IAJ The Integrated Assessment Journal
Bridging Sciences & Policy
Vol. 8, Iss. 1 (2008), Pp. 41–71

Informing Adaptation to Climate Change in the UK: Some Sectoral Impact Costs

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Abstract

Analyses of climate change impact costs to date have been dominated by efforts using global-scale integrated assessment models or national/regional macro-economic models. Whilst these have been useful in scoping out possible economic impacts at these scales, the usefulness of the results is less obvious in informing decisions regarding climate change adaptation. This study takes a first step towards redressing this imbalance by conducting a "bottom-up" study of potential climate change impact costs in the UK that reflects the priorities identified by regional stakeholder groups within the UK. Sectors addressed include: health, built environment, transport, energy, tourism, biodiversity, water resources and agriculture. The UKCIP02 (Hadley Centre) climate scenarios are used with the UKCIP and BESEECH socio-economic scenarios for 3 thirty-year time slices from 2010. We find that there are both significant benefits and costs from climate change in the UK, depending on the sector and the climate change/socio-economic scenario considered. In a number of cases there are benefits and costs for different impacts within the same sector. Notable net benefits are projected in tourism, health, energy and transport winter maintenance. Net losses are projected in the buildings sector—particularly in the Medium-High and High emission scenarios—and transport infrastructure. Costs are generally higher in London and the South East of England and lower in Scotland.

Keywords: Sectoral costs, National climate change impacts

1 Introduction

The development of appropriate climate change policies at a national and international level may benefit from information relating to the costs of the impacts of climate change. Climate change adaptation and mitigation decisions at any scale inevitably involve making trade-offs concerning the use of scarce economic resources. These trade-offs might include, for example, comparing the costs

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of adaptation responses taken now with the future damages that would result from no adaptation, less adaptation or (less) adaptation taken in the future; similarly, we may contrast the national costs of reducing greenhouse gas emissions with the national benefits (as well as costs, where relevant) of such reductions. Assessment of impacts—avoided or not—are clearly integral to any decision-making relating to climate policy. To the extent that economic efficiency is an important criterion in influencing this decision-making it is useful to express climate change impacts in monetary terms. The impact costs then ensure that the mitigation and adaptation decisions are linked in the following way (after Ekins, 1995):

$$C_T^{C1}(e^{C1}, e^{ROW}, a^{C1}) = C_I^{C1}(e^G a^{C1}) + C_A^{C1}(a^{C1}) + C_M^{C1}(e^{C1}) \quad (1)$$

Where: C_T = Total Costs; e = greenhouse gas emissions; a = adaptation measures implemented; C_I = Climate Impact Costs; C_A = Climate Adaptation Costs; C_M = Mitigation costs of greenhouse gas emissions; $C1$ = Country 1; ROW = Rest of World and G = Global. Welfare-efficient optimisation policy therefore aims to minimise the total costs associated with climate impacts, adaptation and mitigation measures. To pursue such an optimization strategy we therefore also want to know the basis on which the trade-offs are made. From the perspective of country 1 interested only in the costs it directly bears, we require:

$$\delta B_A^{C1}(e^G a^{C1}) - \delta C_A^{C1}(a^{C1}) = 0 \quad (2)$$

Whilst for mitigation we require

$$\delta B_M^{C1}(e^{C1}) - \delta C_M^{C1}(e^{C1}) = 0 \quad (3)$$

Where B = Benefits.

To date, the historic emphasis on greenhouse emissions mitigation policy has led to a predominance of studies that estimate the costs of climate change impacts globally or to the US (the world's largest GHG emitter) (e.g. Mendelsohn et al., 2000). These studies have been summarized in Pearce et al. (1996) and more recently Tol (2005*a*). However, as noted by Tol (2005*b*), it seems likely that the informational priorities of the mitigation and adaptation communities regarding impact cost/benefit assessments differ in a number of ways, including time periods of interest and geographical scale. The differential needs of the climate change mitigation and adaptation policy communities suggests that for impact costing research to inform adaptation strategy it should be undertaken at a more local scale. The current paper[1]—with its focus on climate change impacts at the regional and national scale—aims to inform sectoral scoping of adaptation in the UK and its regions by the use of impact costs.

[1]The paper brings together the work of a number of researchers undertaken for a contract with UK Department of Environment, Food and Rural Affairs (Defra). The report can be found at: http://www2.defra.gov.uk/research/project_data/More.asp?I=GA01075&SCOPE=0&M=PSA&V=EP%3A030

In this paper, Section 2 and Section 3 provide an overview of the study's generic and sectoral-specific methodological aspects respectively, before reporting the sectoral results for the UK in Section 4. Some limitations of the analysis are highlighted in Section 5, before conclusions are drawn in Section 6.

2 Method

In order to maintain comparability of sectoral results, as far as possible, consistency and transparency of method is retained within and between sectors (and regions). Outlined below are principal generic methodological components as well as methods specific to each of the sensitive sectors.

2.1 Sectoral and Regional Coverage

Impact costs are estimated for selected impacts in the following sectors: Health; Transport; Built Environment & Cultural Heritage; Agriculture; Biodiversity; Water Resources; Tourism and Energy. These sectors were selected since they accord with those sectors identified in the UK Climate Impacts Programme (UKCIP) regional studies[2] as being most important to stakeholders.

2.2 Physical Risk assessment

Uncertainty. A thread that runs through much of the discussion of climate change costing issues is that of uncertainty. Thus, using the taxonomy developed by Yohe (2003), uncertainty in climate change cost estimates derives from a product of i) the climate model uncertainty and related calibration uncertainty, ii) projection uncertainty, where there is uncertainty about the track that the critical drivers of the model might take in the future, and iii) the contextual uncertainty that derives from the uncertainty associated with change in underlying social and economic structures over time. As a consequence, the whole exercise of estimating climate change costs is confounded by imprecise information. In this analysis uncertainty about climate and socio-economic futures are incorporated using a range of scenario combinations, as suggested above. Uncertainty about baselines derived from the socio-economic scenarios is therefore expressed by the use of multiple scenarios/baselines. Hence cost estimates are presented not as single values, but as ranges based on the full set of plausible socio-economic baselines, and the climate scenarios judged to be most consistent with these socio-economic futures.

Climate data. The basic climate data used is that derived from the UKCIP02 climate scenarios (Hulme et al., 2002). These scenarios are generated using the HadCM3, HadAM3H and HadRM3 climate models, and closely reflect the IPCC emission scenarios given in the Third Assessment Report (IPCC, 2001). Four climate scenarios for the UK are utilized: High, Medium-High, Medium-Low

[2] http://www.ukcip.org.uk/

and Low, that correspond to the IPCC A1F1, A2, B2 and B1 respectively. By using a scenario-based approach a plausible range of possible futures can be addressed in the face of uncertainty. These scenarios present data for precipitation and temperature on a 5×5 km area basis for individual months for three time-slices of 30 years each over the period, 2011–2100. In order to undertake some degree of regional-specific analysis some initial processing of this data has also been undertaken using the UKCIP PROMPTS software. It is recognised that a number of low probability-high impact climate events may occur before 2100. Examples of these events include a slow-down or stalling of the thermohaline circulation, (resulting in significantly cooler mean temperatures than projected under the UKCIP02 scenarios), and the collapse of the Greenland or West Atlantic ice-sheets (resulting in significantly higher sea level rises than currently projected). These extreme events will clearly present a dramatically different hazard and associated risk to the UK than those projected on the basis of the UKCIP02 scenarios. They are not, however, included in the current analysis.

Socio-economic data. In order to quantify the physical units impacted in future time periods the climate scenarios are combined with socio-economic scenarios. The socio-economic scenarios prepared for UKCIP (2001), and subsequently up-dated (PSI, 2005) are utilized. These scenarios are designed to be consistent with the UKCIP02 climate change scenarios; for example, the economic growth rates and technological development patterns underlying the IPCC and UKCIP02 emission scenarios are consistent with those assumed in the UK socio-economic scenarios. The relationships between the UK-focussed climate and socio-economic scenarios and the IPCC SRES (Nakiçenovic & Swart, 2001) are shown in Table 1. The economic dimension of the UK socio-economic scenarios is indicated only; full descriptions of economic, social and environmental dimensions, and the drivers underlying these, are given in UKCIP (2001).

As a minimum, the analysis adopts the two combinations that differ most on the basis of underlying emissions scenarios—Low emissions/Global Sustainability and High emissions/World Markets, consistent with the A1F1 and B1, themselves qualitatively consistent with the IPCC SRES, respectively. The key drivers in the socio-economic scenarios that are expressed in quantitative terms, and that are most utilised in this impact assessment include: GDP growth rates; population; household size and passenger transport (total km and split between modes). The UK socio-economic scenarios were developed for the time-slices centred on the 2020s and the 2050s whilst the present analysis requires coverage to the third time-slice centred on the 2080s. A simple linear extrapolation is therefore made according to the trajectory of the trend data from the present through the 2020s and 2050s, on to the 2080s.

2.3 Monetary Valuation

Unit values for market and non-market impacts. In general, the welfare impacts of climate change in the UK are expressed in terms of willingness-to-pay/accept (WTP/WTA). Such estimates of the welfare effects of climate

Table 1: Summary description of Climate and Socio-economic scenarios. Sources: Hulme et al. (2002) and UKCIP (2001)

IPCC SRES Storyline	UKCIP02 Climate Change Scenario	UKCIP Socio-economic scenario.
A1 Very rapid economic growth; population peaks mid-century; social, cultural and economic convergence among regions; market mechanisms dominate. Subdivisions: A1F1—reliance on fossil fuels; A1T—reliance on non-fossil fuels; A1B—a balance across all fuel sources	High HadRM3 ensemble simulation for A2 emissions scaled to the HadCM3 global temperature for A1FI emissions.	World Markets Globalisation and increased integration in expanded EU assumed to facilitate high rates of economic growth, (3%) based on the growth of the service and distribution sectors
A2 Self reliance; preservation of local identities; continuously increasing population; economic growth on regional scales	Medium-High HadRM3 ensemble simulation for A2 emissions.	National Enterprise Higher degree of protectionism and lack of integration with Europe → lower economic growth than historical long run average (1.75% p.a.)
B1 Clean and efficient technologies; reduction in material use; global solutions to economic, social and environmental sustainability; improved equity; population peaks mid-century.	Low HadRM3 ensemble simulation for A2 emissions scaled to the HadCM3 global temperature for B1 emissions.	Global Sustainability Economic growth at long term average (2.25%). International cooperation & regulation reduces tensions between social and environmental objectives on the one hand and competitiveness on the other.
B2 Local solutions to sustainability; continuously increasing population at a lower rate than in A2; less rapid technological change than in B1 and A1	Medium-Low HadRM3 ensemble simulation for A2 emissions scaled to the HadCM3 global temperature for B2 emissions.	Local Stewardship Economic growth slow (1.25% p.a.). Smaller scale production encouraged. Sectors dependent on int. trade face difficult growth prospects.

change impacts are made on the basis of current market prices in the case of market impacts, whilst benefit transfer of non-market values is utilized on the basis of findings from relevant recent studies of the impact in question. It is assumed that the value of non-market goods—determined by individuals' preferences at the time of the original study—will remain constant in future time periods. Future resource cost estimates are also derived from current resource use configurations. These assumptions are common to the bulk of climate change impact cost estimations—see e.g. Tol (2002*a*,*b*) and Mendelsohn et al. (2000).

In some sectors, however, for certain impacts there exists insufficient data to make robust WTP estimates. These impacts include road and building subsidence, rail buckling, winter road maintenance, flooding of buildings and habitat loss—as indicated in Table 2. For these impacts, repair, replacement or preventative costs are estimated. The major limitation of these estimates is, however, that they essentially measure the costs of specific adaptation options and because of the circularity implied are not useful in cost-benefit analysis of adaptation (Tol et al., 1998). These costs are retained here, the justification being that they at least indicate the potential scale of climate change impacts in the specific sectoral contexts. The omission of WTP/A in these contexts does, however, highlight a research priority.

Non-marginal changes. In common with the majority of previous analyses undertaken at the national or global scale (see, e.g., Mendelsohn et al., 2000; Tol, 2002*a*,*b*), an assumption is made that the climate change impact 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 is valued by multiplying the anticipated change in the quantity demanded by the appropriate price. This, of course, may potentially lead to an under-estimate of the projected extent of impacts and a distorted impression of the distributional impacts (see, e.g., Jorgenson et al., 2004; Bosello et al., 2006, for economy-wide experiments with general equilibrium modeling that attempt to address the limitations of this assumption). However, a particular benefit of using the marginal assumption—apart from the fact that it avoids imposing further modeling assumptions—is that in emphasizing the direct impacts it focuses sectoral attention on the specific adaptation needs. In addition, with the possible exception of the energy and water impacts, for the impacts considered in this paper this assumption appears to be plausible.

Treatment of distributional variations. In some sectors it has been possible to disaggregate the impact cost data on the basis of geographical location within the UK. The relative burden of climate change impacts on groups within the population are also indicated where the sectoral studies allow such groups to be separately identified.

Form of results. Each sectoral study generates a range of impact cost estimates, expressed in annual terms for the three time periods being considered and for the climate-socio-economic scenario mixes explored.

Table 2 summarises the specific impacts quantified by sector. These impacts have been selected on the basis of a) stakeholders' assessment of the impact's potential importance relative to other impacts within the given sector and b) the possibility for quantification, based on data availability. Thus, the sectoral total costs produced are not representative of all potential climate impacts, but may serve to give an indication of the orders of magnitude involved. For each impact studied, the table also shows the monetary proxy used to value the welfare change associated with the impact, the geographical coverage, and the author's subjective assessment of the overall reliability of the estimated costs. This reliability assessment is primarily based on data availability and quality, and the robustness of the impact modeling and valuation based on validation by historical evidence and alternative modeling simulations. IPCC guidance notation on representation of uncertainty[3] is used for this purpose.

For each impact listed in Table 2, the specific climate hazard modeled is shown in Table 3; whether the impact has been valued using market or non-market valuation methods is also described.

3 Impact Functions by Sector

Table 4 presents an overview of the data and modeling used in the sectoral impact estimation process. Models used are identified and an indication is given of their function. The models and modeling techniques implemented in the sectoral analyses were selected on the basis of their ability to utilize the UKCIP02 climate scenarios and reflect the sectoral modeling capabilities that are best able to quantify climate impacts. Key data sources that have been utilized in the sectoral estimation process are listed. Data used is for the most recent time period available, and that best matches modeling needs. It is regionally disaggregated as far as possible. Note that this paper synthesizes the results of a number of individual sectoral studies that are referenced in the description of the derivation of impact functions below. Consequently, for further detail on estimation methods the reader is directed to these references.

3.1 Health—Premature mortality due to heat and cold waves (extremes)

Kovats & Hunt (2006) provide the full sectoral methodology for public health impacts. Temperature-mortality relationships have been derived from epidemiological models that have quantified the short term associations between these variables using routine mortality data (Hajat et al., 2002; Pattenden et al., 2003; Kovats et al., 2004). Estimates of temperature-attributable risk from these models are applied to age- and cause-specific mortality rates in order to estimate the attributable burden of premature mortality (all causes) for selected

[3] Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties. IPCC Bonn.

Table 2: Summary of Sectoral Impacts. Confidence: A = Very confident, very reliable; B = Confident, reliable; C = Plausible, not very reliable; D = Low confidence, unreliable; and E = Very low confidence, very unreliable. Confidence relates to overall assessment, including impact quantification and valuation.

	Specific Impact Quantified	Proxy for Welfare Change	Geographic Coverage	Confidence in Overall Assessment
Health				
Mortality	Premature deaths; years of life lost	WTP	UK regions	C
Morbidity	Respiratory Hospital Admissions	WTP	UK regions	C
Agriculture				
Crops	Δ in Crop yield	Gross margin	English regions	C
Flooding	Δ in Crop yield		English regions	C
Biodiversity				
Selected species and habitats	Δ in species space	Restoration cost	Regional physical assessment; UK level monetisation	D
Tourism				
Visitor Spend.	Δ in visitor numbers	Tourist spend	UK regions	C
Water Resources				
Supply-demand imbalance	Water deficit—households	WTP	2 UK regional case studies	B
Transport				
Infrastructure subsidence	Rail buckling; road subs. Time loss	Restoration cost; WTP	UK level , except for road subsidence—English regions	C
Flooding & coastal inundation	Time loss	WTP	UK level	D
Winter disruption & maintenance	Δ in maintenance req.	Preventative/ Restoration cost	UK level	C
Energy				
Heating	Δ in space heating req.	Δ in Consumer surplus	UK level	C
Cooling	Δ in space cooling req.	Δ in Consumer surplus	UK level	C
Built Environment				
Flooding	Flood damage to buildings	Partial WTP	UK regions	B
Subsidence	Subsidence damage to buildings	Restoration cost	UK regions	B

Table 3: Climatic and Monetary Conventions Used

	Market / Non-market Valuation	Mean / Extreme Weather Variable
Health		
Mortality	Non-market valuation	Extreme temperature
Morbidity	Both. Health resource costs & non-market valuation	Extreme temperature
Agriculture		
Crops	Market prices	Mean precipitation
Flooding	Market prices	Extreme precipitation
Biodiversity		
Selected species and habitats	Market prices (restoration resource costs)	Mean temperature
Tourism		
Visitor Spend.	Market prices	Mean temperature
Water Resources		
Water deficit—households	Revealed preference—market price	Mean precipitation & temperature
Transport		
Infrastructure subsidence	Both. Market prices for restoration costs. Non-market values for Time loss	Extreme temperature
Flooding & coastal inundation	Both. Market prices for restoration costs. Non-market values for Time loss	Extreme precipitation
Winter disruption & maintenance	Market prices for preventative/restoration resource costs.	Mean temperature
Energy		
Heating	Market prices	Mean temperature
Cooling	Market prices	Mean temperature
Built Environment		
Flooding	Market prices	Extreme precipitation
Subsidence	Market prices for preventative/restoration resource costs	Extreme temperature

Table 4: Summary of models and data used in sectoral impact estimation

Specific Impact Quantified	Modeling	Data Inputs
Health		
Mortality: Premature deaths; years of life lost	Temperature-mortality relationships adopted from existing epidemiological models.	Age-specific regional population totals (PSI, 2005); daily meteorological data for each UKCIP02 scenario for selected stations in England, Scotland and Wales (Betts & Best, 2004);
	Application of epidemiological relationships to temperature and population data for time-periods to 2100.	Unit values for health end-points (Various UK Government Department policy appraisal guidelines).
	Application of unit values to physical impact totals	
Agriculture		
Crops: Δ in Crop yield	Regression modeling of climate variables against yields	Regression analysis: historical time series data of weather variables and yields. Data inputs include field (soil, altitude, drainage) for site, and management (planting practices, fertiliser input, irrigation). All available from current site observation.
	Cropsyst yield estimator model	Climatic variables input into weather generator model.
	LARS weather generator model	Current crop patterns and prices
Flooding: Δ in Crop yield	RASP flood risk model	Data inputs: current crop patterns and prices. Precipitation patterns from UKCIP02 Climate scenarios.
Biodiversity		
Selected species and habitats: Δ in species space	SPECIES model (Pearson et al., 2002) parameterises changes in suitable space for species and habitats	Regionally disaggregated temperature and precipn data from UKCIP02 climate scenarios.
		Habitat restoration costs: UK Biodiversity Group (1998); GHK Consulting Ltd. (2006)
Tourism		
Economic welfare effects of Δ in visitor numbers	Hamburg Tourism Model	1995 Domestic and international tourist flows and per visitor expenditure Socio-economic scenario data: per capita income, population (SRES & UKCIP) Climate scenario data: temperature
Water Resources		
Supply-demand imbalance: Water deficit—households	Water resource balance spreadsheet modeling (Wade et al., 2006)	Regionally disaggregated temperature and precipn data from UKCIP02 climate scenarios.
Transport		
Infrastructure subsidence: Rail buckling; road subs. Time loss	Time series regression modeling using historical data	Time delay data from AEA Technology Rail group's internal database; subsidence repair costs from UK Department for Transport.
Flooding & coastal inundation: Time loss	Use of single historical analogue	Flooding time delay costs from Penning-Rowsell et al. (2002)
Winter disruption & maintenance: Δ in maintenance req.	Projecting historical cost modeling under climate scenarios	Winter salting costs from UK Department for Transport.
Energy		
Heating: Δ in space heating req.	Regression analysis of historical temperature-energy demand relationships.	Historic energy demand from Shorrock & Utley (2003).
Cooling. Δ in space cooling req.	Projections of future energy use.	Energy intensity and energy efficiency projections from BRE (2001) and DEFRA (2002). Gas, coal and oil price projections from DTI (2006). Electricity prices from Future Energy Solutions (2002). Service sector demand for air conditioning from Pout et al. (2002).
Built Environment		
Flooding: Flood damage to buildings	RASP flood risk model	Multipliers for flood risk determinants under climate-socio-economic scenarios applied to RASP. Multipliers derived by Evans et al. (2004).
FHRC FLAIR cost database, Penning-Rowsell et al. (2005).		
Subsidence: Subsidence damage to buildings	Regression modeling of subsidence claims against climatic variables	Subsidence claims: Jane Milne, ABI pers. comm.
		Costs of remedial work on subsidence: Graves & Phillipson (2000)

age groups: 15–64; 65–74; 75+. For each UK region and 30 year time-slice the population attributable fraction (%) of mortality due to “cold” and “heat” extremes is estimated. The numbers of attributable deaths are then calculated by applying this fraction to mortality rates and population projections for a given time-slice, using the age-specific regional population totals provided by the BESEECH project (PSI, 2005) and the daily temperature projections derived from the UKCIP02 climate change scenarios (Betts & Best, 2004).

Evidence shows significant short term mortality displacement associated with heat-related mortality (Kunst et al., 1993; Braga et al., 2001; Pattenden et al., 2003), but less clear evidence in the case of cold related mortality. To account for this effect, following methods employed in comparable analysis in the air pollution context (COMEAP, 1998), an average number of years of life lost, (YLL), is assumed for each death. Both metrics of premature death—life-years and deaths—are utilised. We make the conservative assumption that there exists short term mortality displacement for both heat and cold exposures.

It is also assumed that populations acclimatise to a warmer climate. The temperature thresholds for the mortality response are therefore adjusted in relation to projected increases in summer temperatures. Some “loss” of acclimatization is also assumed to occur for winter mortality, and so the threshold for cold related mortality is also adjusted in relation to increased winter temperatures.

We use unit values of £15,000 and £1.2m for a life-year and a fatality respectively, as currently utilised in UK Government policy appraisal, their range reflecting the continuing uncertainty over appropriate metric and absolute value in this area of non-market valuation.

3.2 Agriculture—changes in crop yields & gross incomes from mean precipitation and loss of yields from flooding

Hanley et al. (2006) provides details of the agricultural sectoral study. Changes in crop yields are projected under climate change scenarios. The crops chosen for analysis are Winter and Spring varieties of Wheat, Barley, Oats and Oil Seed Rape and pasture. Relationships between climatic variables and crop yields are initially established at three sites in Scotland. Annual precipitation is found to have the most robust relationship and is therefore the only climate variable used in the subsequent analysis. Cropsyst, a crop yield estimation model (Stockle et al., 1994) is used by Hanley et al. (2006) to make the climate impact assessment. Daily precipitation data under climate change scenarios is input to the Cropsyst model using a weather generator, LarsWG, that effectively down-scales the 50 km^2 scale UKCIP02 climate change scenarios.

Field level data required by Cropsyst includes altitude and slope of the site, and soil data such as soil texture, pH, water content etc (derived for the Scottish sites from Murphy et al. 1998). Management data required are fertiliser input, irrigation, planting date and criteria for harvest or clipping. Fertiliser input data are taken from the Scottish Farm Management Handbook (FMHB) (SAC, 2001).

Planting dates were chosen for each year group after an analysis of crop yield data for sample crops planted on various days (in a weekly time step). This allowed for some adaptation by farmers to changing climatic conditions thus accounting for the "dumb farmer scenario", without assigning farmers precognisense of the coming years weather. This was the only way in which adaptation, other than that provided by the management model, was included in the analysis and it was assumed that this adaptation would take place; as such data derived from this study includes this level of adaptation. There is no allowance for profit maximising adaptations to occur to land use and land management over time as climate changes.

Potential yields are estimated for the various crops and pasture at each site under the climate change scenarios. The management model within Cropsyst is then used to identify the optimal agricultural land use for farmers given economic constraints and changing potential yields. The Scottish crop yield results from the Cropsyst model are transferred to England in order to predict changes in yield for crops in English regions, and so predict changes in farm incomes.

In order to move from yields to income it is necessary to analyse gross margins, i.e., the profit cost relationship for each unit of yield. Using gross margin data from SAC (2001) it is possible to calculate a value per tonne of grain output and average variable costs and so a change in per hectare profit in each region. From this, the overall regional impacts of climatic change on the agricultural sector are calculated through a simple multiplicative process. Gross profit margins for the individual crops are applied to the changes in revenue per hectare and multiplying these by the hectarage in each region produces regional aggregate changes in gross margins as a proxy for overall welfare changes. The assumption of constant prices is clearly a strong one; in reality one might express socio-economic changes such as further reform of the EU Common Agricultural Policy, together with international supply side impacts from climate change itself, to have altogether different effects on crop prices that may dwarf—in direction, scale and distribution—the welfare impacts identified here.

Flood impacts on crops are estimated by Evans et al. (2004). They use the Risk Assessment for flood and coastal defence for Strategic Planning (RASP) model. The RASP model uses information on the location of river channels, the type of flood plain and the standard and condition of flood defences, in combination with rainfall and run-off patterns under climate and socio-economic scenarios, to calculate the annual average damage from flooding at a regional scale. Current crop prices and crop land use patterns are assumed.

3.3 Tourism—changes in visitor numbers and expenditure

Hamilton & Tol (2006) report the full sectoral tourism study. This estimates the changes in visitor numbers at the regional scale in the UK under the UKCIP02 climate scenarios. The analysis is undertaken using the Hamburg Tourism Model (HTM), which is a model of bilateral international tourism flows. In this model, in order to examine the impacts of climate change at the regional scale, the domestic and international flows of tourists to 36 regions of the UK are estimated. The model is calibrated for 1995, using data for total international departures and arrivals for each country. Bilateral tourism flows are generated by the model, independent of data (e.g., WTO, 2003). As reported in Hamilton et al. (2005) the model allows tourism to grow with economic growth but assumes saturation of demand—demand is constrained to a maximum of 12 trips per person per year.

The model includes a matrix of tourism flows from one country to the next and estimates the size of domestic tourism. This matrix is perturbed with scenarios of population and income growth and climate change. The perturbations on the supply side are perturbations on the relative attractiveness of holiday destinations; the latter defined by the relationship between temperature and visitor numbers identified through regression of historical data. The perturbations on the demand side are perturbations on the number of tourists from origin countries. For all countries apart from the UK, scenarios for population and per capita income growth are taken from the IMAGE 2.2 implementation of the IPCC SRES scenarios (IMAGE Team, 2001; Nakiçenovic & Swart, 2001). The original SRES scenarios are specified for 17 world regions; the growth rates of countries in each region are assumed equal to the regional growth rate. For the UK, population and per capita income growth rates are taken from the UKCIP socio-economic scenarios (UKCIP, 2001).

The simulation estimates the number of outbound tourists, inbound tourists and domestic tourists in each country for 5 year time steps. This data for the UK as a whole is then downscaled to the regions of the UK. The HTM global model estimates the average daily expenditure per international tourist and the average length of stay per international tourist. Equivalent data for the domestic tourist, (UK Tourism Survey, 2006), is also utilized in order to estimate changes in aggregate tourist expenditure in each UK region resulting from socio-economic and climatic change.

3.4 Transport—time delays from rail buckling and flooding of road and rail routes; changes in expenditures on summer road subsidence and winter maintenance

The paper by Horrocks et al. (2006) presents full details of the transport sectoral study. The study uses the summer 2003 warm weather event as an analogue with which to estimate impact costs under future climate change scenarios for rail buckling and road subsidence in the UK. The autumn floods of 2000 in the UK are used as an analogue for the impact costs of equivalent events under climate scenarios, whilst projected numbers of "zero-celcius" days allow winter maintenance costs to be scaled relative to historical patterns.

Sufficient data points relating climatic variables to transport impact costs and so to allow regression analysis only exist for rail buckling. In the absence of such data relating to road subsidence and transport infrastructure flooding, impact costs are only estimated under climate scenarios for weather events of equivalent intensity and so under-estimate aggregate impact costs that would result under a full range of event frequencies.

For rail buckling, monthly time-series analysis regressing data on delay minutes[4] to temperature identifies the most robust regression model of the "warm summer" impact. In the case of road subsidence, time-delay impacts have not been possible to estimate. Instead, subsidence repair costs are estimated and in fact represent the reactive costs of adapting to this impact; they can, however, serve to indicate the scale of the welfare impact, and, under current statutory obligations, represent the impact cost to the local public administration. Time series analysis of incidence is confined to roads in the management of local authorities which tend to be relatively minor in traffic volume terms since the more major A-roads and Motorways are built to a different construction specification and are therefore less vulnerable to subsidence. Indeed, there was no additional subsidence repair work required on these roads following the summer of 2003. It is assumed that the costs of additional structural highway maintenance schemes and emergency repairs incurred in 2003 will be equivalent to those incurred in hot and dry summers of a similar intensity to 2003 under climate scenarios.

Estimates of the travel time savings resulting from avoided ice and snow disruption have not been made under climate change scenarios; instead, the costs incurred in meeting these statutory levels of maintenance are used as a proxy for the climate change impact costs. The number of winter days when temperatures fall to 0°C or below is used to predict the number of days when salting runs—when salt is sprinkled on the road to prevent icing—will be required. Costs incurred in the period 1961–1990 (i.e. non climate change) are scaled on the basis of the number of zero-celcius days projected under climate scenarios, relative to the non-climate change baseline.

Climate change-induced flood impacts on road and rail are estimated on the basis of the time delay costs associated with the Autumn 2000 floods in the UK—a 1 in 50 year event. The multipliers for the effect of precipitation on generic (non-impact specific) flood risk under climate change scenarios were derived by Evans et al. (2004) and applied to the cost estimates. They then provide estimates of how the impacts of a given intensity of flood event under non-climate change baseline are projected to increase under climate change scenarios with increased weather event frequency. The multipliers represent combined effects of socio-economic and climate changes on flood risk relative to the 1961–1990 baseline, so that the climate change signal alone cannot be isolated.

3.5 Energy—changes in demand for space heating and cooling in domestic and service sectors

Watkiss & Horrocks (2006) describe the energy sectoral study in detail. They describe how current relationships between energy demand and temperature in

[4]If a train is more than 3 minutes late from one recording point to the next, then a delay in minutes is recorded.

the UK are projected under climate change scenarios, combined with predicted changes in socio-economic scenarios and energy efficiency improvements/air conditioning uptake for the domestic and service sectors.

In the domestic sector, historical relationships in the UK between average energy demand for space heating per household and the average internal temperature, average external temperature, average heat loss and average space heating efficiency are regressed. The relationship between domestic energy consumption and external temperature is found to be most robust (Shorrock & Utley, 2003), and is projected under climate change scenarios in order to estimate changes in domestic energy consumption and expenditure. Projected future rates of adoption of air conditioning in domestic building differ according to socio-economic scenario in the Watkiss & Horrocks (2006) analysis; however, improvements in the energy efficiency of air conditioning units are not considered. The projections also do not account for the extent to which rising temperatures might influence the uptake of air conditioning units, and so lead to likely under-estimation of uptake and resulting use.

Energy use in the service sector is estimated in Watkiss & Horrocks (2006) by using an established relationship between the increase in demand for space heating and the projected future increase in floor area. Useful energy demand for air conditioning in the service sector is estimated from Pout et al. (2002). Floor area under alternative socio-economic scenarios is determined by service sector growth rates. Assumptions regarding future projections of energy intensity and energy efficiency are estimated from BRE (2001) and DEFRA (2002), respectively. Gas, coal and oil prices are those published in DTI (2006). Electricity prices used are from Future Energy Solutions (2002). Changes in the costs of energy infrastructure are not included but may potentially be seen to be significant.

3.6 Built infrastructure—fluvial and coastal flooding; domestic property subsidence

The methodology relating to the estimation of flood, coastal erosion and subsidence impacts on buildings is presented in detail in Hunt & Taylor (2006). Flood and coast impact estimates are derived principally from Evans et al. (2004). Three specific sources of damage to built infrastructure are considered: fluvial & coastal flooding; intra-urban flooding and coastal erosion. Estimation of the physical flood damage was made using the Risk Assessment for flood and coastal defence systems for Strategic Planning (RASP) system (Hall et al., 2003), which allows climate and socio-economic changes affecting flooding to be imposed on geographically mapped physical receptors on a national scale, thereby generating estimates of the number of physical units impacted by flooding. The principal drivers of the size of impacts of flood risk identified in Evans et al. (2004) included: climate change (precipitation and temperature); catchment run-off; fluvial systems and processes; flood management; human behaviour; socio-economics, and; coastal processes (including sea level rise and storm surges). For each of these drivers, Evans et al. (2004) derived multipliers to express the flood risk change relative to the non-climate change baseline, for each consistent climate change/socio-economic scenario combination.

The risks of urban flooding are assessed by up-scaling simple urban drainage models to generate national-level flood risk estimates. Insufficient data existed to apply these risk analysis methods in Scotland and Northern Ireland; a more approximate flood risk mapping exercise was undertaken for these countries on the basis of scaling up from historic event damages.

Physical flood impact data is converted into monetary terms by applying unit flood damage costs derived from the FHRC FLAIR cost database, incorporated in Penning-Rowsell et al. (2005). The database includes material costs only. The Evans et al. (2004) results for the UK for the 2050s and 2080s are used to estimate climate change impact costs for the 2020s time-slice by linear interpolation to 1995.

In order to quantify the effect of climate change on property subsidence we use historical data to regress observed monthly temperature and precipitation data against claims for building subsidence recorded by the Association of British Insurers. We then use the OLS regression results to project subsidence incidence under climate change scenarios, the building stock at risk being determined by the population and household size data derived from the UKCIP socio-economic scenarios. We do not have estimates of willingness to pay to avoid household subsidence risk; instead, we use the expenditure incurred to replace (or restore) the asset damaged as a result of climate change. A unit value of £10,000 per case of household subsidence adopted by Graves & Phillipson (2000) is used to represent the typical costs of undertaking specific remedial work in the event of property subsidence.

3.7 Biodiversity—changes in suitable climate space: selected species and habitats

Details of the methodology used in the biodiversity sectoral study are to be found in Berry et al. (2006). The authors use the SPECIES model to simulate changes in suitable climate space for selected species and habitats in the UK at the national scale, disaggregating results by region. A combination of literature review and existing SPECIES model outputs (Pearson et al., 2002), was used to identify species and habitats whose territorial behaviour could be simulated within the model. Selection criteria included: that they be of national and regional significance, sensitive to climate change, or be rare or of conservation concern in particular priority habitats. A total of 60 species and 11 habitats were selected; not all occur in each region. Model outputs are expressed in terms of percentage changes in suitable climate space. Outputs are generated for the 2020s and 2050s; estimates for the 2080s are based on linear extrapolation from the earlier time periods.

There are no willingness-to-pay studies that value changes in biodiversity as a consequence of climate change in the UK. Indeed, there is very limited data with which to value changes in biodiversity arising from any cause. Data on medicinal values of species (e.g., Bonalume Neto & Dickson, 1999) and membership of conservation groups (e.g. http://rspb.org.uk was considered. However, neither source provided data that could plausibly be applied to the type of changes in species and habitats projected under climate change scenarios in the UK.

Therefore, in order to scope the potential scale of the impact, restoration and re-creation cost data from the UK Biodiversity Action Plan (UK BAP) is utilized instead. It is assumed that where the SPECIES modeling projects a loss of climatic space for one or more species in a given regional habitat, the average percentage loss for the species considered is equivalent to the percentage of habitat that is either degraded or destroyed. The percentage loss is assumed to be the average loss over the 30-year period in each time-slice. Annual unit costs for restoration and re-creation are derived on a per hectare basis for each habitat, where possible. These unit costs are taken from the estimates of direct restoration and re-creation costs calculated for actions in the UK BAP (UK Biodiversity Group, 1998; GHK Consulting Ltd., 2006). The restoration and re-creation costs implied for each habitat using are then calculated by multiplying the estimates of the area degraded or lost by the annual restoration and re-creation costs in the UK BAP.

3.8 Water resources—economic losses to households of climate-induced water deficits

The impact of climate change on one extractive service (Public Water Supply), from the point of view of one user group (households) in two UK regions—South East England and the other in South East Scotland—is considered in this sectoral study (see Boyd & Walton, 2006 for full details). In addition, adaptation options to remove water deficits are considered: the resource costs of such adaptation options and the associated net benefits of reducing the deficits are estimated.

For each of the two case studies, the 30-year average household water deficit is estimated for each of the three 30-year time slices to 2100 under each of the four climate-socioeconomic scenarios. Whilst climate change is projected to reduce aggregate water availability and increase household demand in the UK, socio-economic change is also projected to increase household demand for water over time, resulting in net water deficits. Wade et al. (2006) model these changes to 2100.

Economic losses to households as a consequence of water supply deficits are determined using market data. Specifically, the willingness-to-pay of households for each additional unit of water along their demand curves, are estimated by applying own price elasticity of demand, η, obtained from meta-analyses of long run estimates from Espey et al. (1997) and Dalhuisen et al. (2003). Assuming constant elasticity, the demand curve is specified for household water use in each time period and used to estimate total economic losses to households in each of the two regions.

A range of adaptation options for managing public water supply are also identified on the demand and supply-sides (see Wade et al., 2006, for full descriptions of the individual options). Option employment is modeled according to cost-effectiveness, subject to their technical feasibility, (a number of the options are novel in some way and have been judged not to be available in the 2020s), and their availability under a specific socio-economic scenario. Thus, on the basis of the options available in each scenario, cost-water yield curves are constructed and applied so that the water deficit is eliminated at least cost in each time period. The economic welfare loss estimates are then combined with the resource cost estimates sequentially over time periods to 2100 to determine the annual average net benefits of adaptation in each case study region.

4 Results

4.1 Sectoral aggregate results

Table 5 summarises the monetary estimates made for each of the impacts listed in Table 2. The cost or benefit estimates are expressed as average annual values, averaged over each 30-year timeslice. The monetary estimates presented are not adjusted for growth in real GDP projected under the socio-economic scenarios. This protocol is inconsistent with the incorporation of physical aspects of socio-economic change in deriving sectoral impact cost estimates. However, it allows us direct comparison with present day economic values; inclusion of GDP growth would simply increase the average annual values by a multiple determined by the compound economic growth rate in each socio-economic scenario.

The estimates do not, generally, incorporate adaptation responses. The exceptions to this are the impacts where restoration costs have been used to proxy the welfare effects of the climate change impacts. Additionally, health estimates have built in them long term acclimatization. The costs of planned adaptation options have been separately estimated for the two regional case studies in the water resource sector. Monetary estimates of impacts in the tourism and energy sectors are expressed in terms of changes in consumer expenditures. However, no account of the associated changes in resource costs and producer surplus in these sectors has been made. Since no estimation of the gross margins (revenue minus variable costs) has been possible the data cannot be interpreted as proxies for welfare costs or benefits, and are presented separately at the bottom of Table 5.

On the basis of the results presented in Table 5 for the partial set of impacts and sectors studied, a number of conclusions can be drawn. First, both benefits and costs may result from climate change in the UK, depending on the sector and the climate change-socio-economic scenario combination considered. The most sizeable benefits are projected in the tourism, health, energy and transport (winter maintenance) sectors. Highest costs are projected in the buildings sector, particularly under the two high emission scenarios, and the transport sector (infrastructure damage in summer). The profile for flood impacts on buildings—of net benefits and net costs across the two low emission and two high emission scenarios, respectively—is explained by the influence of the socio-economic scenarios on the impacts. For example, in the low emission scenarios the corresponding socio-economic scenarios allow a pattern of spatial development more accommodating of flood risk, such that housing is located out of flood risk area or is designed to more effectively disperse flood waters from the property. As may be expected, as climate change is exacerbated, the climate change impact costs (benefits) generally exhibit an upward trend across the three time-slices, to the end of the twenty-first century, that trend being most marked in buildings and transport.

Second, in sectors such as health and energy, benefits and costs reflect seasonal-specific impacts. In both sectors, the winter benefits are found to outweigh summer costs, partly reflecting the fact that the winter vulnerabilities are greater in the non-climate change baseline. That is, just as more deaths occur in the (baseline) winter, more energy is required for heating in the winter; changes in either are therefore likely to dominate equivalent impacts in the summer. In the agricultural sector, summer rainfall is found to be the dominant climate variable determining crop yields. In the first half of the twenty-first century yields rise in the face of reduced summer rainfall, before falling significantly in the second half as reduced rainfall restricts growth, though no account is taken of projected increases in winter rainfall that may potentially offset this constraint.

Third, whilst significant additional tourist expenditures in the UK are predicted under all climate change scenarios, (Scotland and South-West England being the largest beneficiaries), these increases in expenditure in part reflect transfers from other (non-tourism) sectors to the tourist sector. Additionally, the high regional economic benefits projected suggest potentially significant strains on regional infrastructures and natural environmental resources.

This constraint has not been modeled in this exercise but suggests future research effort in this sector should be focused on quantifying the size of this type of constraint and developing cross-sectoral adaptation strategies that ameliorate the constraint.

Fourth, whilst the impacts considered are fairly evenly split between those driven by changes in mean weather variables and those driven by changes in extreme weather variables, the majority of the costs or benefits are derived from the latter, energy notwithstanding. Flood impacts are most significant, while impacts driven by 'hot summers', such as subsidence and heat stress, are also sizeable. Energy impacts are high relative to other sectors because the climate sensitivity is common to all households in the UK; all households are assumed to reduce their heating demand as winter temperature meant rise under climate scenarios.

Fifth, the results for biodiversity derived from expenditures that would need to be incurred in order to maintain and restore habitats that may be negatively impacted by climate change cannot be regarded as robust. An alternative method used by Tol (2002*a*), values global impacts on species, ecosystems and landscapes by assuming that climate change is unambiguously perceived as bad and that the actual change does not matter, though the fact that something has changed, does matter. This change is then valued by the "warm-glow" effect that arises from the fact that people's willingness to pay reflects their desire to

Table 5: Summary of the Estimated Partial Sectoral Costs or Benefits of Climate Change in the UK (£m, 2004 prices)

UK												
Sector/Impact	**Annual Average Costs (£ million, 2004 prices) (-ve denotes benefit)**											
	2020s				**2050s**				**2080s**			
	Low	M-L	M-H	H	Low	M-L	M-H	H	Low	M-L	M-H	H
Health												
Mortality - summer	<1	<1	<1	<1	2	2	2	3	3	3	4	8
Mortality - winter	-4	-5	-4	-5	-16	-8	-8	-12	-8	-8	-10	-15
Agriculture												
Crops - mean precpn. (Eng. only)	-203	NQ	NQ	-172	-68	NQ	NQ	90	49	NQ	NQ	294
Flooding (Eng & Wales)	<1	5	<1	<1	<1	11	1	-2	<1	18	2	-4
Biodiversity												
Selected species and habitats	<1	NQ	NQ	<1	1	NQ	NQ	3	NQ	NQ	NQ	NQ
Transport												
Infrastructure subsidence	<1	<1	<1	2	4	6	29	52	35	19	62	101
Flooding & coastal inundation	7	9	9	12	9	13	13	19	13	19	19	26
Winter disruption & maintenance	-26	NQ	NQ	-45	-64	NQ	NQ	-148	-102	NQ	NQ	-340
Built Environment & Cultural Heritage												
Flooding - fluv. & coastal (Eng. & Wales)	-68	-117	105	189	-170	-294	262	473	-272	-470	419	353
Flooding - intra-urban	-33	-25	92	8	-82	-62	230	23	-131	-100	368	32
Subsidence (Eng. only)	6	5	6	15	26	41	119	185	162	114	213	316
Water Resources												
Water deficit - households	*	NQ	NQ	*	*	NQ	NQ	*	*	NQ	NQ	*
	Changes in Consumer Expenditure (£ million, 2004 prices); -ve denotes reduction in consumer spend; +ve denotes increase in consumer spend											
Tourism												
Visitor Spend.	2,430	1,180	1,330	4,220	10,380	7,830	7,890	11,080	14,830	11,280	12,620	28,930
Energy												
Heating	-400	-500	-500	-500	-900	-900	-1,200	-1,600	-1,200	-1,300	-2,100	-2,800
Cooling	10	20	20	30	300	300	100	1,200	300	100	300	1,200

Notes: NQ = not quantified; * = regional case studies reported separately; black values = costs, red values = benefits contribute to a vaguely described "good cause", rather than to a well-defined environmental change. However, notwithstanding the fact that this method is similarly reliant on strong assumptions, it is not obvious whether, and what, part of the value of £35 per person per habitat Tol uses should be used in the national and sub-regional context. Only valuation studies undertaken at these scales with the involvement of well-informed populations are likely to shed light on the true welfare impacts of biodiversity.

4.2 Regional water resource case studies

The water resource case studies, conducted in two regions only, estimate: (a) the gross economic losses to households of water deficits (or supply shortfalls) resulting from socio-economic development and climate-change; (b) the resource costs of removing those deficits; and (c) the associated net benefits—i.e. the difference between (a) and (b). Table 6 presents the estimated net benefits of eliminating the projected household water deficits; it is assumed that marginal benefits of employing additional options are greater than the marginal costs of their provision. The estimated water deficits include both the influence of economic development and social change, and climate change. This is in contrast to the values reported in Table 5 which relate solely to the impact of climate change.

The analysis also explores the effect of combining emission scenarios with socio-economic scenarios different from those that would be globally consistent, but that might occur at a national level. The results suggest that there is an economic case for safeguarding households against climate change induced shortfalls in water availability. Whilst the values in Table 6 are based on medium range unit costs, additional sensitivity analyses suggest that this conclusion remains valid even if the estimated costs of adaptation are based on high range unit costs. The results are also consistent across different emission-socio-economic scenario combinations; the Global Sustainability socio-economic scenario and the Low emissions scenario slightly reduce the net benefits of adaptation.

This study, in synthesizing multi-sectoral estimates of impact costs, is the first of its kind in the UK and consequently there exist no comparable results. However, previous studies of flood impacts (e.g., DEFRA, 2001) derive impact cost estimates of the same order of magnitude—£195–£420m average annual damage for England and Wales in 2075—though comparability is limited by methodological differences with this study, specifically, assumptions of no socio-economic change and climate change scenarios represented by 10% and 20% increases in riverine flood flows. The present study does however add to and complement existing studies that estimate costs of specific weather events projected to increase under the UKCIP02 climate scenarios. For example, Subak et al. (2000) estimate the economic impacts of the hot summer and warm year of 1995 including e.g., resource savings of £355 million on energy expenditure and losses of £207 million related to agricultural livestock production. Also, ABI (2003) estimates the financial costs to insurance companies of the October 1987 wind-storms in the UK as being £2,500m.

Table 6: Estimated Annual Net Benefits of Adapting to Household Water Deficits in Case Study Regions: Medium Costs

		Net Benefit of Adaptation in EA Southern Region		Net Benefit of Adaptation in SE Scotland	
		(£ mn / yr)	(£ / HH / yr)	(£ mn / yr)	(£ / HH / yr)
GSLE	2020s	6.9	3.5	24.6	31.3
	2050s	1.4	0.6	1.9	2.2
	2080s	15.9	5.5	3.9	3.9
GSHE	2020s	6.2	3.1	30.9	39.4
	2050s	6.4	2.7	2.9	3.2
	2080s	26.0	9.0	5.8	5.7
WMLE	2020s	13.1	6.4	36.1	40.5
	2050s	27.7	10.7	8.9	8.4
	2080s	39.0	12.0	13.4	10.8
WMHE	2020s	20.2	9.8	52.2	58.6
	2050s	35.3	13.7	6.0	5.7
	2080s	39.5	12.2	13.4	10.8

Notes: "GS" = Global Sustainability; "WM" = World Markets; "LE" = Low emissions; and "HE" = high emissions.

4.3 Incidence of Impacts

Whilst the sub-national analysis is not reported in detail in this paper, key distributional impacts are highlighted in Table 7. Though it has not proved possible to estimate all sectoral impacts on a regionally disaggregated basis, the available sectoral estimates, summarized in qualitative terms in column 3 of Table 7, suggest that South-East England is most vulnerable—in part at least a function of the fact that this region is more highly populated relative to other regions. Scotland is projected to benefit from increased tourist visits, but as a consequence of its distinct habitats and species, its biodiversity is likely to be relatively vulnerable. Indeed, increased tourist numbers are likely, in practice, to further exacerbate this vulnerability. The main stakeholder groups likely to be most directly affected by the climate change impacts are also identified.

5 Limitations of the analysis

Scenario Interpretation. The research reported here serves primarily to scope out the potential extent of selected impacts, and an implied scale of adaptation response that might be required. In the majority of cases the causal link between a climate variable and an impact has been characterised by modeling the consequences of a single climate variable on a single exposure unit; joint probability variables have not been considered. Complex lagged relationships between climate variables and impacts are also not considered. It seems clear, however, that to inform many micro-scale adaptation decisions, more sophisticated analysis of this type at a sub-regional spatial resolution will be required. Similarly, with the exception of flood impacts—for which Evans et al. (2004)

Table 7: Incidence of Selected Impacts of Climate Change in the UK

	Stakeholder Group / Social Group Primarily Affected	**Regions Experiencing Significant Impacts**
	Health	
Mortality—summer	Elderly	London and South East England
Mortality—winter	Elderly	London, SE and NE England
	Agriculture	
Crops	Farmers	E. England & E. Midlands
Flooding	Farmers	SE & NE England
	Biodiversity	
Selected species and habitats	Not known	Eastern England, Scotland
	Tourism	
Visitor Spend.	Tourist service providers; transport and utility infrastructure providers	Scotland; NW England
	Water Resources	
Water deficit—households	Only households considered	Only SE England & SE Scotland considered
	Transport	
Infrastructure subsidence	Infrastructure users & providers	No regional disaggregation
Flooding & coastal inundation	Transport users	No regional disaggregation
Winter disruption & maintenance	Infrastructure users & providers	No regional disaggregation
	Energy	
Heating	Energy users and suppliers	No regional disaggregation
Cooling	Energy users and suppliers	No regional disaggregation
	Built Environment	Cultural Heritage
Flooding	Property owners in vulnerable urban areas & flood-plains; insurers	SE & NE England
Subsidence	Property owners on London & Gault Clay soils; insurers	SE England & London

report a more elaborate workshop-based process—interpretation of the socio-economic scenarios is limited to those aspects of economic development and social change for which quantitative projections are provided; the qualitative descriptions of the various components of the socio-economic scenarios have not been interpreted in quantitative terms. It is therefore likely that by restricting the interpretation of socio-economic change in this way, the baseline (future society) scenario and the associated climate impacts will be skewed. However, other research (e.g., Metroeconomica, forthcoming) on building subsidence and health impacts is inconclusive on whether there is a systematic bias one way when qualitative socio-economic variables are interpreted in quantitative terms.

Partiality of coverage. Coverage is restricted in a number of ways. First, the climate change scenarios used are derived from three models; future work should consider the outputs of a range of global and regional climate models, and include low probability-high consequence events. Second, though the selection of impacts to be explored reflected regional stakeholder interests, they constitute only a sub-set of those identified in other research (e.g., West & Gawith, 2005). It would therefore be a mistake to interpret the sectoral total costs as anything other than indicative of a proportion of the true sectoral costs. Third, data availability constrains the definition of many historical analogue-based impact functions, particularly at the regional scale. It is to be hoped that the current results will at least raise awareness sufficiently for a number of regionally based private utilities and local government offices to start to collate data that would facilitate such analysis. Fourth, in the energy and water sectors the potential scale of the impacts, combined with the fact that energy and water are important inputs to other economic activities, suggests that non-marginal impacts may occur, resulting in significant cross-sectoral impacts.

A further potentially important omission is the impact of climate change elsewhere in the world, which may have knock-on, or indirect, effects on the UK and its economy. For example, there may be global implications of large-scale, extreme weather events such as tropical cyclones and continental droughts, as well as the "socially contingent" consequences of these events (Clarkson & Deyes, 2002). Furthermore, where changes in climatic means impact upon on the availability (and price) of agricultural products and raw materials produced in other countries, impacts on the UK may be significant, depending on the share of these goods in total UK consumption expenditure, and on the availability of unaffected substitutes. Consequently, it is not informative to aggregate over the impacts to derive national or sub-national totals. Rather the estimates serve to scope the relative risks of climate change, to better inform the identification of 'hot-spots' where further micro-scale assessments and adaptation strategies could focus.

6 Conclusions

The paper presents monetized estimates of gross climate change impacts in the UK. Welfare and expenditure changes across the eight sectors considered vary according to the time period, location and scenario combination studied. For example, annual savings on energy consumption in the UK as a whole are estimated to be £390m–£470m in the 2011–2040 time period and £900m–£1.6bn in the 2071–2100 time period, depending on scenario combination; flood impacts on buildings vary from annual welfare gains of £470m to losses of £420m in the 2071–2100 time period, depending on scenario combination. Non-market values are utilized in estimating health and transport sectoral impacts.

Whilst the costs of certain adaptation options have been used as proxies for the costs of particular climate change impacts in, the transport and biodiversity sectors, the sectoral estimates are meant to be viewed as gross impacts, before adaptation is accounted for. It is clear, however, that for each impact considered there are a range of adaptation options available. The regionally-focussed water resources case study, in which the costs and benefits of eliminating the change-induced water resource shortfall were quantified, serves to show what may be possible, though the incorporation of actions within wider sectoral and cross-sectoral development strategies that have water resource implications were not considered.

The wide ranges of costs and benefits that result from the application of different climate change and adaptation scenarios in the results shown may serve to signify the relative merits of alternative paths of economic development. For example, the analysis of flood impacts indicates clear benefits for water management strategies and other sectoral strategy documents adopt specific development paths with lower climate impact costs, or higher benefits. A related point is that for those sectors, such as tourism, where baseline socio-economic change is found to be more important than climate change in determining the size of climate risks, understanding the implications of alternative paths of socio-economic development should be the first step in developing an adaptation strategy. At the same time, the findings point to other sectors, such as the built environment, where climate change is most important in determining the size of climate risk, and where therefore "hard" adaptation options (in addition of course to mitigation) may be more central to a climate risk management strategy.

6.1 Further research

There are a number of areas in which research would be most valuable can be highlighted. The first is 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. A second research priority is the modeling of cross-sectoral impacts of climate change. A shortcoming of the present analysis is that in many cases the effects on other sectors of impacts in one sector are not taken into account e.g. the impact on transport of increased tourism numbers. The recognition of these cross-sectoral linkages is vital for the realistic parameterization of impact and adaptation analysis and hence in developing effective adaptation strategies.

A third research priority arises from the fact that the analysis in some sectors—in particular, transport,—was conducted at a national level. Furthermore, results were presented, at best, at the regional scale. Local and regional planners—both private and public—in all sectors would benefit from micro-scale case studies of both impact and adaptation since climate risks and adaptive capacity and adaptation strategies could be evaluated at a more appropriate scale.

The projected impacts and costs of climate change are contingent on the level of autonomous or partial adaptation, if any, in the baseline case. However, the current state of knowledge on these forms of adaptation means that they are 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 and local adaptation strategies.

Finally, the scope of the impact coverage in this study should be complemented by qualitative and quantitative research into the climate change impacts that occur internationally but which are likely to have secondary impacts on the

UK. It is expected that climate change impacts in other countries and world regions will lead to secondary impacts that may have significant political and economic implications for the UK.

7 Acknowledgements

The UK Department for Food and Rural Affairs provided financial support through the Climate Change Impacts and Adaptation: Cross-Regional Research Programme for the project—Project E—Quantify the cost of impacts and adaptation. The many partners on that project contributed much of the technical detail in the sectoral studies outlined here, and one—Richard Tol—had previously stimulated my initial interest in this area of research. Richard Boyd and Anil Markandya have provided helpful comments on parts of earlier versions of this paper whilst two anonymous reviewers have subsequently improved it immeasurably. All errors and opinions are mine.

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