the local or regional level. If we wish to develop estimates at the regional and national scale, the consequence of adopting an approach based on sub-national, sector-based case studies is that it becomes necessary to extrapolate costs from: (a) the local level to the corresponding regional level and (b) from a particular region to other UK regions, not directly covered by case studies.

One approach that we use is to create ‘impact-transfer functions’; an example is given in Box 2.

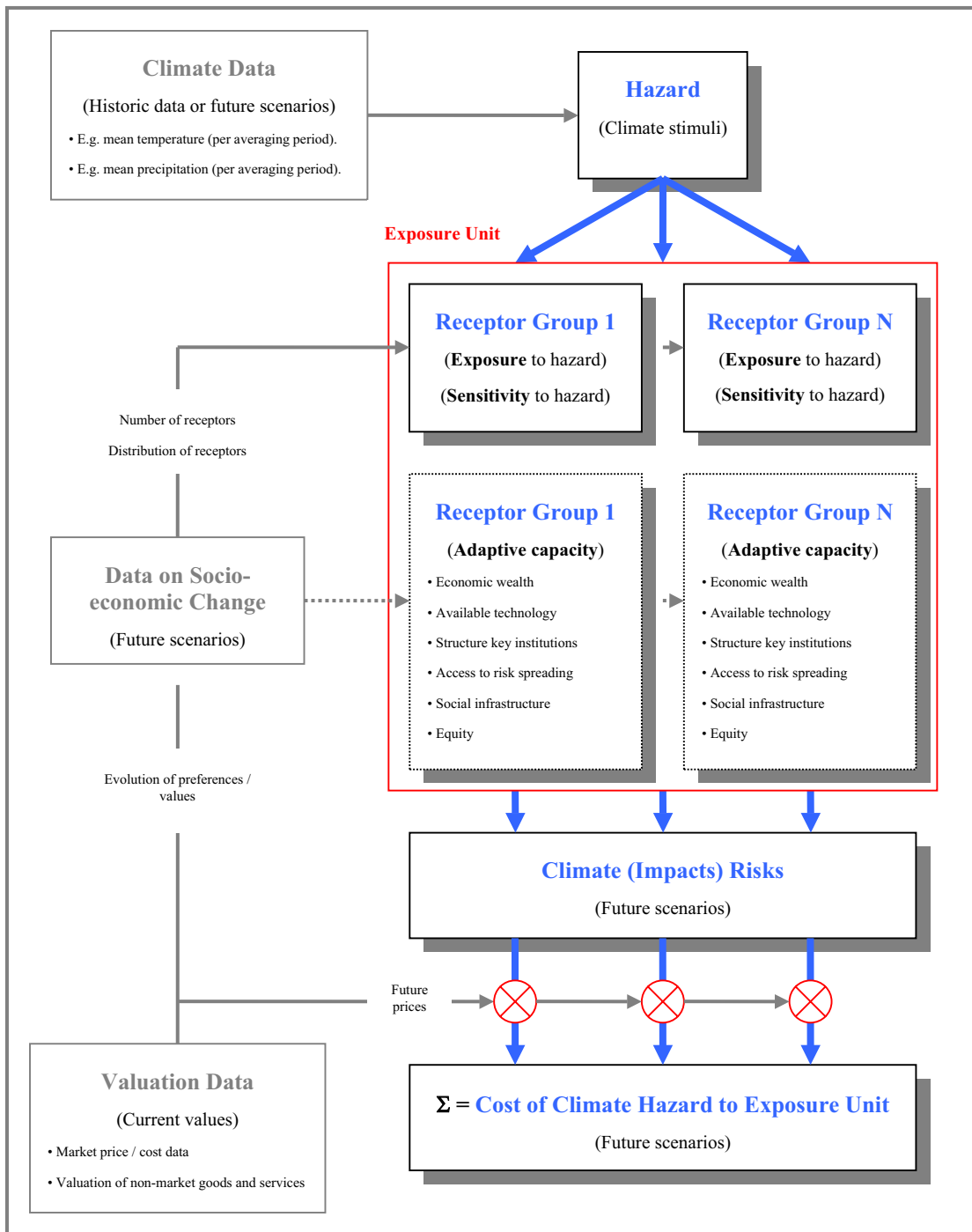
Box 2: Example: Use of Impact-transfer Function in Health Sector

In health sector cost assessments, for example, the temperature-mortality incidence function is first estimated in one region and applied in that region under alternative climate change scenarios in order to generate total cases for this region. The function is then transferred to other regions, and applied to the relevant socio-economic variable – in this case the size of the population aged over 75 – under alternative socio-economic (and climate change scenarios). In this way totals are generated for these regions.

The ‘impact-transfer function’ approach is not, however, appropriate in two specific instances.

1. The first instance is when impacts in one region have clear repercussions (or knock-on effects) in other regions. This is the case in, for example, the tourism sector. Here, the potential exists for varied inter-regional transfers of tourists, as drier and warmer summers suggest – on the basis of current preferences – increased visitors from some parts of the UK to others, such as Scotland and Northern Ireland. In this case it is necessary to model the impacts across UK regions simultaneously within a linked-regional modelling framework.
2. The second instance is when the physical impacts of climate change (and adaptation options) are very location-specific, because particular combinations of vulnerable receptors (human and natural) and predicted climate hazards (e.g. precipitation patterns) are unlikely to occur in other regions. The impact of climate change on water resources is an example where the use of ‘impact-transfer functions’ is limited to extrapolation from the local level to the corresponding regional level, but not beyond.

Figure 1: Schematic of Costing Methodology in Practice



Notes: grey line = input data flow; blue line = impact pathways; dashed lines indicates parts of the framework where lack of data and understanding of the underlying relationships limits the extent to which this link is usually accommodated. “X” denotes the multiplication of unit values (e.g. £ per life year lost) and physical impacts measured in the same units (e.g. life years lost).

Physical Risk Assessment

In broad terms, the basic approach to cost assessments is - for each exposure unit considered⁴ - to multiply relevant unit values (or ‘prices’) by quantified changes in the physical state of a population(s) of vulnerable receptors, where the ‘change’ in the physical state is induced by climate change. Thus, the first stage involves quantifying the climate induced risk in measurable, physical units (i.e. the Physical Risk Assessment). The following sub-sections discuss the key elements of this Assessment.

Climate Data

In the cost assessments undertaken to date the climate data used is derived from the UKCIP02 climate scenarios (Hulme et al, 2002). These scenarios were developed for conducting impact and adaptation assessments in the UK, and present data for precipitation and temperature on a 5 x 5 km area basis for individual months for three 30-year time-slices over the period 2011–2100. Typically, precipitation and temperature variables from a range of scenarios are used (high, medium-high, medium-low and low), so that a plausible range of possible futures (and impacts and costs) can be addressed, in the face of uncertainty. At a minimum, cost assessments include both a ‘high’ (leading to a plausible upper limit of climate change) and a ‘low’ (leading to a plausible lower limit of climate change) emissions scenario. In this way, the cost assessments allow for some evaluation of the UK benefits of pursuing a lower carbon future. Moreover, using the plausible upper limit of climate change is useful for assessing and planning adaptation policy for the worse-case scenario.

In order to undertake regional-specific costing studies, the UKCIP02 data is processed to generate variables at a regional level of aggregation – e.g. the average monthly temperature in South West or South East England.

The baseline climate for a particular climate variable is normally taken as the average over the 30-year period 1961-90. In the majority of cost assessments, physical impacts and associated costs are calculated for three standard 30-year averaging periods, to match the available climate data: 30 years centred on the 2020s (2011-2040); 30 years centred on the 2050s (2041-2070); and 30 years centred on the 2080s (2071-2100).

The UKCIP02 climate scenarios provide precipitation and temperature data for assessing the future costs (and benefits) of climate change. To assess the impacts of historic climate events – e.g. the heat wave of summer 1995 or 2003 – time series data from the Met Office is used (see Box 6).

⁴ An exposure unit is essentially the system at risk to the climate hazard – e.g. a sector, such as transport, or a sub-sector, such as rail.

Box 3: Example: Quantifying Impacts of Historic Events: Impact of the summer 2003 weather on energy use

Data on the average monthly Central England Temperature (CET), covering the period 1980 to 2004, were obtained from the Met Office. The monthly average temperature data for June, July and August were converted to a quarterly average for each year.

Over the period 1961 to 1990 the average CET temperature during Q3 was 15.06 C. In 2003 the average CET temperature in Q3 was 2.27 C above this longer-term average.

To establish if there is any correlation between average CET in Q3 and electricity and gas use during Q3, for each end user (and for total use across all end users), the following steps are taken:

- Plot energy consumption for Q3 over time.
- Identify the trend by fitting a linear trend line to the time series (1980-2002, excluding 2003).
- Create a de-trended version of the original data series by subtracting the fitted trend data from the observed data. The de-trended data points are referred to as the 'residual' data.
- Calculate the correlation coefficient between the residual data series and the average CET in Q3.

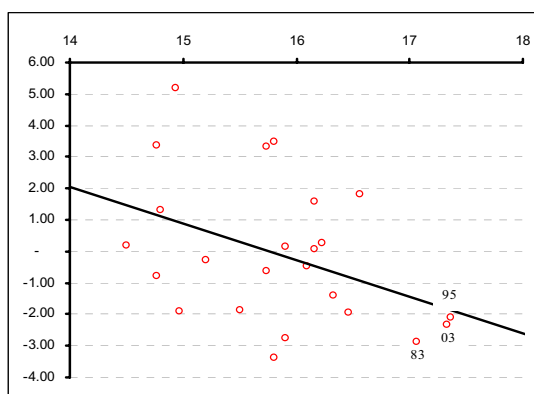
To determine the impact of the temperature anomaly experienced during summer 2003, two possible approaches are followed:

- Use the estimated (long-term) trend line to predict energy use for Q3 2003, and then subtract this predicted value from actual average energy use for 2003. The difference between the two is referred to as the energy use 'residual' (relative to the long-term average).
- Create scatter plots of the estimated 'residual' gas and electricity use data against average CET for Q3. Fit a linear regression line to the scatter plots (an example is shown below). Use the regression equations to directly estimate the energy use 'residual' for Q3 2003 (as a function of the actual average CET in Q3 2003).

For both approaches forecasting errors (lower and upper 95% confidence interval) are calculated.

When calculating the economic impact of summer 2003 on energy use, only values in which: (a) the correlation between CET in Q3 and the 'residual' data exhibit dependence and (b) the estimated 'anomaly' is outside the forecasting errors of the regression lines, are included.

Scatter Plot of 'Residual' Gas Sales (TWh) in Q3 for Domestic Use against Average Q3 CET (degrees C)

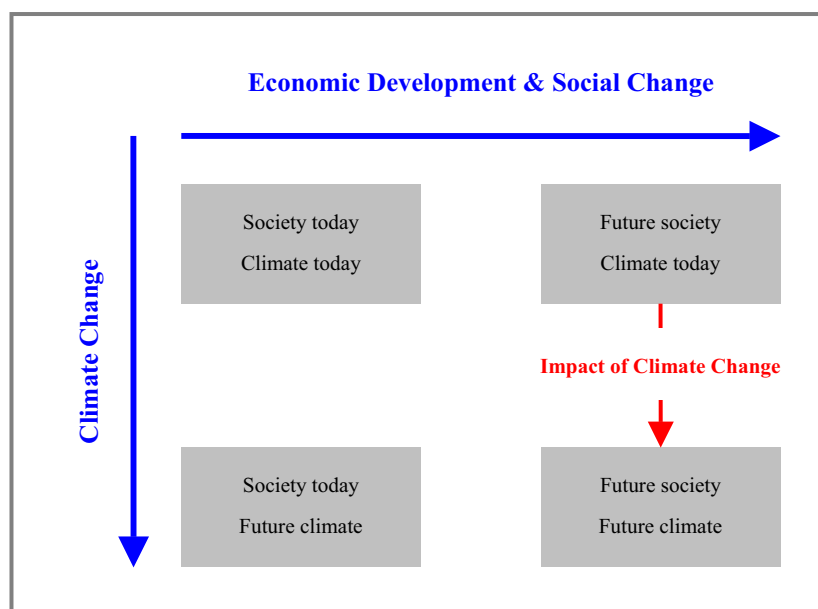


Source: Metroeconomica (forthcoming)

Socio-economic Data

The impact pathway (cause-and-effect chain) from the climate stimuli to changing climate risks is complex and often includes many non-climate (moderating) factors, such as demographics, social institutions, income levels and distribution, education levels, infrastructure and technology, knowledge and skills, and behaviour. Future climate risks are therefore not only determined by climate change, but also by contemporaneous economic development and social change. It is therefore essential that socio-economic change is incorporated in estimates of future climate-induced impacts (as shown in Figure 2).

Figure 2: Cost Assessments: Considering Concurrent Socio-economic Change and Climate Change



The majority of cost assessments we have undertaken adopt the socio-economic scenarios prepared for UKCIP (UKCIP, 2001). These scenarios are thought to be the most appropriate, since they are relatively recent, are stakeholder-led and build upon other exercises that have attempted to construct socio-economic scenarios for the UK, such as the Foresight scenarios (see DTI, 1999). The BESEECH project (2006) has further developed the UKCIP socio-economic scenarios, and the up-dates afforded by this project are incorporated in more recent applications of the Costing Methodology.

The UKCIP scenarios are designed to be consistent with the construction of greenhouse gas emission scenarios that were prepared for the IPCC, (IPCC Special Report on Emission Scenarios, 2001) and which form the basis of the UKCIP02 climate change scenarios. However, there is no direct correspondence between the UKCIP02 (emissions) scenarios and the socio-economic scenarios, not least because the latter are specifically aimed at the UK, whereas the emissions scenarios used in UKCIP02 are global in nature. An approximate correspondence can nonetheless be

drawn; Table 2 shows a number of combinations that could be considered in order to appreciate the full range of uncertainty.

At a minimum, all cost assessments adopt the two most extreme combinations (i.e. Low Climate-Global Sustainability and High Climate-World Markets. Where data permits the two other combinations labelled ‘C’ (consistent) have also been considered.

Table 2: UKCIP Recommended Climate – Socio-economic Scenario Combinations

		Socio-economic Scenarios			
		Global Sustainability (GS)	Local Stewardship (LS)	National Enterprise (NE)	World Markets (WM)
Emission Scenarios	Low	S,C	S		S
	Medium-Low		C		
	Medium-High			C	
	High	S	S		S,C

Notes: ‘S’ may be combinations used in sensitivity analysis; ‘C’ may be combinations used if consistency between scenarios is considered.

In order to incorporate non-climate (moderating) factors consistently into cost assessment the socio-economic variables need to be expressed in quantitative terms. The key drivers of economic development and social change that are expressed in quantitative terms within the available socio-economic scenarios, and that are used most in cost assessments, include:

- GDP growth rates (real % change per annum);
- Value added, by broad economic sector;
- Population, by region;
- Household size, by region;
- Households, by region (calculated from other variables);
- Land use; and
- Passenger transport (total km and % split between modes).

Values for these variables are provided for the time-slices centred on the 2020s and the 2050s (or for 2021 and 2051 in the case of the BESEECH project). However, cost assessments extend to the 30-year period centred on the 2080s through extrapolation. Therefore, in order to generate values for this later epoch trend lines are typically fitted to the three available data points for each variable of interest – i.e. the base year

value provided, and the values for the 2020s and the 2050s. The trend line with the best fit is then used to predict a value for the 2080s. In some cases, a value for the 2080s is obtained using a linear extension of the trend between the 2020s and the 2050s.

The indicators of socio-economic change serve three purposes in cost assessments, as shown in Figure 1:

1. They describe the evolution of the ‘stock-at-risk’ (population of receptors exposed, such as residential property) to a particular climate hazard (e.g. inland flooding) at a specific location (e.g. North West England) over time.
2. They describe the evolution of ‘prices’ (the value of the ‘stock-at-risk’, such as residential property values, the value of human-related intangible impacts of flooding, the Value of a Life Year) over time.
3. They influence the adaptative capacity (the ability of a system to moderate or cope with potential damages or to take advantage of opportunities) of the ‘stock-at-risk’ over time (e.g. the knowledge and resources available to develop flood defences, early warning systems, etc.).

All cost assessments include (1). Since cost assessments should be conducted in constant (base year) prices, (2) is only an issue where it is believed that the value of the ‘stock-at-risk’ will change in real terms over the forecast period. However, within the available socio-economic scenarios the only quantified variable which can be used as a proxy for the likely evolution over time of prices / values is real GDP growth (or specifically, real GDP growth per capita). Typically, the base year price corresponding to the quantified change in the physical state of the affected receptor is multiplied by projected GDP per capita (it is implicitly assumed that the elasticity of the marginal utility of income is 1.0). It is the view of some stakeholders, however, that inflating prices by projected GDP per capita can mask the impact of climate change, relative to regional or national GDP. The process of inflating prices over the forecast period is therefore not always undertaken; costs / benefits are simply expressed in base year values.

It is important to note that hitherto the Physical Impact Assessment has concerned itself with the interpretation of the socio-economic scenarios in a non-climate change context. In other words, the nature and direction of socio-economic development is assumed to be independent of climate change. This is because the objective of the Physical Impact Assessment is to identify the gross impacts of climate change, before adaptation is considered. It is also the case, however, that the nature and direction of economic development and social change will influence the shape and form of adaptation (i.e. adaptive capacity) to climate change.

However, the influence of economic development and social change on adaptative capacity has not, to date, been included in cost assessments, at least quantitatively. Algorithms relating key variables from the available socio-economic scenarios to vulnerability, through enhancement (or deterioration) of adaptive capacity are not available at present. Rather, the socio-economic scenarios are interpreted so as to provide a qualitative assessment of either the likely availability of known adaptation options or their likely affect on future vulnerability. Box 4, below, demonstrates how the socio-economic scenarios are interpreted for these two purposes.

Box 4: Example: Accounting for the influence of economic development and social change on adaptive capacity and climate risks

The table below shows the hypothesised (qualitative) influence of socio-economic factors on total number of heat-related health effects in the UK under alternative socio-economic scenarios, based on expert interpretation of the scenarios. The quantified heat-related health impacts are then evaluated in the context of the overall direction of influence of the socio-economic factors.

Socio-economic factor	Socio-economic scenario			
	World Markets	National Enterprise	Local stewardship	Global Sustainability
Building design & air conditioning	- ve	+ ve	+ ve	- ve
Health education/information	+ ve	+ ve	- ve	- ve
Changes in working practices	+ ve	+ ve	- ve	- ve
Elderly persons living alone	+ ve	+ ve	-	-
Urban poverty	+ ve	+ ve	- ve	- ve
Overall	+ ve	+ ve	- ve	- ve

The table below shows a range of options for managing Public Water Supply. These include both options that reduce demand and options that increase supplies. A number of the options were judged to be novel in some way and were said to be unavailable in the 2020s (and even the 2050s). A judgement was also been made as to whether an option is likely to be available under a specific socio-economic scenario; for example, options that involve considerable energy use have been deemed unacceptable under the Global Sustainability scenario. The availability of an option will affect the estimated cost-yield curves and thus the costs of reducing (adapting to) supply shortfalls.

	Type	Socio-Economic Acceptability			Feasible in Timeslice		
		WM	NE	GS	2020s	2050s	2080s
1 New reservoir	PWS Supply	Y	Y	N	N	Y	Y
2 Raising of reservoir	PWS Supply	Y	Y	Y	N	Y	Y
3 Canal transfer	PWS Supply	Y	Y	Y	N	Y	Y
4 River transfer	PWS Supply	Y	Y	N	N	Y	Y
5 Pipeline transfer	PWS Supply	Y	Y	N	N	Y	Y
6 Bankside storage	PWS Supply	Y	Y	Y	Y	Y	Y
7 Surface water abstraction (unsupported for PWS)	PWS Supply	Y	Y	N	Y	Y	Y
8 Groundwater abstraction or enhancement	PWS Supply	Y	Y	N	N	Y	Y
9 Desalination	PWS Supply	Y	Y	N	Y	Y	Y
10 Wastewater re-use (direct PWS)	PWS Supply	Y	Y	Y	N	Y	Y
11 Wastewater re-use (direct non-PWS)	PWS Supply	Y	Y	Y	N	N	Y
12 Wastewater re-use (indirect PWS)	PWS Supply	Y	Y	Y	Y	Y	Y
13 Wastewater re-use (indirect non-PWS)	PWS Supply	Y	Y	Y	Y	Y	Y
14 Artificial recharge and recovery	PWS Supply	Y	N	Y	N	Y	Y
15 Operational improvements	PWS Supply	Y	Y	Y	Y	Y	Y
16 Artificial recharge of aquifers	PWS Supply	Y	N	Y	N	Y	Y
17 Tariffs for measured supply	PWS Demand	Y	Y	Y	N	Y	Y
18 Educational projects	PWS Demand	Y	N	Y	Y	Y	Y
19 Improved leakage control	PWS Demand	Y	N	Y	N	Y	Y
20 Rainwater use (new development, non-potable)	PWS Demand	N	N	Y	N	Y	Y
21 Greywater use (new development, non-potable)	PWS Demand	N	N	Y	N	Y	Y
22 Waste minimisation of industrial / commercial	PWS Demand	Y	Y	Y	Y	Y	Y
23 White good subsidies	PWS Demand	Y	N	Y	N	Y	Y
24 Retrofit of toilets (dual flush / interruptible flush)	PWS Demand	Y	N	Y	Y	Y	Y
25 Metering (domestic)	PWS Demand	Y	N	Y	Y	Y	Y

Source: Metroeconomica (forthcoming) and S. Wade, HR Wallingford.

Modelling Framework

Figure 3 characterises the various different development-climate-adaptation cases that underpin the analytical framework for the Physical Impact Assessment. (The main steps are graphically illustrated in Figure 4.) The rows in Figure 3 show the evolution of climate overtime; C_0 denotes the existing climate and C_1 denotes a future climate. The columns show the evolution of society over the same timeframe; S_0 denotes society today and S_1 denotes a future society. Planned adaptation is given by A , and is a determined by the current or future state of society and/or the current or future climate state.

If $\mathbf{R} [S, C, A (S, C)]$ represents the physical impact (however measured) from a climate hazard of interest, then $\mathbf{R} [S_0, C_0, A (S_0, C_0)]$ describes the situation in a chosen base year (today). The physical risk to future society from the same hazard is characterised as $\mathbf{R} [S_1, C_0, A (S_0, C_0)]$, in the absence of planned adaptation (the **Projected Baseline** in panel (a), Figure 4)⁵. Thus, the change in risk, $\Delta\mathbf{R} (S_0, C_0): S_0 \rightarrow S_1$ due to economic development and social change is given by $\mathbf{R} [S_1, C_0, A (S_0, C_0)]$ less $\mathbf{R} [S_0, C_0, A (S_0, C_0)]$ ⁶.

The physical risk to future society from the hazard in a future climate is characterised as $\mathbf{R} [S_1, C_1, A (S_0, C_0)]$, in the absence of planned adaptation (the **Future Risks** line in panel (b), Figure 4). The change in risk to future society due to climate change, $\Delta\mathbf{R} (S_1, C_0): C_0 \rightarrow C_1$ is thus given by $\mathbf{R} [S_1, C_1, A (S_0, C_0)]$ less $\mathbf{R} [S_1, C_0, A (S_0, C_0)]$ ⁷. Graphically, this is characterised by the distance between the Future Risks and Projected Baseline in Figure 4. Policies and measures can be implemented to reduce the anticipated risks to future society⁸, yielding the lower risk state $\mathbf{R} [S_1, C_1, A (S_1, C_1)]$, shown by the **Future Risks after Adaptation** line in panel (c), Figure 4. The gross benefits of adaptation are given by $\mathbf{R} [S_1, C_1, A (S_0, C_0)]$ less $\mathbf{R} [S_1, C_1, A (S_1, C_1)]$, and the residual climate risk is $\mathbf{R} [S_1, C_1, A (S_1, C_1)]$ less $\mathbf{R} [S_1, C_0, A (S_0, C_0)]$.

⁵ In Figure 4 the x-axis characterises the risk state $\mathbf{R} [S_0, C_0, A (S_0, C_0)]$, which may be thought of as a Fixed Baseline.

⁶ Although not shown in Figure 4 policies and measure could be implemented to adapt to $\Delta\mathbf{R} (S_0, C_0): S_0 \rightarrow S_1$ giving rise to state $\mathbf{R} [S_1, C_0, A (S_1, C_0)]$. In this case, the gross benefits (in physical units) of adaptation are given by $\mathbf{R} [S_1, C_0, A (S_0, C_0)]$ less $\mathbf{R} [S_1, C_0, A (S_1, C_0)]$, and the residual development risk is $\mathbf{R} [S_1, C_0, A (S_1, C_0)]$ less $\mathbf{R} [S_0, C_0, A (S_0, C_0)]$.

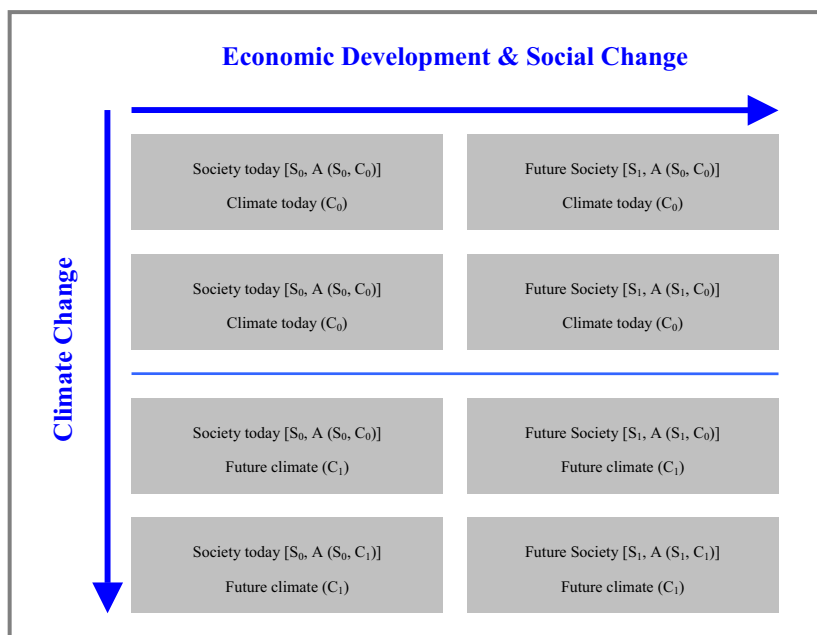
⁷ It is also possible to quantify the change in risk due to climate change relative to a fixed baseline, although this is typically not done: $\Delta\mathbf{R} (S_0, C_0): C_0 \rightarrow C_1 = \mathbf{R} [S_0, C_1, A (S_0, C_0)]$ less $\mathbf{R} [S_0, C_0, A (S_0, C_0)]$.

⁸ Planned adaptation can reduce climate risks in one of four ways. With reference to Figure 1, it may involve:

1. Reducing the exposure of the 'stock-at-risk' to a climate hazard (e.g. constructing flood defences or restricting development in flood plains).
2. Reducing the sensitivity of the 'stock-at-risk' to a climate hazard (e.g. implementing early warning systems).
3. Changing the non-climate (moderating) risk factors (e.g. managing land use – agriculture, forestry - in upper catchment).
4. Mitigating the impacts of the climate hazard (e.g. purchasing insurance, strengthening emergency response planning).

While nearly all cost assessments to date quantify $\mathbf{R} [S_0, C_0, A (S_0, C_0)] =$ Fixed Baseline, $\mathbf{R} [S_1, C_0, A (S_0, C_0)] =$ Projected Baseline and $\mathbf{R} [S_1, C_1, A (S_0, C_0)] =$ Future Risks, the estimation of $\mathbf{R} [S_1, C_1, A (S_1, C_1)] =$ Future Risks after Adaptation is rarely possible. Even when adaptation policies and measures can be identified, which is not always the case, information on their effectiveness (in reducing risks) is sparse. As a result few cost assessment have been able to determine the gross benefits of adaptation.

Figure 3: Analytical Framework for Physical Impact Assessment



Two generic approaches are typically taken to quantify climate risks:

1. Using historical analogues of, usually extreme, weather events. This typically involves, first, identifying a weather-related event of significance in a particular location or region (e.g. road subsidence in Cambridgeshire due to the hot, dry summer conditions of 2003, the windstorm that hit the Isle of Man on the 7th and 8th of January 2005). Second, the impacts of the event on a population(s) of receptors are identified and quantified, to the extent possible. Typically, news/press releases and existing studies are reviewed and (affected) stakeholders consulted (see Box 5). The Impact Matrices in the Costing Guidelines are also useful in helping to identifying the full range of potential impacts. Third, meteorological or hydrological data is assessed to characterise the frequency of the event under the baseline climate (e.g. a hot and dry summer such as that of 1995 has been historically characterised as 1-in-100 year event⁹). Fourth, the UKCIP02 climate scenario data is used to establish the anticipated frequency of the event under various climate scenarios. Fifth, the quantified impacts of the historical analogue are extrapolated over the

⁹ MAFF (2000) Climate Change and Agriculture in the United Kingdom, page 5.

study period, based upon interpretation of the socio-economic scenarios. Finally, the expected annual risk (the product of the quantified impacts and the estimate probability of occurrence) is computed for the baseline climate and plausible future climate(s); the difference between the two is the expected annual impact of climate change¹⁰.

2. Using models of varying forms. These include: (a) single equations (cause-effect functions) that include a climate variable as a determinant (e.g. the mortality-temperature relationships derived from epidemiological models which are used to quantify changes in mortality from heat and cold stress); (b) the climate envelope or niche models that simulate changes in the suitable climate space for species under different climate scenarios (used to quantify the impacts of climate change on biodiversity); or (c) the agriculture models that estimate expected changes to yields as a function of crop parameters, management practices and (baseline and projected) climate data.

Box 5: Example: Identifying / quantifying impacts from Windstorm on Isle of Man

The windstorm of 7-8 January 2005 saw wind gusts of 112 mph recorded on the Mountain Road. Gusts reached 85 mph at Peel breakwater, 92 mph at Ronaldsway Airport, 96 mph at Douglas and 98 mph at the Point of Ayre. At one point the winds were Storm Force 11. The storm peaked at around 5-6 am on Saturday.

The following impacts are examples that were identified in local press archives. This type of information was used to construct the Impact Matrix found at Annex A.

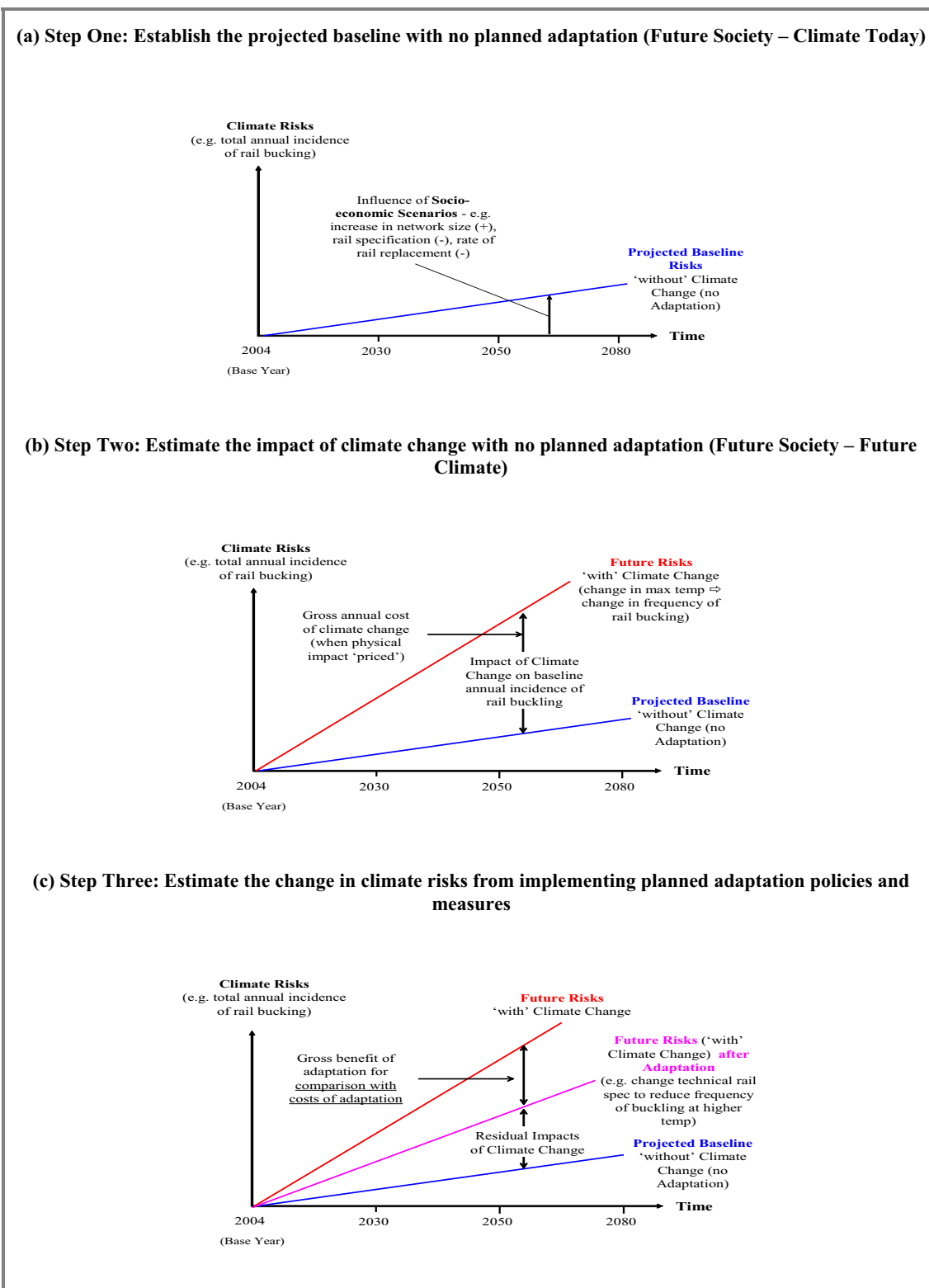
- There were reports of significant damage to private residences and property (e.g. cars), with chimney stacks being blown over and roof slates being dislodged.
- As of the 10th of January, it was reported that about 400 properties remained without power and that it could take to the end of the week before electricity supply is restored. At the height of the storm about 900 customers were without power as poles were blown over, power lines ripped out of walls and trees crashed onto overland cables.
- The island's water treatment works and pumping stations are powered by electricity. During the peak of the storm on Saturday morning alarms indicated power failures at 10 sites, including Ballure Water Treatment Works and Ballagawne Water Treatment Works. The Isle of Man Water Authority deployed mobile generators at affected installations to ensure potable water supplies to customers. However, a number of customers remained without water on Saturday due to broken mains, which were damaged by uprooted trees.
- As a result of the storm all flights were delayed and ferry sailings disrupted.
- Bus services were cancelled on Saturday the 8th as the emergency services battled to clear roads around the island of uprooted trees and other debris. Services resumed on Sunday.

Affected stakeholders were subsequently consulted to help quantify the impacts and provide relevant cost information, where available.

Source: Metroeconomica and Acclimatise (2006) "Costing the Impacts of Climate Change in the Isle of Man: Estimate cost of historic weather events".

¹⁰ Sometimes the impacts under the baseline climate and future climate scenarios are first valued and the probabilities of the event(s) occurring under each scenario are subsequently applied. In these cases, the expected annual damages are computed for the baseline climate and future climate scenarios; the difference between the two is the expected annual cost of climate change (see Box 6).

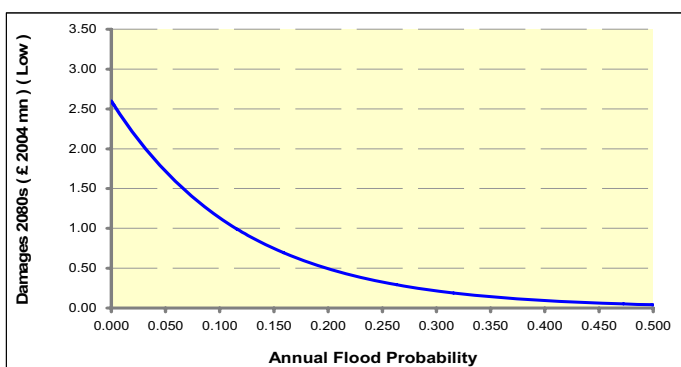
Figure 4: Steps in the Physical Impact Assessment



Note: linear functions are used simply for ease of exposition. We do not, however, mean to imply that risks will necessarily increase in a linear fashion, given the numerous thresholds that are likely to exist.

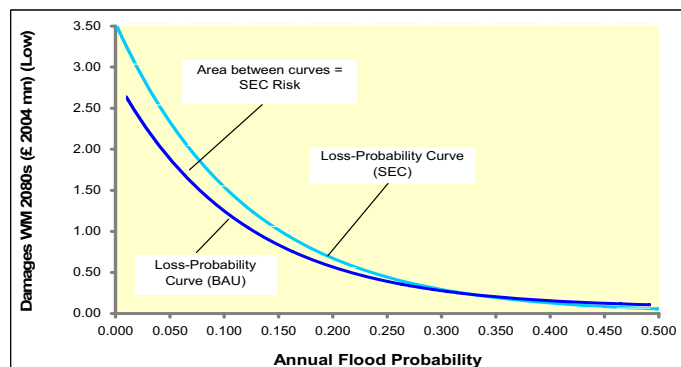
Box 6: Example: Using historical analogues: flooding risks, Sulby River, Isle of Man

The Sulby River on the Isle of Man has a history of flooding; over the last 30 years the Sulby area has been flooded on at least 6 occasions. On the 8th of December 2000 the Sulby River overflowed, leading to serious flooding of about 30 residential and commercial properties in Sulby at Carrick Park Estate and along the Mill Race. This particular flood was characterised as a 1-250 year event (annual probability = 0.004); the cost was estimated at between £2.7 and £3.3 million (this includes the cost of damage to residential and commercial property, temporary accommodation, clean-up, additional power for dehumidifiers, health effects, emergency services and second-order impacts). The figures below show the estimated (low) loss-probability curves (which summarise the costs arising from a range of possible flooding events with varying return periods) under three scenarios for the 2080s.



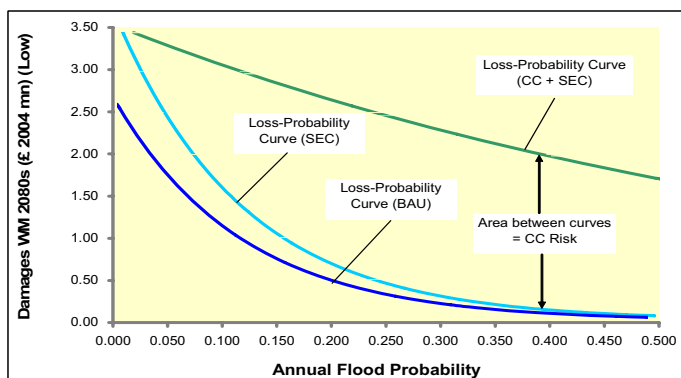
Fixed Baseline
(No planned adaptation)

The loss-probability curve is recalculated as the number of properties and residents increases (NB ‘prices’ were not adjusted in accordance with projected growth in GDP per capita, for the reasons set out in the main text); based on interpretation of the World Markets (WM) socio-economic scenario.



Projected Baseline
(No planned adaptation)

The loss-probability curve (Projected Baseline) is shifted as the probability of each flood event changes as a result of climate change; based on ‘precipitation driver multipliers’ derived from UKCIP02 (low emissions) climate scenario data.



Future Climate Risks
(No planned adaptation)

Notes: SEC = socio-economic change; CC = climate change; BAU = business-as-usual; and WM = World Markets scenario.

Valuation of Climate Risks

Once the climate risks of interest have been quantified it is then possible to determine their relative economic importance by expressing them in monetary terms. Each climate risk is valued using the appropriate technique, as identified in the UKCIP Costing Methodology. Since there is no standard taxonomy for classifying valuation techniques, which can be a source of confusion where different terms are used to categorise the same techniques, the Costing Methodology simply splits the valuation techniques into two categories:

1. Methods based on data from **conventional markets**. (An example is shown in Box 7.)

The techniques in this category value climate change risks using the market price of the affected good / service – i.e. the price observed 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.

2. Methods based on data from **surrogate or constructed markets**.

The techniques in this category are used to value climate change risks either:

- 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
- 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 or conjoint choice experiments). These two types of techniques are also known in the technical literature as revealed preference and stated preference techniques, respectively.

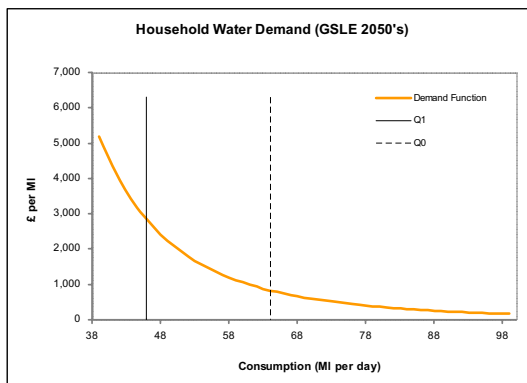
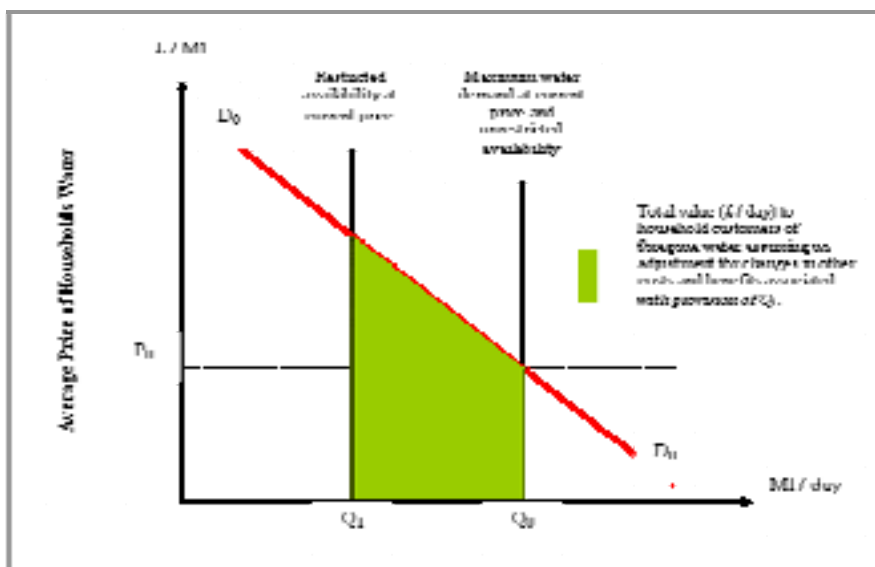
The Costing Methodology contains a decision tree to help the user identify the appropriate technique for valuing the climate risks of interest. The decision tree is consistent with the procedure for selecting valuation techniques in the Green Book, which is shown in Figure 5.

For climate risks where it is not possible to use prices derived from market data, with few exceptions (e.g. a new empirical study was undertaken to value aspects of cultural heritage affected by climate change-induced flooding), valuation is generally based on the ‘transfer’ of data from existing primary (valuation) studies (see Box 8). This inevitably introduces additional uncertainty in the results. To help minimise these uncertainties, the Costing Methodology provides a **value transfer** guideline to assist with transferring existing valuation data to the context of interest.

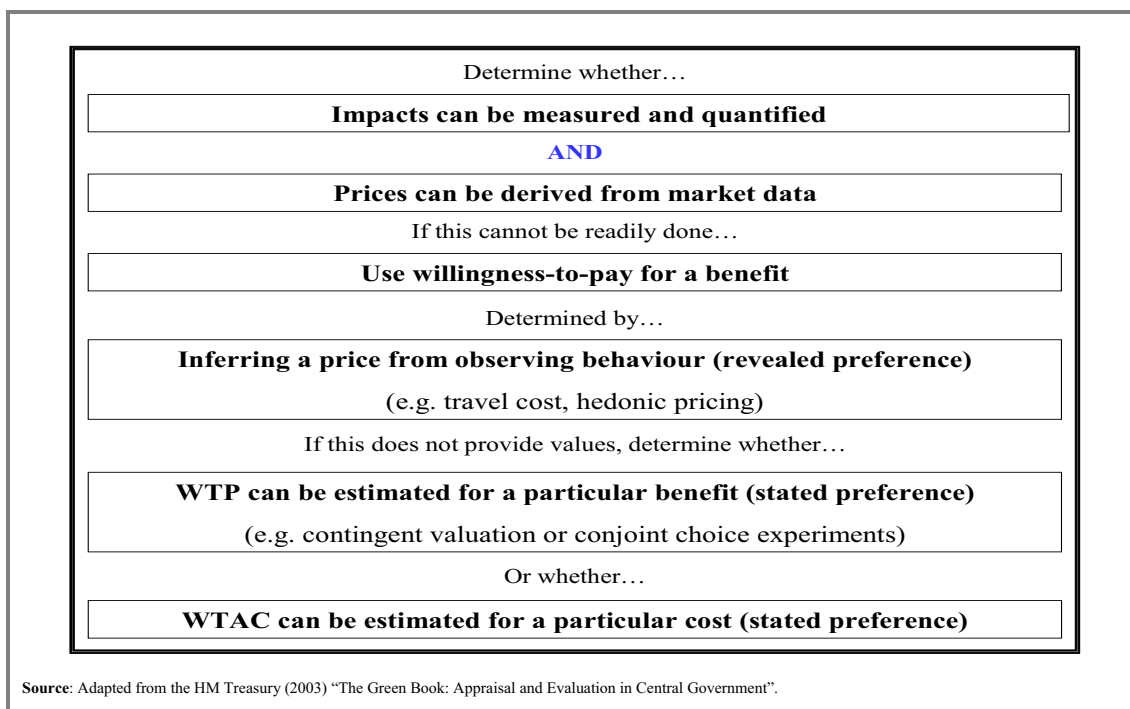
Box 7: Example: Valuing impacts using market data: shortfalls in household water supply

In the UK water is a marketed good. It is therefore possible to determine the economic losses to households from water supply shortfalls using market data. Specifically, the willingness-to-pay of households for each additional unit of water can be approximated along their demand curves, as illustrated by D_0-D_0 in the first figure below. Household demand curves for water can be derived from the Price Elasticity of Demand. The approach requires that maximum household water demand is defined as the volume of water households would use at existing price levels (P_0) and with unrestricted availability (Q_0). In any epoch where supplies are less than the maximum demanded by households (e.g. Q_1), economic losses are given by the value (or benefits) that households would gain from the provision of additional units of water, at P_0 , until Q_0 is met (the shaded area in the figure). Economic losses therefore reflect the total value to households of any foregone water use, assuming no adjustment for other costs and benefits that may arise from the provision of Q_1 , such as reduced operating costs or water charges.

The second figure applies this approach and shows the estimated household water demand curve for south and east Scotland under a Global Sustainability (GS) – Low Emissions scenario for the 2050s. The water shortfall is given by the distance between Q_0 and Q_1 as measured on the x-axis. The total economic losses to household Public Water Supply (PWS) customers in South and East Scotland (given by the area under the demand curve bounded by Q_0 and Q_1) would be about £45 million per year or just over £50 per household per year, in the absence of intervention.



Source: Metroeconomica (forthcoming)

Figure 5: Hierarchy of Valuation Techniques**Box 8: Example: Valuing non-market impacts****Acute Mortality from Heat and Cold Stress**

There are three elements that need to be considered when estimating the total welfare losses from impacts on human health. These elements are:

- Resource costs (i.e. medical costs);
- Opportunity costs (i.e. the value of foregone productivity); and
- Disutility or 'human' costs (i.e. pain or suffering and concern and inconvenience to family members and others).

Acute mortality as a result of exposure to hot weather most frequently affects people who are elderly, ill or both. Two metrics are currently used to value premature mortality: (1) the value of a prevented fatality (VPF) and (2) the value of a life year (VOLY). The latter providing a means of explicitly accommodating different lengths of remaining life expectancy.

Valuation of acute mortality focuses on disutility of 'human' costs: it is assumed that the resource costs associated with the death would be incurred in any case when the individual dies; and it is also assumed that since acute mortality most often affects the elderly, they will have retired from the work-force so that opportunity costs are not relevant. The disutility or 'human' costs of acute mortality as a result of exposure to hot weather can be valued using the central value of a life-year currently recommended by the Interdepartmental Group on Costs and Benefits (IGCB) within UK Government: £15,000 per life-year. A reasonable range around this central value – supported by two recent studies (Chilton et. al. 2004; Markandya et. al. 2004) is £5,000 to £50,000. As a sensitivity test, a VPF of £1.2 million – a value used by the Department for Transport – may be adopted. (Note that the VPF value was derived from studies undertaken to evaluate mortality risks in other (risk) contexts. Clearly, the application of these values in a context different from that for which it was derived provides an additional source of uncertainty.)

Source: Metroeconomica (forthcoming)

Two key methodological issues, relating to valuation, arise during cost assessments. These are:

- **The compatibility of units**: When it comes to the valuation of climate risks, particularly if non-market goods or services are affected, the potential exists for these risks to be quantified in units that are not aligned with the unit values available for benefit transfer. Thus, while the framework shown in Figure 1 implies a sequential process, it is often necessary to identify potentially relevant unit values during the early stages of the Physical Impact Assessment. The climate risks can then be defined (and modelled) in a manner that ensures consistency between physical and monetary units.
- **Non-marginal changes**: In all cost assessments to date it is generally assumed that the climate change hazard or adaptation response under investigation results in ‘marginal’ impacts, in the sense that the impact is sufficiently small so as to have no effect on the price /value of affected goods and services. As a result, costs (or benefits) are calculated by simply multiplying the estimated impacts by the appropriate unit values. In some cases, however, the climate hazard or adaptation response may result in ‘non-marginal’ impacts on the exposure unit, which may in turn change relevant prices by changing the underlying demand and supply conditions. This may lead to second-order effects on other exposure units (and feedback effects on the exposure unit(s) of interest). To date, cost assessments have not had sufficient resources to address this possibility quantitatively, but rather include qualitative assessments of instances where the use of extended partial equilibrium or general equilibrium analysis may be particularly appropriate.

Options Appraisal

The Physical Impact Assessment and Valuation stages of the Costing Methodology are combined to generate estimates of the welfare costs (or benefits) of specific climate hazards to the exposure unit(s) of interest. The majority of cost assessments stop here, at least in terms of quantitative analysis (see below), providing local, regional and national decision-makers with first estimates of the potential costs (benefits) of climate-related risks (opportunities) in sectors relevant to their area of policy.

If adaptation policies and measures are identified and their effectiveness (in terms of reducing risks) and associated implementation costs quantified, then economic (Options Appraisal) analysis of the costs-benefits of specific exposure units adapting to climate risks can be undertaken. This has been possible in a few cost assessments, where the adaptation options are ‘structural’ in nature (e.g. engineering works to reduce the probability and/or consequences of flooding, supply-side measures to increase available water resources). Generic data relating to both the effectiveness and costs of such structural measures is often accessible; in some cases it is even possible

to obtain site-specific data¹¹. Figure 7 illustrates how the consideration of planned adaptation is incorporated into the overall framework.

Typically, the costs of adaptation are assessed on the basis of cost-effectiveness analysis (CEA). Options Appraisal is performed within the framework of cost-benefit analysis (CBA). The costs of the adaptation options thus provide a link between the CEA and the CBA. No attempt is usually made to 'optimise' the adaptation response (i.e. to equate marginal adaptation costs with marginal adaptation benefits); rather, the focus is simple to study the costs and benefits of specific adaptation options. The use of CEA and CBA in appraising adaptation options is illustrated in Box 9 and Box 10, respectively.

Several key methodological issues arise during Options Appraisal. These include¹²:

- **Discounting and discount rates**: As mentioned above, to match the available climate data from UKCIP02 cost assessments usually estimate climate risks and associated costs for three standard 30-year averaging periods: 30 years centred on the 2020s; 30 years centred on the 2050s; and 30 years centred on the 2080s. For each of these three points in time the (30-year) average annual cost or benefit is reported, often accompanied by an undiscounted¹³ profile of the costs or benefits over the entire period. The present value of these streams of costs or benefits is not always calculated. This is only necessary during Options Appraisal, when the costs of (near-term) adaptation options must be compared with the (longer-term) benefits of the climate risk(s) avoided. If streams of future costs, benefits or net benefits are converted to present values (or to Equivalent Annual Costs) the discount rate profile recommended in the Green Book is adopted: a real annual discount rate of 3.5% is used for years 0-30; a real annual discount rate of 3.0% is used for years 31-75; and a real annual discount rate of 2.5% is used for years 75-125.
- **Treatment of uncertainty**: A theme that runs through much of the discussion about climate change and the economic analysis of climate change is that of uncertainty. The whole exercise of estimating the costs of climate hazards to specific exposure units is confounded by imprecise information, as illustrated in Figure 6. Uncertainty about climate and socio-economic futures is normally incorporated into the cost assessments using a range of scenario combinations (e.g. Low Climate-Global Sustainability and High Climate-World Markets). Likewise, uncertainty about the risk assessment and valuation is incorporated through the use of ranges (e.g. low and high unit values, low and high dose-response coefficients). Hence, cost or benefit estimates are presented not as single values, but rather as ranges. In some cases, Interval Analysis is used, in which the absolute lower (upper) value of the range of estimates for each element of the Costing Methodology is combined to define the lower (upper) bound cost or benefit estimate This identifies the extreme lower and upper

¹¹ For example, in a case study of the impacts of climate change on river flooding on the Isle of Man, an engineering study of flood defence schemes for the river of interest was made available by the island's Department of Transport.

¹² Detailed guidance on all these issues is provided in the UKCIP Costing Methodology.

¹³ Discounting is the standard technique used to add and compare costs and benefits that occur at different points in time.

estimated outcomes for a given set of input variables, modelling assumptions, etc. Of course, other ways of dealing with uncertainty are also available.

- Treatment of unvalued impacts:** Application of the Costing Methodology depends on sufficient quantitative data being available in an appropriate form. In many cases, even though a climate hazard is known to give rise to a specific risk(s), there is insufficient data or methods to quantify that risk. Moreover, given state-of-the-art economic valuation, it is not always possible to value certain risks, even when it has been possible to quantify them. So as not to paint a misrepresentative picture of the total costs of climate change to a specific exposure unit, it is as equally important for the cost assessment to clearly show what anticipated risks are **not** included in the totals, as it is to show what risks are included. The lack of monetary estimates for specific climate-induced risks does not mean that those risks can be overlooked in any decision-making process. Thus, all anticipated climate risks facing an exposure unit are normally identified (e.g. in the form of an Impact Matrix, similar to that found at Annex A). For risks where Physical Impact Assessment is not possible, they are usually qualitatively assessed in terms of their likely relative importance, based on the expert judgement of (affected) stakeholders. In the summary cost tables, these risks are identified as “NQ” (not quantified). If valuation is not possible, though physical impacts have been quantified, these are reported in the summary tables. The likely relative importance of the physical impacts, in the context of the total estimated climate change costs facing an exposure unit, is again qualitatively assessed on the basis of expert judgement.

Figure 6: Climate Change Costing and Cascade of Uncertainty

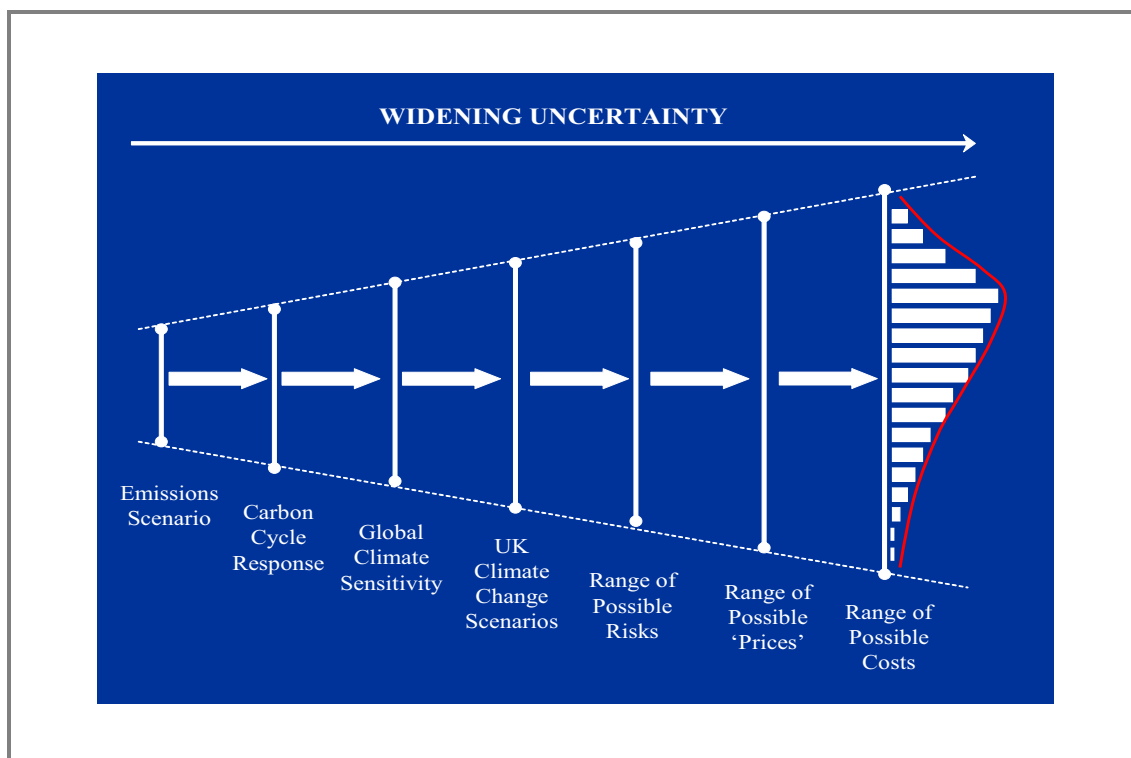
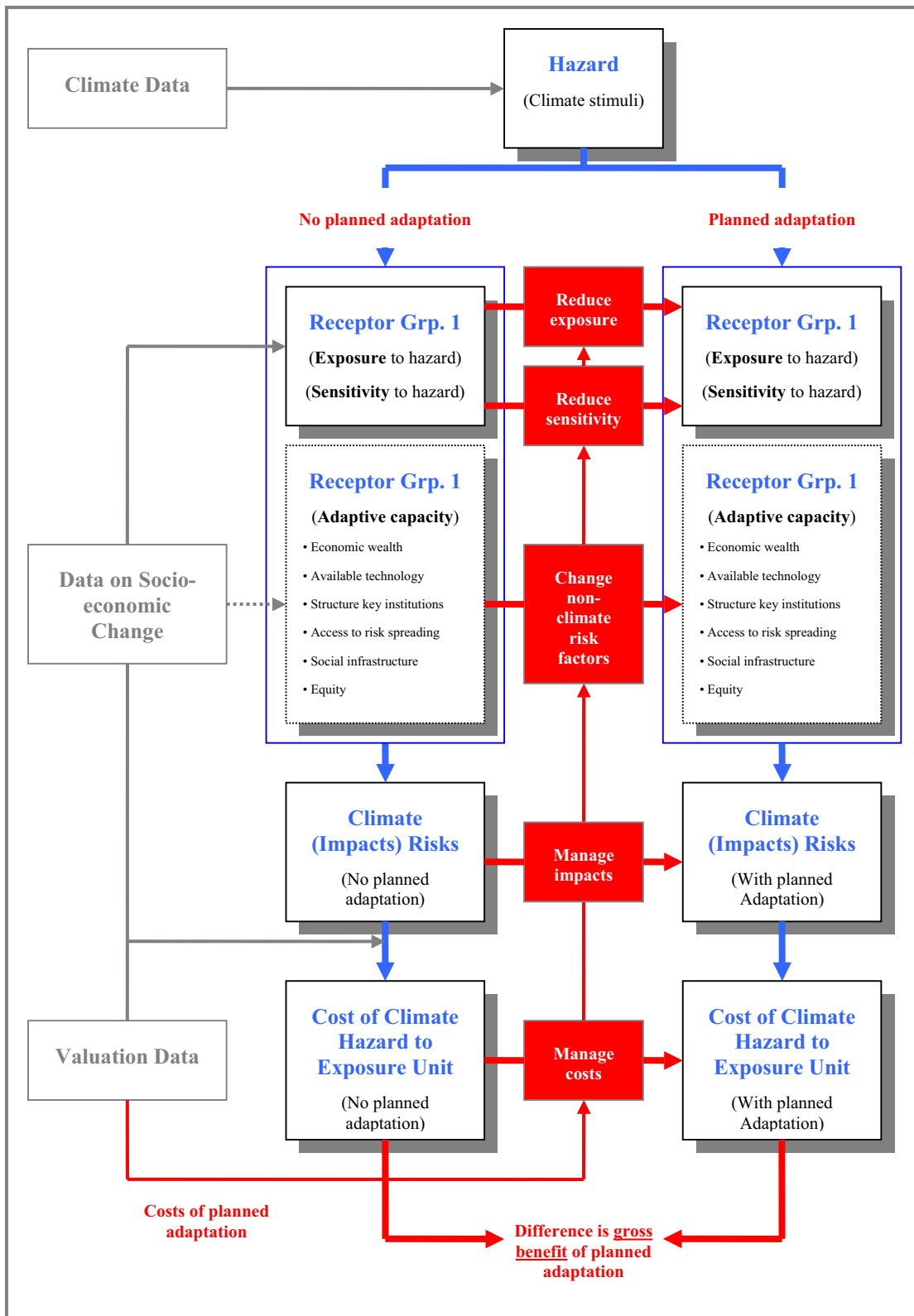


Figure 7: Incorporating Planned Adaptation into Costing Methodology

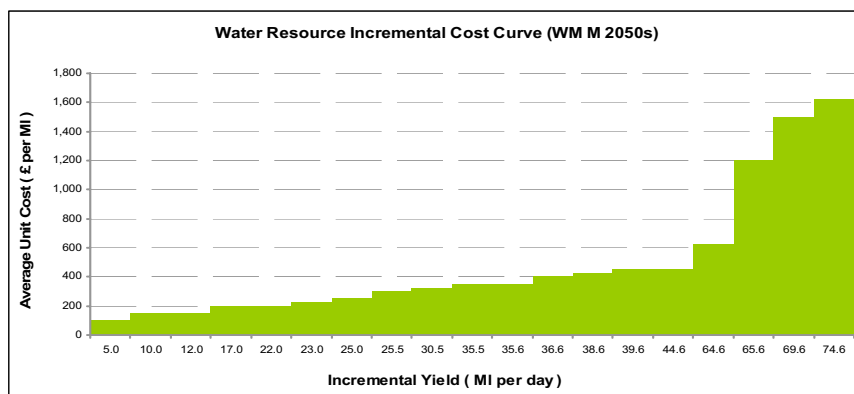
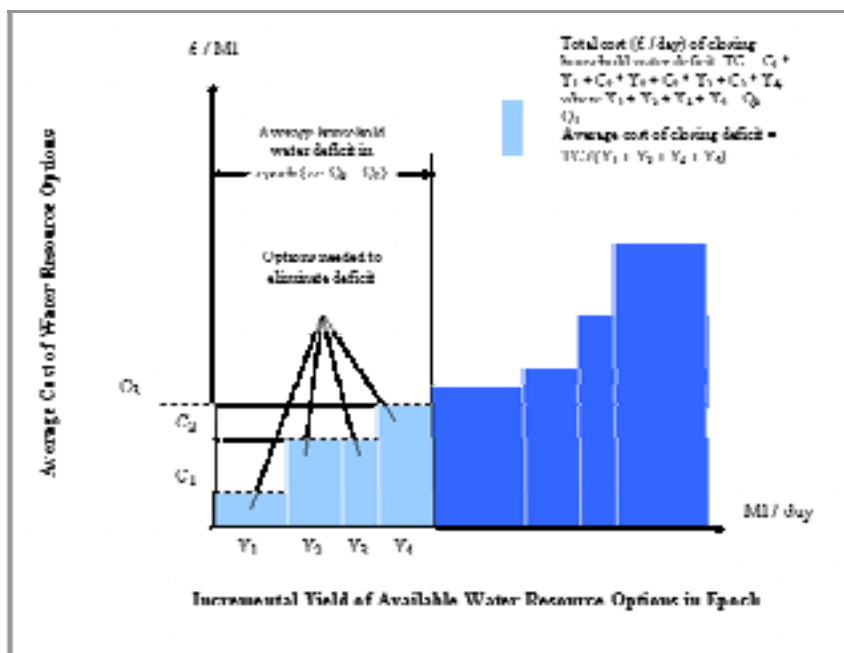


Notes: Red pathways denote adaptation activities and outcomes.

Box 9: Example: Estimating the costs of adaptation using CEA: closing water supply shortfalls for households

In Box 5 a range of options for managing Public Water Supply (PWS), including both options that reduce demand and options that increase supplies, were listed. Given information on both the yield per measure per epoch (MI per day) and the total implementation cost per measure per epoch (pence per m³), cost-effectiveness analysis (CEA) can be used to determine the least-cost programme of measures for closing any given water deficit, under different climate scenarios. The results of the CEA can be summarised in the form of cost-yield curves, similar to that illustrated immediately below. The total cost of closing a climate change induced water supply-demand imbalance can be determined from such curves, as the figure illustrates. The availability of an option in a given epoch will affect the shape of the cost-yield curve and thus the costs of reducing (adapting to) supply shortfalls.

The second figure below shows the estimated (medium) cost-yield curve under a World Markets scenario for the 2050s – taking into account scenario specific issues of acceptability and feasibility (recall Box 5). The total (medium estimate) cost of eliminating a shortfall in household PWS supplies in a case study in EA Southern Region was estimated at between £13 and £25 million per year for the low and high emissions scenario, respectively. Under the low emissions scenario the first 8 options (green steps, left-to-right) on the cost-yield curve are required to remove the shortfall in supply; the first 12 measures (green steps, left-to-right) are required to remove the shortfall in supply under the high emissions scenario.

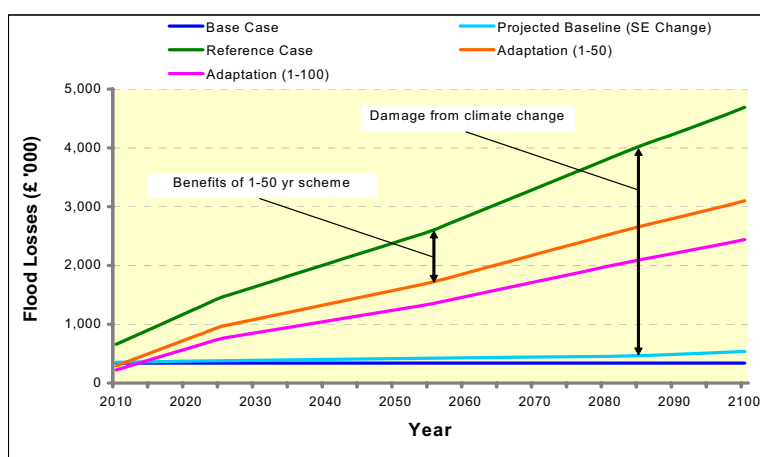


Source: Metroeconomica (forthcoming)

Box 10: Example: CBA of adaptation: flooding risks, Sulby River, Isle of Man

In Box 6 (low cost) loss-probability curves were presented for flooding at Sulby for the 2080s. Similar curves were constructed for the 2020s and the 2050s, and for two different adaptation schemes (1-50 and 1-100 year levels of protection). A set of curves based on high cost estimates were also generated. These curves provided the basis for a CBA of protecting Sulby to climate induced flood risks under various scenarios. CEA was used to evaluate a range of adaptation schemes in order to identify the least cost options for delivering 1-50 and 1-100 year protection.

The figure below shows the profile of (undiscounted) flood damages under a World Markets-Low Emissions scenario (low cost estimate) for the Base Case, the Projected Baseline, the Reference Case (with Future Risks) and two adaptation cases. The tables present the estimated economic cost of climate-induced flooding and the benefits of adaptation; the present value costs of the 1-50 year and 1-100 year scheme are £2.0 and £2.6 million, respectively. The schemes pass a standard cost-benefit decision rule since the benefit-cost ratios are considerably higher than 1.



	Base Case		Development & SE Change		Development & SE & Climate Change		Impact of Climate Change	
	Low	High	Low	High	Low	High	Low	High
World Markets	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)
Total losses to 2100 (undiscounted)	33.04	38.10	40.86	47.09	246.53	298.64	205.67	251.55
PV total losses 2004 to 2100	9.71	11.20	10.94	12.62	43.62	52.70	32.67	40.08
Equivalent annual losses	0.35	0.41	0.40	0.46	1.58	1.91	1.19	1.46
Annual average losses 2020s (undiscounted)	0.34	0.39	0.38	0.44	1.42	1.72	1.04	1.28
Annual average losses 2050s (undiscounted)	0.34	0.39	0.42	0.49	2.64	3.21	2.22	2.72
Annual average losses 2080s (undiscounted)	0.34	0.39	0.48	0.55	4.04	4.86	3.56	4.31
Benefit-Cost Ratio								

	Losses with Adaptation (1-50 Scheme)		Losses with Adaptation (1-100 Scheme)		Gross Benefits Adaptation (1-50 Scheme)		Gross Benefits Adaptation (1-100 Scheme)	
	Low	High	Low	High	Low	High	Low	High
World Markets	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)	(£ mn)
Total losses to 2100 (undiscounted)	160.82	195.46	126.49	154.74	85.72	103.17	120.04	143.90
PV total losses 2004 to 2100	27.07	32.90	21.22	25.97	16.55	19.80	22.39	26.73
Equivalent annual losses	0.98	1.20	0.77	0.94	0.60	0.72	0.81	0.97
Annual average losses 2020s (undiscounted)	0.91	1.10	0.71	0.87	0.51	0.62	0.71	0.85
Annual average losses 2050s (undiscounted)	1.75	2.13	1.38	1.68	0.90	1.08	1.27	1.52
Annual average losses 2080s (undiscounted)	2.67	3.22	2.10	2.56	1.37	1.64	1.94	2.31
Benefit-Cost Ratio					8.23	9.84	8.66	10.34

Conclusions

It has certainly proved possible to cost the impacts of climate variability and climate change at a sub-national level using the UKCIP Costing Methodology, in combination with the UKCIP02 climate scenarios and various socio-economic scenarios available for the UK. Furthermore, given sufficient information on the identity, cost and effectiveness of adaptation policies and measures, it has also been possible to prioritise actions within the framework of cost-benefit analysis. Despite these successes, the application of the Costing Methodology across all sensitive sectors and regions, with respect to all key hazard-impact causal chains, and considering both ‘soft’ and ‘engineering’ adaptation policies and measures has been restricted due to a lack of appropriate impact data, values and methods. Below, we highlight some generic areas in which research would be most valuable in addressing these restrictions.

1. **Improvement in the availability and quality of non-market values available for monetising climate change impacts.** The absence of willingness to pay data for some sector-specific impacts (e.g. in habitat and biodiversity) and the applicability of existing valuations to climate change contexts (e.g. health, water and energy) limits the extent to which impacts can be expressed in a common unit of currency, which in turn restricts aggregation across impacts and sectors, and the prioritisation of climate risks across sectors and regions. New empirical studies are needed to address these limitations.
2. The analysis in some sectors - in particular, transport, was conducted at a national level. Local and regional planners (both private and public) in these sectors would benefit from **micro-scale case studies** since climate risks and adaptive capacity and strategies could be evaluated at a more appropriate scale.
3. The projected impacts and costs of climate change are contingent on the level of (autonomous or partial) adaptation, if any, in the reference case. However, the current state of knowledge on these forms of adaptation means that they nearly always omitted from the impact and cost assessment. **Improved understanding of the types of autonomous or partial adaptation likely to be undertaken in selected sectors, and their associated effectiveness and costs** is needed. Not only will this improve the accuracy of projected impacts, it will also identify other entry points for national adaptation strategies.
4. **Stakeholder analysis on the relative value of climate change impact assessments reported in physical, monetary and other metrics for use in sectoral decision-making.** Whilst climate change adaptation assessments are in their infancy it would be advantageous to explore by, e.g. survey based research the relative strengths and weaknesses of alternative impact metrics.
5. **Exploration of transferability of impact assessment and valuation methodologies from the UK to other countries.** Lessons learnt from experience to date may be used in informing impact assessment and valuation in other countries in order to both increase awareness of what can be done, and to inform, e.g. European and other adaptation strategies.

Annex A: Example: Impact Matrix for Windstorms, Isle of Man – Potentially Relevant Economic Impacts

First-order Impact	Sector Affected	Potential Economic Impacts	Relevant Stakeholders
<p style="text-align: center;">Winds ↑ Direct Physical Damage ↑ Habitat ↑ Forestry ↑ Agriculture land ↑ Transport infrastructure ↑ Buildings (residential, commercial, industrial, agriculture, government) ↑ Historical and cultural heritage ↑ Human health ↑ Utilities</p>	Habitat	Mortality in 'valued' species (foregone use and non-use value) Destruction of 'valued' ecosystems (foregone use and non-use value)	General public, tourists, national interest groups, government departments
	Forestry	Destruction of trees (loss of timber products and producer surplus) Destruction of trees (loss of recreation and amenity)	Timber producers, consumers, national interest groups, government departments, general public
	Agriculture land	Loss of crops (lost producer surplus) Loss of livestock (lost producer surplus)	Local farmers, consumers of farm products, government departments
	Transport infrastructure	Loss of infrastructure/equipment (replacement necessary) Damage to infrastructure/equipment (repairs necessary)	Transport operators, contractors, local public (users and employees in this sector), business and wholesale distributors
	Buildings (residential, commercial, industrial, agriculture, government)	Loss of private and public property (replacement necessary) Damage to private and public property (repairs necessary)	Households, property owners, insurers, contractors, business
	Historical and cultural heritage	Loss of cultural objects (foregone amenity and non-use value) Damage to cultural objects (repairs necessary)	Local public, tourists, national interest groups, government departments, insurers, business
	Human health	Increased risk of mortality (fatal injuries) Increased risk of morbidity (non-fatal injuries and anxiety)	Local public, employers, insurers, NHS, government, regulators
	Utilities	Damage to transmission network Damage to power generation infrastructure	Power generators and suppliers, electricity customers - both households and business (prices), regulator, insurers, other utilities, government departments
		Damage to water treatment facilities and pumping stations Damage to distribution and sewer system	Water authority, customers - both households and business (prices), regulator, insurers, government departments
		Damage to waste water treatment plant	
Damage to telecommunication system / lines		Telecommunication suppliers, customers - both households and business (prices), regulator, insurers, government departments	

Source: Metroeconomica and Acclimatise (2006) "Costing the Impacts of Climate Change in the Isle of Man: Estimate cost of historic weather events".

First-order Impact	Sector Affected	Potential Economic Impacts	Relevant Stakeholders
<pre> graph TD Winds --> ShortTermDisruption[Short-term Disruption] Winds --> Evacuation ShortTermDisruption --> RoadTransport[Road transport] ShortTermDisruption --> AirTransport[Air transport] ShortTermDisruption --> SeaTransport[Sea transport] Evacuation --> HouseholdsGovernment[Households / Government] </pre>	Road transport	Increase in travel cost (individual, work time) Increase in travel cost (individual, non-work time) Disruption to inputs / sales (business losses) Change in demand for unaffected, alternative transport routes or modes Increase in highway agency's costs	Local population, users and operators of public transport (buses), businesses, highways authorities
	Air transport	Increase in travel cost (individual, work time) Increase in travel cost (individual, non-work time) Disruption to inputs / sales (business losses) Change in demand for unaffected, alternative transport routes or modes Increase in airport authority's costs	Users and operators of airlines, tourists, businesses, airport authorities
	Sea transport	Increase in travel cost (individual, work time) Increase in travel cost (individual, non-work time) Disruption to inputs / sales (business losses) Change in demand for unaffected, alternative transport routes or modes Increase in harbour authority's costs	Users and operators of airlines, tourists, businesses, harbour authorities
	Households / Government	Increase in costs of 'emergency service' and related activities Temporary accommodation costs Disutility costs to individual (e.g. from stress and anxiety)	Local public, emergency services, government departments

Second-order Impact	Sector Affected	Potential Economic Impacts	Relevant Stakeholders
<p>Damage to Utilities</p> <p>↑</p> <p>Outages / Disconnections</p> <p>↑</p>	<p>Electricity</p>	<p>Disutility (individual)</p> <p>Lost output / increased costs (business customers)</p> <p>Additional costs / foregone producer surplus (supplier)</p>	<p>Power generators and suppliers, electricity customers - both households and business (lost services), regulator</p>
<p>↑</p>	<p>Water</p>	<p>Disutility (individual)</p> <p>Lost output / increased costs (business customers)</p> <p>Additional costs / foregone producer surplus (supplier)</p>	<p>Water authority, customers - both households and business (lost services), regulator</p>
<p>↑</p>	<p>Telecommunications</p>	<p>Disutility (individual)</p> <p>Lost output / increased costs (business customers)</p> <p>Additional costs / foregone producer surplus (supplier)</p>	<p>Telecommunication suppliers, customers - both households and business (lost services), regulator</p>
<p>Damage to property</p> <p>↑</p> <p>Short-term disruption</p> <p>↑</p>	<p>Commerce and industry</p>	<p>Lost business during repairs / replacement (lost producer surplus)</p>	<p>Manufacturing and service sector, insurers</p>

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