Scoping Study: Reviewing the Coverage of Economic Impacts in the CCRA

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Report to the Committee on Climate Change Adaptation Sub-Committee

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Summary

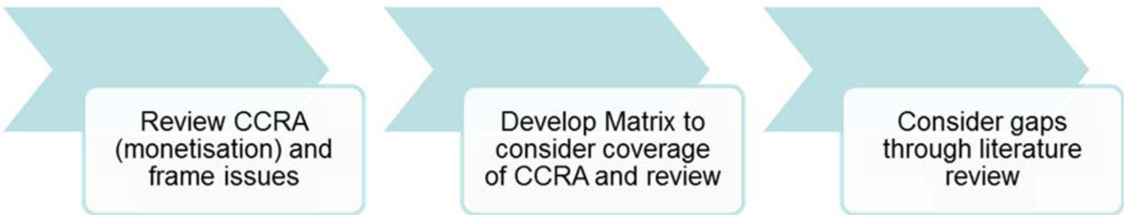
The Adaptation Sub-Committee (ASC) of the Committee on Climate Change (CCC) has commissioned this report to review the coverage of Economic Impacts in the UK Climate Change Risk Assessment (CCRA).

The CCRA has undertaken a monetisation exercise and has valued around 100 individual Tier 2 risks. These results provide important information on the size of the domestic risks to the UK from climate change and the scale of the challenge for adaptation. However, the quantified economic results from the CCRA show relatively modest impacts when expressed in net economic terms. This arises because of the UK's temperate climate, but also because of the boundaries set for the CCRA, i.e. due to the coverage of the analysis.

The focus within the CCRA has been consistent with the responsibilities set out in the Climate Change Act, and with the most obvious starting point for a domestic risk assessment. However, the CCRA itself – and other commentary – recognises that there are additional risks relevant to the UK, which the UK needs to adapt to. These additional risks are important in communicating the overall messages of the CCRA to policy makers and end users, particularly when reporting economic values. Furthermore, as part of the CCRA lessons review, it is useful to consider what these additional risks are, to consider what could (or should) be included in the next CCRA (i.e. CCRA2).

Against this background, the CCC has commissioned a rapid review to identify these additional risks and scope their potential scale. It is stressed that the study has used existing information to assess these gaps, rather than undertaking new analysis or detailed review. It has also focused on the economic cost coverage, to communicate the potential scale.

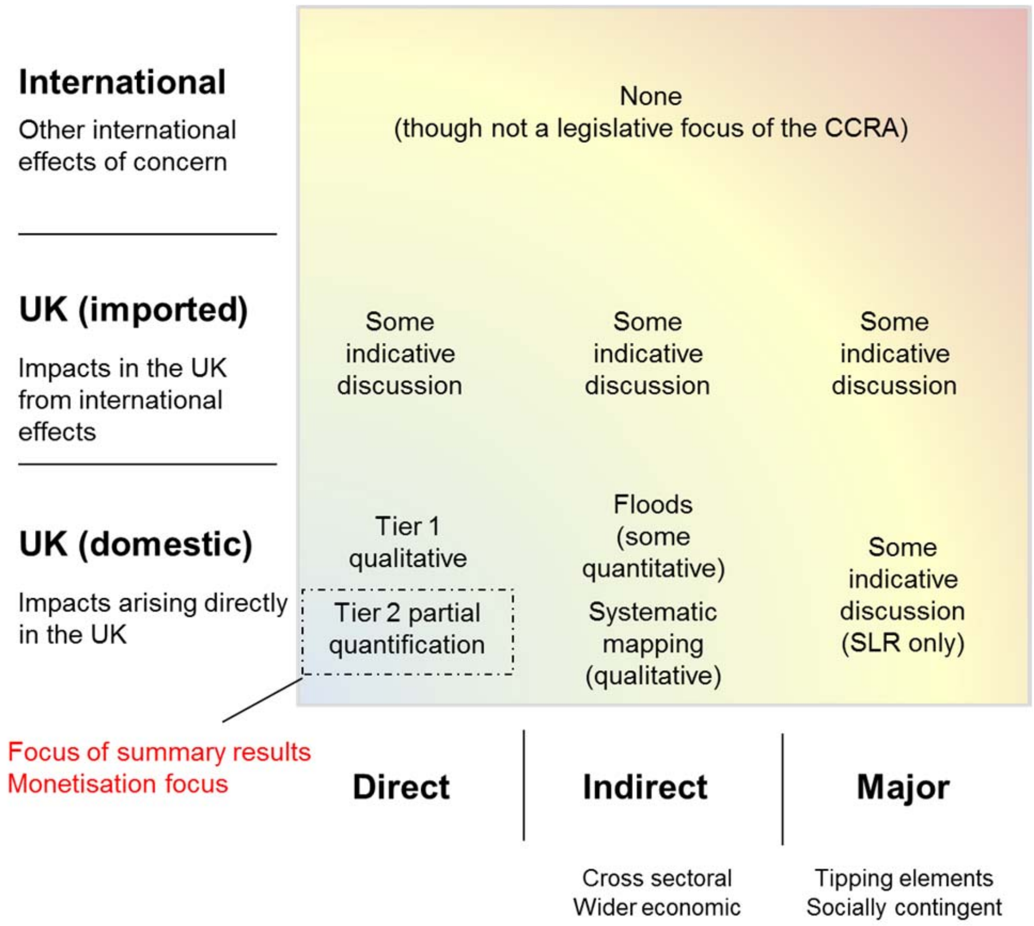
The study has started with a review of the CCRA results. It has then developed a matrix for assessing the coverage of the economic costs of climate change, and has mapped the CCRA against this matrix. Finally, it has reviewed the literature to explore the potential size of the gaps in the CCRA quantitative coverage. The study outline is shown below.



The matrix developed assesses the various risks from climate change to the UK, splitting these into direct effects (primary), indirect effects (cross sectoral or wider multiplier effects), and major effects (catastrophic or tipping elements), the latter including risks that are not captured by the UKCP09 projections or that may arise post 2100.

It then considers the geographical domain of the risks, i.e. whether these effects occur directly in the UK, whether the effects occur at the international level and then subsequently impact on the UK (i.e. they are imported into the UK), and a final wider category that captures the broader international concerns of global climate change, which might not lead to effects in the UK, but are relevant to the UK in the context of international policy, development, security, etc.

The coverage of the CCRA quantitative and economic results have been mapped against this matrix. The results are shown below.



In summary, most of the quantified analysis in the CCRA (and the summary results) is focused on direct UK domestic impacts, shown in the bottom left-hand corner of the matrix, and the monetisation exercise is almost exclusively focused on this area. This focus is to be expected: the direct risks are an obvious priority for the first CCRA, and are the main area of concern in relation to the Climate Act. They are also likely to represent many of the priorities for early adaptation in the UK. Nevertheless, while the UK CCRA has consistently assessed a very large number of direct risks - one of the major advances of the study - the assessment and monetisation is inevitably partial: the quantified analysis could not cover all the 600 or so Tier 1 risks (though many of these would be expected to be low); the analysis has often used single rather than multiple climate impact functions; it has not been able to fully take account of all possible threshold effects (due to lack of underlying evidence); and the assessment has not factored in the influence of the speed of change for higher scenarios.

These omissions might all be expected to increase the economic costs of climate change for the UK, though it is difficult to know how important they might be (though the CCRA estimates did not include autonomous adaptation, nor many planned adaptation measures, both of which would reduce costs). These omissions are not a criticism of the CCRA– which has covered a more comprehensive set of risks than many international studies and addressed the risks of most obvious direct importance – but it is simply a recognition that assessing a large number of risks is challenging.

It is also noted that the CCRA results reported in the summary and synthesis reports have focused on central trends (the p50 from the medium scenario) and this implies UK risks (and economic costs) are more modest than suggested by the analysis of the distribution of effects (i.e. the p10 to p90). While this additional information on the distribution is included in the main sector and evidence reports, it would be useful for future CCRAs to bring these aspects into the summary results.

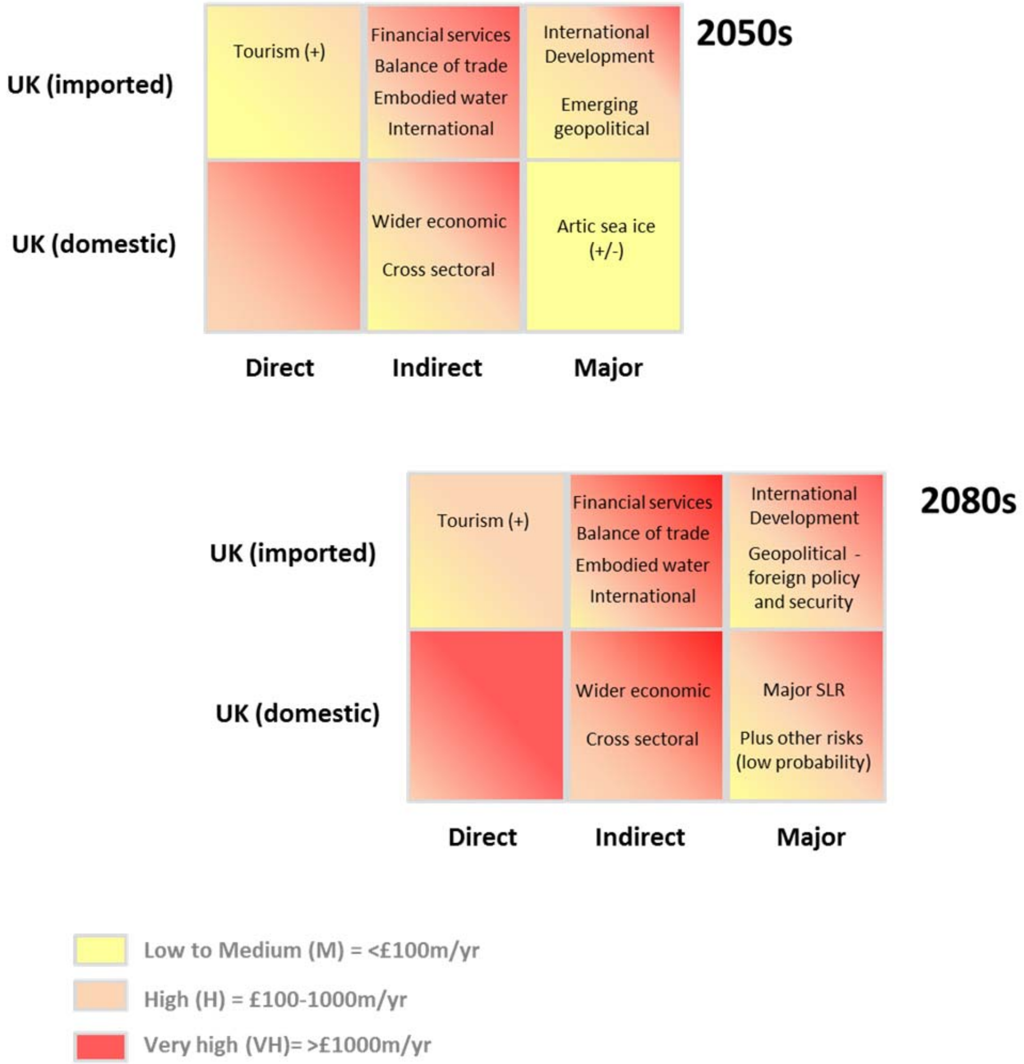
Looking to the rest of the matrix, the coverage is much lower in the CCRA. It is highlighted that all of the other areas of the matrix involve very complex issues, that there is a lack of evidence for quantitative analysis, and that the coverage reflects the low levels of underlying evidence in risk assessment and climate modelling in these areas. It is also stressed that the CCRA did acknowledge many of these wider risks across the matrix in qualitative terms, reporting the available information. However, while it is not expected that the first CCRA would be able to address all of these wider effects, it is important to recognise their omission when interpreting the quantified CCRA results, to make sure these effects are not overlooked. Indeed, much of the wider literature highlights that the other areas of the matrix could be a very large risk driver for a temperate country such as the UK.

The study has then gone on to review the literature to investigate the scale of the gaps in the rest of the matrix. Overall, the study finds that the information on the rest of the matrix – especially in terms of economic information – is sparse. Nonetheless, the review does reveal the potential importance of these effects.

- For indirect (cross-sectoral) effects the available literature indicates significant additional economic costs are likely, which may be of a similar order of magnitude to direct effects. At the same time, there is also the potential for some dampening effects from autonomous market driven adaptation that have the effect of reducing aggregate economic costs measured by GDP.
    - As well as highlighting their potential economic importance, these indirect effects are important because cross-sectoral adaptation responses may be both more effective and efficient than sectoral-based responses only.
    - In relation to international effects, the available literature indicates that in certain contexts, these risks are likely to be high. The increasingly globally integrated nature of UK economic activity, for example in commodity trade and financial services, exacerbates these risks particularly where the most significant global climate risks coincide with areas of current and planned market expansion, such as South and East Asia, Africa and South America. A specific issue on imported embodied water has also been identified by the review.
    - As well as greater attention to risk management in these areas, pre-emptive international development support is likely to reduce risks associated with regional political and strategic stresses resulting from migration and conflict. National level adaptation strategies need to ensure these risks are considered.
- For major (catastrophic) events, the very limited evidence suggests that major sea level rise is an important long-term risk for the UK. These risks involve more uncertain elements, but high economic costs. As an example, the economic costs of >1 m of sea level rise would significantly increase flood costs (the largest direct cost reported in the CCRA) to potentially > £10billion/year. Moreover, these risks are already beginning to be considered in adaptation planning, thus they warrant a more explicit consideration within future CCRAs as a whole.

While this initial study can only be considered indicative, especially as such a small body of literature exists, the review findings indicate that each of these categories could be very sizeable, and when combined, they would be of at least the same order of magnitude as the direct domestic effects captured in the CCRA. The possible severity of a selection of the likely major gaps over time is illustrated in the figure below. The figure shows the possible size of future risks across the matrix, focusing on UK specific elements. It is stressed that the estimates are indicative only, and reflect the limited available evidence found in this study. The relative size of the economic costs is indicated by the colour shading, the gradient reflecting the fact that effects will vary across the UKCP09 projections and will vary in likelihood and magnitude.

Possible Severity of Climate Change Risks to the UK: "Indicative Estimates"



Note the existing CCRA economic estimates are included in the bottom-left hand cell. Other cells present indicative estimates for the relative economic importance of the additional areas not captured in the CCRA.

The key conclusion (and recommendation) from the study is that the other areas of the matrix include risks to the UK that should be included in the next CCRA (i.e. CCRA2).

However, in order to allow these risks to be assessed, there is a need for early research to provide the evidence base to allow a more considered, and especially a quantitative analysis, of these risks. A number of such priorities are highlighted in the report - with analysis in the short term and into the next CCRA. In general terms these include:

- The development of a consistent set of impact scenarios applied to international areas of concern for the UK to allow quantitative risk assessment;

- The consistent application of impact modelling in non-linear, global and regional bio-physical systems to, in order to better incorporate tipping points in risk assessments;

- Investigation of the limits to adaptation and the resulting relative roles of adaptation and mitigation in UK, given new knowledge of the risks associated with tipping elements.

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Report submitted to the Committee on Climate Change Adaptation Sub-Committee, June 2012.

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We are extremely grateful to comments from the ASC members and from the external reviewer, Dr Nicola Ranger from LSE. It is stressed that the discussion here – and any errors – are the responsibility of the authors.

1. Introduction

The UK Climate Change Risk Assessment (CCRA) represents a key part of the Government's response to the Climate Change Act 2008, which requires a series of assessments of climate risks to the UK, both under current conditions and over the long term.

The CCRA has compared over 100 impacts (prioritised from an initial list of over 700), based on the magnitude of the impact and confidence in the evidence base. It has used a consistent method and a consistent set of climate projections from UKCP09 to look at current and future risks and opportunities.

The CCRA has also undertaken a monetisation exercise and has valued the 100 or so risks (known as the Tier 2 risks). This valuation exercise provides information on the relative significance of different risks, within and across sectors. A number of the most important risks are now being assessed in the Economics of Climate Resilience (ECR) study, which is considering the potential costs and benefits of adaptation.

The CCRA monetisation results provide important headline results from the CCRA, and useful information on a number of issues, many of which have direct policy relevance. These include:

- Communicating the scale of the economic costs of climate change in the UK;
- Providing information and communicating the size of impacts between and across sectors;
- Indicating the possible scale of the challenge for adaptation;
- Providing information – which considered alongside other areas - helps to highlight the economic benefits of domestic mitigation.

However, because of the interpretation of the statutory obligations in the Climate Change Act, the study boundaries set by Defra, other on-going work undertaken by Government, and the availability of evidence, the CCRA has not assessed the full risks of climate change to the UK. It therefore does not quantify (or monetise) all of the possible risks from climate change to the UK. It is stressed that this omission is not a criticism of the CCRA, but rather a reflection that the first CCRA has rightly focused on the immediate domestic risks of climate change.

Nevertheless, whilst the CCRA includes a very broad analysis – more so than many other previous studies – the quantified analysis, summary results, and the monetisation have a relatively narrow focus when compared to the broader set of climate risks addressed by many other climate change risk studies.

There is therefore the potential that the CCRA results and monetisation values could be misinterpreted. In the absence of additional information on wider vulnerabilities and risks, the CCRA could wrongly be taken to imply that overall risks of climate change in the UK are relatively low, or that adaptation should not be a priority for Government policy or should be left to happen autonomously. Previous literature has shown that such an interpretation would be misplaced, and there are very important international and major risks (CCC, 2008), as well as a very strong need for adaptation as identified by the Committee on Climate Change (CCC, 2010). These additional areas are also relevant when considering the benefits of the low carbon transition for the UK.

Against this background, the Adaptation Sub-Committee (ASC) of the Committee on Climate Change (CCC) has commissioned a rapid review to investigate and scope these additional issues, reported in this paper. One of the main aims of this work is to provide an input to the CCC CCRA lessons review, in order to outline what these additional risks are, and to help consider future recommendations for what should be included in the next CCRA (i.e. CCRA2).

It is stressed that the study has aimed to scope out the gaps using existing information, rather than undertaking new analysis or detailed review. It has also focused on the economic cost coverage, to communicate their potential scale.

The study has started with a review of the CCRA results. It has then developed a matrix for assessing the coverage of the economic costs of climate change, and has then mapped the CCRA against this matrix. Finally, it has reviewed the literature to explore the potential size of the gaps in the CCRA quantitative coverage. The study outline is shown below.

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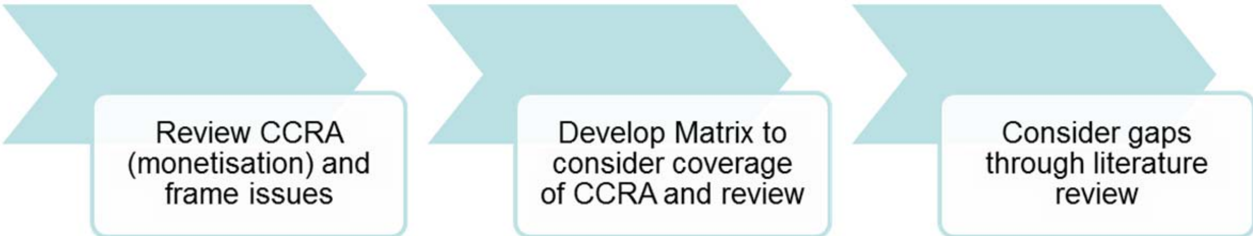


Overview of the Study.

The report is set out as follows:

Chapter 2 provides a high level summary of the CCRA monetisation results.

Chapter 3 provides a framework and matrix to assess and map the coverage of the CCRA.

Chapter 4 provides a rapid review of the potential gaps in the matrix.

Chapter 5 provides some initial recommendations and research priorities.

2. Summary of the CCRA monetisation results

Aggregated monetary risks

The purpose of the valuation step in the CCRA was to express the identified Tier 2 risks and opportunities in monetary terms, as far as possible. This provides one way to help assess the relative importance of different climate change risks in the UK, providing a common metric to compare direct impacts within, and between, sectors.

The approach considered costs from the perspective of social welfare, as measured by individuals' preferences using a monetary metric, generally expressed through willingness to pay to avoid the risk. This approach captures a range of market and non-market costs and benefits to society, including some environmental and social impacts.

The monetisation method used inputs of physical impacts from the Tier 2 quantitative or semi-quantitative analysis (e.g. kWh of energy used for cooling, number of health impacts, etc.). It converted these impacts to monetary values using unit costs corresponding to the metrics of physical impacts, within a partial equilibrium analytical framework.

The monetary unit values and overall approach were based on the guidance in the HM Treasury Green Book and Supplementary Guidance[1]. The analysis also used the costing guidance specific to climate risks developed for UKCIP by Metroeconomica (2004) and relevant economic appraisal guidance and values used in individual Government Departments. Where quantitative risk data were not available, informed judgement and scoping analysis were used by the CCRA team to estimate the potential order of magnitude of risks.

It is stressed that for some categories, notably biodiversity and ecosystem services, the application of such valuation approaches is challenging. Whilst progress has been made in recent years, the values available can only be considered to be very partial, and this limitation is emphasised in the reporting of the results.

The values were presented in constant 2010 prices for the three time periods considered (2020s, 2050s, and 2080s), without any adjustments or discounting. The results were presented in this way to facilitate direct comparison, over time, and between sectors. However, the study stresses that use of these values in subsequent policy analysis (e.g. in looking at the costs and benefits of adaptation to reduce these impacts), would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal).

The monetary values presented in the CCRA evidence report are generally given for projections of the Medium Emissions Scenario, for the central estimate (p50) for the 2050s, in line with the general reporting of summary values. These are mostly with no socio-economic change (i.e. they reflect the economic costs of the marginal change from climate change alone), although for some categories there is inclusion of population change. The headline reported economic values in the Evidence Report (HRW, 2012) are shown in below (Figure 9.5 in the Evidence report).

[1] http://www.hm-treasury.gov.uk/data_greenbook_supguidance.htm

Code	Risk	2020s	2050s	2080s
FL6a	Residential properties at significant risk of flooding	-H	-H	-VH
FL7a	Non-residential properties at significant risk of flooding	-H	-H	-VH
AG1b	Changes in wheat yield (due to warmer conditions)	+H	+H	+H
BE9	Reduction in energy demand for heating	+H	+H	+VH
AG1a	Changes in sugar beet yield (due to warmer conditions)	+M	+M	+M
WA5	Public water supply-demand deficits	+M	-H	-H
BD2	Risks to species and habitats due to coastal evolution	-M	-M	-H
BD7	Risks to coastal habitats due to flooding	-M	-M	-H
BE2	Increased subsidence risk due to rainfall changes	-M	-M	-M
FL14a	Agricultural land lost due to coastal erosion	-M	-M	-M
FL4a	Agricultural land at risk of flooding	-M	-H	-H
BU8	An expansion of tourist destinations in the UK	+H?	+H?	+H?
HE6	Decline in winter morbidity due to higher temperatures	+H	+H	+VH
HE5	Decline in winter mortality due to higher temperatures	+M	+M	+H
EN3	Heat related damage/disruption to energy infrastructure	-L/M	-L/M	-L/M
FL15	Flood risk for Scheduled Ancient Monument sites	-L	-L	-M
FO1a	Forest extent affected by red band needle blight	-L	-L/M	-M
HE1	Summer mortality due to higher temperatures	-L	-M	-M
HE2	Summer morbidity due to higher temperatures	-M	-H	-H
HE4a	Mortality due to summer air pollution (ozone)	-L	-L	-M
TR1	Disruption to road traffic due to flooding	-L	-L	-M
BE3	Overheating of buildings	-M	-M	-H
EN10	Energy transmission efficiency capacity losses due to heat - over ground	-M	-M	-M
EN2	Energy demand for cooling	-M	-H	-H
FL11a/b	Power stations/sub-stations at significant risk of flooding	-M	-M	-M/H
FL12a/b	Hospitals and schools at significant risk of flooding	-M	-H	-H
HE3	Extreme weather event (flooding and storms) mortality	-M	-M	-M
HE7	Extreme weather event (flooding and storms) injuries	-M	-M	-M
WA7	Insufficient summer river flows to meet environmental targets	-H	-H	-H
BD3	Risk of pests to biodiversity	-L	-M	-M
BD4	Risk of diseases to biodiversity	-L	-M	-M
BD5	Species unable to track changing 'climate space'	-L	-M	-M
BD9	Changes in species migration patterns	-L	-M	-M
BD10	Biodiversity risks due to warmer rivers and lakes	-L	-L	-M
BD11	Generalist species more able to adapt than specialists	-L	-L	-M
BD12	Wildfires due to warmer and drier conditions	-L	-L	-M
BU1	Climate risks to investment funds	-H?	-H?	-H?
BU9	A decrease in output for businesses due to supply chain disruption	-M	-M	-M
BU10	Loss of staff hours due to high internal building temperatures	-H	-H - VH?	-H - VH?
MA3	Increased ocean acidification	-L	-M	-M
MA2a	Decline in marine water quality due to sewer overflows	-L	-M	-M
MA2b	Risks of human illness due to marine pathogens	-L	-M	-M
MA5	Opening of Arctic shipping routes due to ice melt	+L	+M	+M
MA6	Distribution of marine alien/invasive species	-M	-M	-H

Confidence

Range of potential magnitude (all estimates) and time of onset (Medium emissions scenario, central estimate) for those risks considered important from an economic perspective (See notes)

Cost	
-L	Low (£1-9m/yr)
-M	Medium (£10-99m/yr)
-H	High (£100-999m/yr)
-VH	Very high (£1000m/yr+)
?	Uncertain

Benefit	
+L	Low (£1-9m/yr)
+M	Medium (£10-99m/yr)
+H	High (£100-999m/yr)
+VH	Very high (£1000m/yr+)
?	Uncertain

Confidence (including valuation)	
	High
	Medium
	Low
	Very low

Guide on interpretation of Figure 9.5

In Figure 9.5 the confidence ranking is modified further to include the valuation step and as such the confidence score is low in most cases. There are also many assumptions and caveats related to this figure.

- Values are presented in current prices, for the central projection.
- Some results are presented for a scenario of future climate change only, whilst others include climate change under assumptions of future socio-economic change.
- In some cases the magnitude of the impact (or opportunity) changes across the full UKCP09 projections (the p10 to p90 range) and in some cases even changes in sign.
- Care must be taken in aggregating risk categories, as there are some overlapping impacts, and thus the risk of double counting at the UK level.
- Furthermore, it is stressed that these results do not include autonomous adaptation, and in general, do not take account of existing planned adaptation measures.
- The list of possible impacts is partial, Further, consideration of the range of scenarios – and the range of estimated levels of future climate change – include much higher economic costs associated with higher rates of changes, non-linear increases, and exceedences of threshold levels.
- Finally, these current estimates do not include consideration of the economic costs of climate change overseas, and how these might affect the UK, or the potential economic costs of major events post 2100.

All of these issues are critical to the assessment of the overall aggregate costs of climate change in the UK.

A number of key points emerge from the headline economic values – reflecting the underlying quantification and summary results of the CCRA.

- Only flooding is identified as being a major risk with "high" consequences and high confidence in the 2020s (i.e. > £100 million/year)[2]. There are a number of other potential high risks (e.g. impacts on climate fund/fund management, working hours lost to high temperatures, river flow quality), though with greater uncertainties attached to them.
- Flooding is the only risk that has "very high" consequences with high confidence even by the 2080s (> £1 billion/year).

Note that in some cases certain risks potentially overlap. An example is that there is energy use for building cooling (quantified as an autonomous response - and impact - in the energy sector), and

[2] Flooding is a major risk today and the annual spend on flood risk management is approximately £600 million. Consequently, this risk has been well researched and there is a strong body of evidence underlying the assessment. There is inevitably an element of bias towards a risk that is well "measured" over those that have been less well studied.

building overheating and productivity loss or additional health risks (considered in the business, buildings and health sectors)[3].

Further, a number of the risks have positive and negative effects across the annual seasons. If expressed in net terms, i.e. the sum of positive and negative, the overall economic costs are reduced. For example, the reduced demand for energy for heating in winter balances against the increased demand for energy for cooling in the summer. In this case the analysis suggests a net positive effect in economic terms i.e. the reduced total cost of heating outweighs the increased cost of energy for cooling and highlights this as an opportunity[4].

The results indicate that the net economic costs to the UK are of the order of tens of billions/year by the 2050s (in current prices) for the Medium emissions, median (p50) estimates. However, there are a large number of caveats to this interpretation. In reality, the median values shown in the Figure above very significantly understate the full extent of risks – and thus the potential scale of adaptation required. This is because:

- The valuation focus reflects the underlying level of physical risk quantification. The impacts only cover the Tier 2 risks that could be quantified: it does not cover the full range of Tier 2 risks, or the full much longer list of Tier 1 risks (an additional 500 or so risks). The economic valuation of risks is therefore partial and can only be considered a sub-total of possible direct risks.
- In many cases the range across the full UKCP09 projections, i.e. the p10 to p90 range of the low to high UKCP09 scenario, can significantly alter the magnitude of the impact, and in some cases even change the sign. The summary results reported (for the main threats and opportunities to the UK, for the quantified analysis, and for the economics) are mostly reported for the p50 medium scenario, thus they provide an indication of median central trends, not the full range of risks, or mean values (see below).
- Related to the point above, the CCRA analysis has predominantly used linear functions and applied these across the range of climate outputs. Such an approach does not take account of the rate and speed of change, which would be expected to dramatically alter the functional form and the level of economic costs. To illustrate, the projections for the UK include increases in summer temperature of between approximately 1 and 8°C in the South East of England by the 2080s: clearly, the rate of change and the level of damages for an 8°C summer would be very different, and it would also infer much greater levels of adaptation (including relative adaptation costs, due to the need to act more rapidly).
- For several impacts, there are potential threshold effects, i.e. where a linear marginal model does not capture the level of change. The CCRA has assessed the Tier 2 risks for potential threshold effects, but these are not included in most of the quantified analysis, and these thresholds do not come across in the presentation of medium scenario p50 results.
- Some of the benefits are considered to be a little optimistic, notably the analysis of agriculture, because the analysis has focused (in this case) on a single climate parameter. Other studies give a much wider range of changes that include potentially negative impacts for such categories.

[3] Additional energy use for cooling would reduce productivity losses or reduce health risks, thus in practice, there will be some element of interaction between these two categories and they are not additive.
[4] There are also positive and negative health impacts associated with reduced cold (positive) – and increased heat (negative) - though in this case a simple aggregation of positive and negative effects across the year is inappropriate.

- Most results are presented for a scenario of future climate change only, rather than under assumptions of future climate and socio-economic change together, which usually leads to higher impacts (e.g. see Evans et al, 2004).
- However, these estimates do not include autonomous adaptation and, in general, do not take account of existing planned adaptation measures, thereby potentially overstating actual risks.

It is difficult to know how much these issues affect the outcomes of the CCRA, and the overall scale of the economic costs. With the exception of the final point, all of the issues above might be expected to increase the economic costs of climate change. However, it is difficult to know – or even speculate on the potential effects these factors would have on the overall monetised results.

It is acknowledged that all of the points above involve very complex issues, which are difficult to assess quantitative, and which reflect emerging evidence in risk assessment and climate modelling. It is not expected that the first CCRA would be able to address all of these issues, but it is important to recognise their omission when interpreting CCRA results.

It is also acknowledged that many of these issues above are discussed in the detail of the CCRA analysis (in the sector reports and the detail of the Evidence themes). However, they do not come through as strongly in the Evidence summary information and summary reports.

This reflects an important issue of the communication. It is very difficult to succinctly report a large number of results from the range of climate scenarios, the distribution of climate model projections, and from the additional effects of socio-economic projections. For each of the later time periods (the 2050s and 2080s), the reporting of the p10, p50 and p90 from the low, medium and high UKCP09 projections alone involves nine separate outputs for each time period[5].

Some form of summary and synthesis is therefore inevitable. However, the reporting of the main CCRA results (e.g. in the Act report, the main summary report, and the Evidence report summary) does this through the presentation of the central trend, i.e. the p50 medium This does not fully capture risks, and it also has the effect of making the overall impacts of climate change in the UK appear more benign. While the upper risks are captured in the Evidence reports - in the analysis in the scorecards (see below) - the overall summary results do convey uncertainty. This has important issues for the interpretation of the results for adaptation (and for mitigation), discussed briefly below.

The Median, Mean and the Distribution of the CCRA Results

The UKCP09 projections have provided a very rich source of climate information, which has been used in the CCRA. As highlighted above, while this provides many benefits, it also provides new challenges, in the form of communicating this information to policy makers.

A critical issue for any risk assessment is how to capture, report and use the information from a detailed risk information. In the case of climate change, this involves some particularly important areas, because of the uncertainties involved, and because of the way that risks may change across

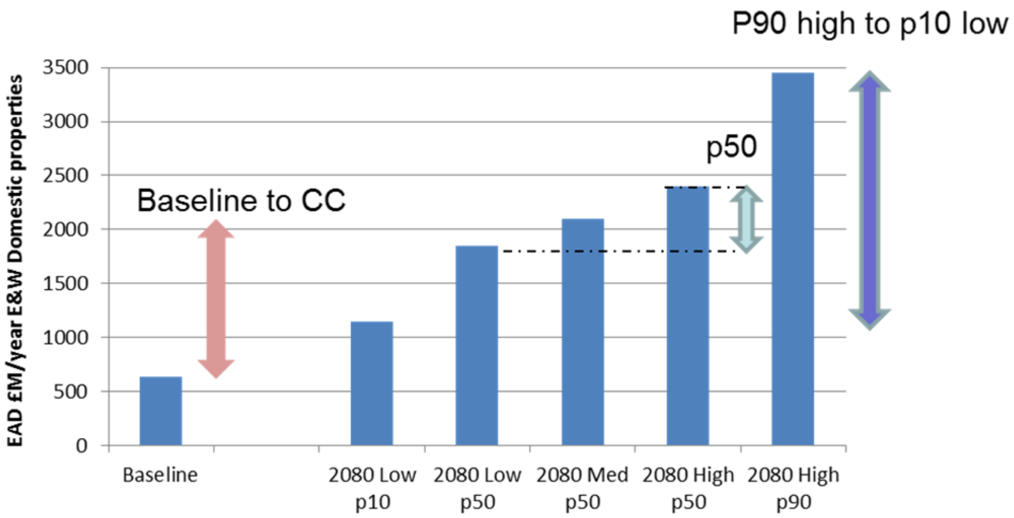
[5] The CCRA sector reports tried to address this by focusing on five outputs (p10, low, p50 low, p50 medium, p50 high, p90 high), but it was not possible to report these in a single summary.

the distribution of future climate scenarios and model projections. This is extremely important in the context of the economic analysis. It is also extremely important for subsequent policy use and interpretation of the overall results.

To illustrate this issue, this study has taken the example of flood risks. Looking at the aggregated economic results above, the most important impact is flooding, captured through metric FL6 and FL7 of EAD (Expected Annual Damage), which combines the river and coastal flooding for residential and non-residential properties. The results are shown below for FL6 (residential flooding), looking at the effects of climate only (no socio-economic change), with the 2080 values plotted in the Figure.

Table FL6b_01 - EAD to residential property at risk due to tidal or river flooding including climate change (£ millions)

		2020s			2050s					2080s				
Nation	Baseline	Medium p10	Medium p50	Medium p90	Low p10	Low p50	Medium p50	High p50	High p90	Low p10	Low p50	Medium p50	High p50	High p90
England & Wales	639	750	1,100	1,600	900	1,400	1,600	1,800	2,450	1,150	1,850	2,100	2,400	3,450
Wales	105	120	140	180	120	160	180	200	220	150	200	210	230	260



Expected Annual Damage (£Millions/year) Risk Metric FL6b residential properties at risk due to river or tidal flooding (England & Wales): With climate change only. 2080s

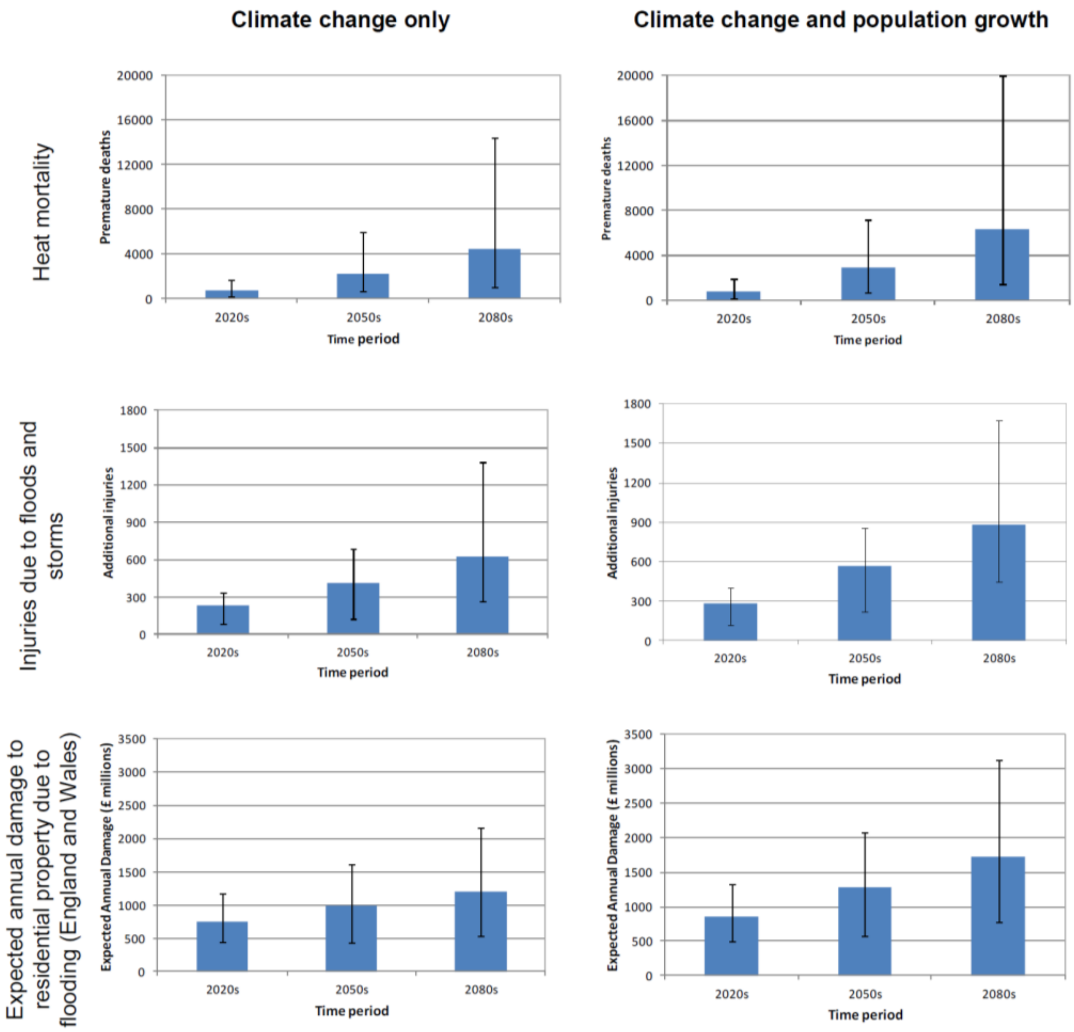
This shows that the median values (p50) for all three UKCP09 scenarios are relatively small. However, when the distribution across the projections is considered, e.g. the p10 to p90 range, there are clearly much greater risks involved which involve a significant step change from the median projections (note also that the p90 value for the medium scenario also shows a similar trend).

This is an important issue in communicating the economic results, in risks more generally, and in the consideration of adaptation responses. It is a point which is partly recognised in CCRA Evidence Report which states

Both the anticipated rates of change and the level of uncertainty are important characteristics in the context of monitoring potential climate risks and adaptation outcomes (an ASC objective). In addition, risks with relatively fast anticipated rates of rise, like overheating in urban environments, may be regarded as higher priority for action'.

The Evidence report captures with the example of health

'For the metrics shown this figure [see below] *also highlights the relative importance of the uncertainty when set against the absolute level of risk. Taking the top and bottom plots as an example. For heat mortality the variability in the projected risk across all the different scenarios considered, as indicated by the black error bars, is very large, particularly as a proportion of the central estimate for Medium emissions (the blue bar)'.*



Results for selected risk metrics with rapid to slow rates of long term increase in risk

Source Evidence Report

However, this raises an important issue of reporting the central tendency across much of the CCRA.

This is an issue that has arisen in the context of the global economic costs of climate change (see Watkiss et al, 2006: 2011). The figures above show a strong skewed nature for climate change risks, i.e. with potentially very large economic damages from the ends of the distribution (e.g. from the p90). This means that mean values are much higher than median values.

This issue has been demonstrated in the analysis of the social cost of carbon (SCC, the marginal social cost of a tonne of GHG emitted). A meta-analysis of the SCC study values (Tol (2005) revealed a median value of $14/tC but a mean value of $93/tC.

The key implication of this is that the reporting of p50 results is likely to underestimate the central outcomes of climate change as part of the CCRA.

The CCRA does capture this fact through the use of the full range of outcomes, as described in the Evidence Report.

Box 2.3 Climate scenarios used in the CCRA method

The CCRA made use of UKCP09, including the underlying RCMs[31], the probabilistic projections[32] and, in a small number of cases, the Weather Generator[33]. Further details describing UKCP09 are included in Annex A and can be found on the UKCP09 projections web site, which provides an updated Science Report and further guidance. The following climate scenarios were used when the probabilistic projections were considered in the assessment:

- 2020s: **p10 Medium, p50 Medium, p90 Medium**;
- 2050s: **p10 Low**, p50 Low, **p50 Medium**, p50 High, **p90 High**; and
- 2080s: **p10 Low**, p50 Low, **p50 Medium**, p50 High, **p90 High**.

These changes in climate were used to define a plausible range of outcomes for each time period **and were not used as probabilities** (Box 2.4). Instead, the scenarios in **bold** were used to define the 'UKCP09 range.' The naming convention above is used in Chapter 3 on the biophysical impacts of climate change but thereafter they are referred to as Lower, Central and Upper estimates for describing the potential risks for UK society.

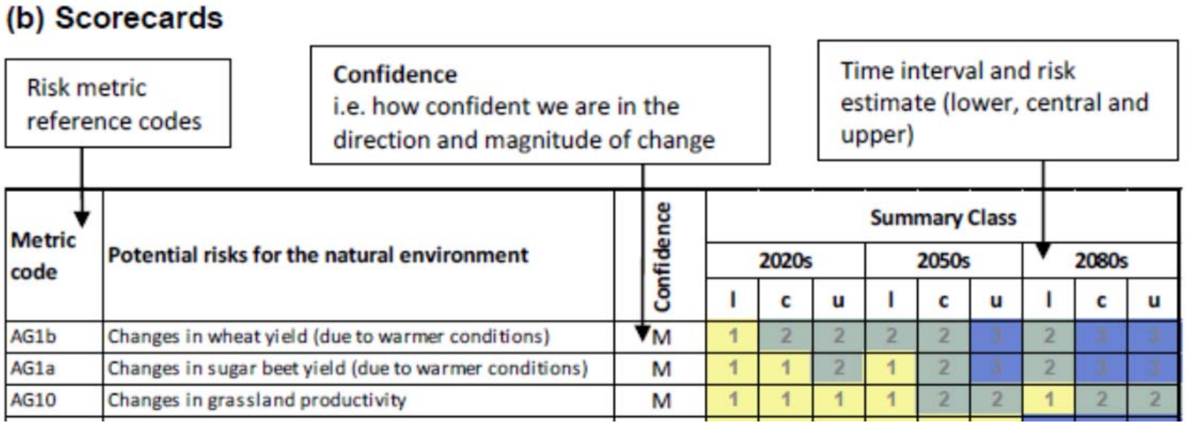
When the RCMs or Weather Generator outputs were considered a similar approach was taken that aimed to capture a reasonable range of possible changes in climate. Full details of the methods used are included in individual sector reports and some further information on UKCP09 is provided in Annex A. The choice of climate model was one factor that affected the level of confidence assigned to each individual risk metric (Box 2.5).

The UKCP09 range considered does not cover the full possible range of climate changes, but provides a consistent framework for this assessment. When these are combined with socio-economic changes the range of uncertainty increases significantly.

	Low Emissions			Medium Emissions			High Emissions		
	p10	p50	p90	p10	p50	p90	p10	p50	p90
2020s				L	C & X	U			
Range				←Range→					
2050s	Lx	X	x	X	C & X	x	x	X	xU
Range	←				Range				→
2080s	Lx	X	x	x	C & X	x	x	X	xU
Range	←				Range				→

Note that the Evidence report uses the convention of **Lower, Central and Upper**, to reflect p10 low, p50 medium, and p90 High. These are included in the scorecards, as shown below[6]. Further, the information on the range is included in the CCRA sector reports. However, to the uninformed reader, the implied range of values may not be obvious.

[6] The health sector analysis captures uncertainty by plotting low –high lines on graphs – but other sectors are not presented in this way.



Metric code	Potential risks for the natural environment	Confidence	Summary Class 2020s l	c	u	2050s l	c	u	2080s l	c	u
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
AG10	Changes in grassland productivity	M	1	1	1	1	2	2	1	2	2

A second issue here is in relation to a point raised in the bullet points above, on the shape of the damage functions, in absolute terms, and in terms of the rate of change. The depth damage functions used for flooding assessment – and many (though not all) of the functions used in other Tier 2 risk analysis - are based on linear functions or near linear functions.

There is growing evidence that these assumptions are unlikely to hold true across the full range of climate projections. In recognition of this, the damage functions used in the global economic Integrated Assessment Models mostly use a quadratic functional form for relating climate change to damage costs (Staunton et al, 2009), recognising that climate impacts will be non-linear (IPCC, 2007).

This fact, and the issue that the rate of change associated with the higher levels of climate change (e.g. for a p90 scenario), has the effect that the high (e.g. p90) results of climate change in the CCRA are likely to be underestimates, which amplifies the issue raised above.

Of course, this is not a criticism of the CCRA: it has based its analysis on the available evidence and this is an area that is still emerging, but it has very important implications for communicating the range of risks, and also for possible adaptation planning.

Thresholds

Closely related to the issue above are potential thresholds. The discussion of major global thresholds is considered in a later section - the focus here is on possible thresholds for the damage functions and impacts considered in the CCRA.

This is an issue that was recognised in the CCRA. Earlier versions of the Evidence report did assess and report on thresholds, but these were not included in the final version. Nonetheless, specific sectoral summarises to recognise the issue: as an illustration, the CCRA Evidence Report states that for biodiversity:

'Due to the inherent complexity of ecosystems and non-linearity of many of the responses to climate parameters, it is difficult to assess the magnitude of future risks to biodiversity with any certainty'.

and that:

'Understanding ecosystem changes is particularly complex; there may be tipping points in land, aquatic and marine ecosystems that have major and possibly irreversible changes, which we currently know little about'.

It is therefore important to recognise that in looking at the economic values – and indeed the overall quantitative results from the CCRA – that these thresholds effects are not always (or even mostly) captured. While these clearly affect the economic results (and their interpretation) it also has much wider implications. A key risk driver will be the need to recognise these thresholds and if possible to avoid them (an issue for both adaptation and mitigation).

The benefits of mitigation

Whilst it has not been a primary focus of the CCRA, the results can also provide some potential context on the domestic benefits of mitigation. The CCRA evidence report acknowledges this as follows:

'Mitigation, through the reduction of greenhouse gas emissions, will contribute to risk reduction over the long term (100 years) and this assessment has shown that the consequences of a High emissions scenario are substantially greater for the UK than the Low and Medium emissions scenarios for the 2080s.'

However, considerable caution is needed in interpreting this statement, for four reasons.

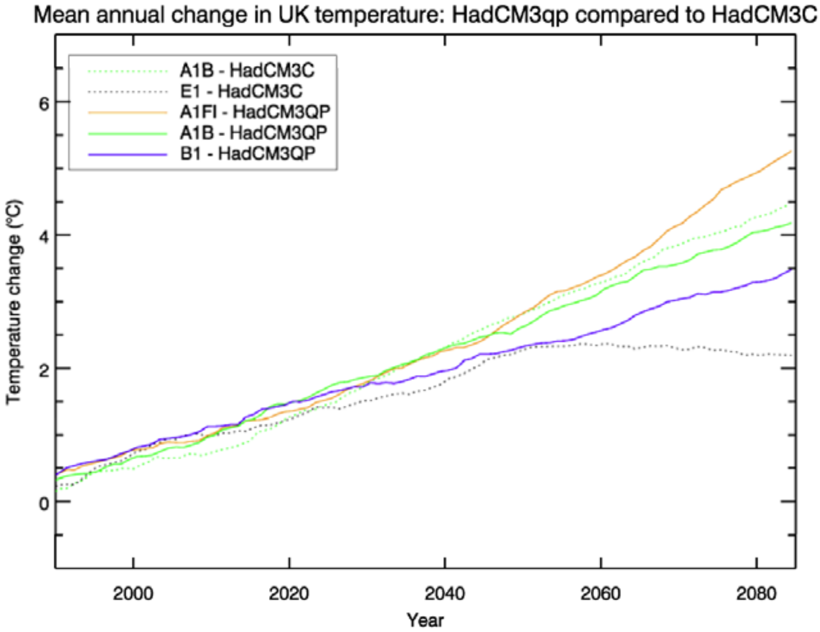
First, mitigation involves a much wider set of global aims, prioritised around avoiding dangerous climate change. These cannot be captured through the domestic discussion which is the focus of the CCRA.

Second, in relation to the summary estimates, the difference between the UKCP09 high and low scenarios p50 values does not fully capture the domestic benefits of lower carbon pathways in the UK. A more relevant analysis would be to look at the nature of risks from the tails of the distribution, and the importance of mitigation in reducing the likelihood of the p90 high.

This is recognised in the CCRA, which states,
Comparison of UKCP09 to the results of Met Office modelling of an 'aggressive mitigation' scenario suggests that a certain amount of warming is inevitable due to historic greenhouse gas emissions. The comparison of potential risks under the lowest and highest risk scenarios considered in the CCRA shows that following a lower emission pathway may significantly reduce potential risks in terms of flooding, water resources, forestry and overheating in urban environments. This is evident in the scorecards at the end of each themed chapter, which show the differences between the low end of the Low emissions scenario, central estimate from the Medium emissions scenario and high end of the High emissions scenario for the lower, central and upper estimates respectively. Further data for each emissions scenario are provided in each Sector Report. This finding supports a 'triple track' approach of mitigation, adaptation and management of residual risks to reduce the consequences of climate change

Third, and perhaps most importantly, the UKCP09 low scenario is not a mitigation scenario, as it is based on the B1 SRES scenario. **This means that the use of the UKCP09 low scenario**

underestimates the benefits of mitigation, i.e. with the pathway consistent with the UK's Low Carbon Transition. This can be clearly seen in the results of a more recent analysis that compares the UKCP scenarios (B1, A1B and A1Fi) with a 2 degree (E1) scenario below.



Any consideration of the benefits of mitigation therefore needs to consider the full range of results from the CCRA (capturing the p10 'Low' scenario, which is actually be closer to a 2 degrees mitigation scenario), and the higher risks associated with the P90 'High' emissions scenario, along with the issues discussed in subsequent chapters in relation to other domestic and international factors.

Finally, because the CCRA (as set out in the legislation) only looks out to the end of the century, it misses some of the main benefits of mitigation which are beyond 2100.

All four of these points are critical in interpreting the CCRA in the context of the mitigation debate. It is highlighted that further consideration of these issues might be useful in undertaking the next CCRA.

3. Framing the CCRA in a wider climate risk context

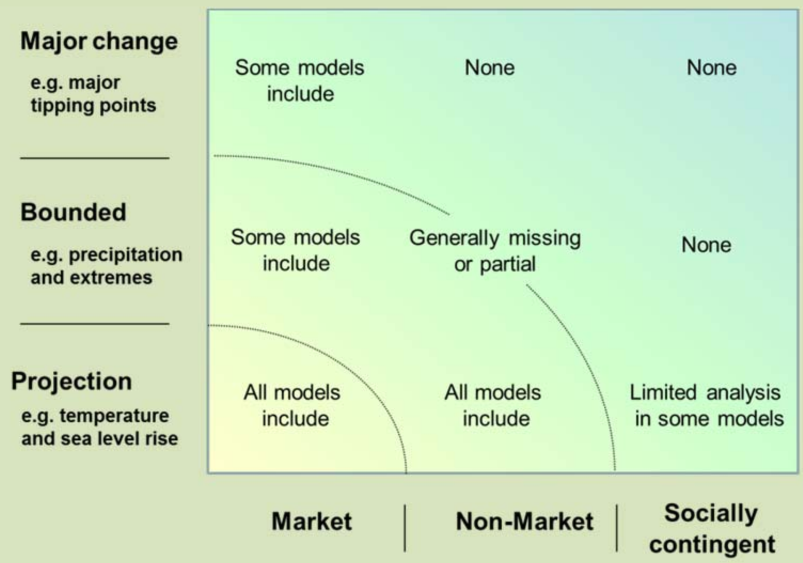
This section develops a framework to consider the coverage of the CCRA. The aim is to assess a more complete representation of the full economic costs of climate change for the UK and then map the CCRA against this.

What are the Full Economic Impacts of Climate Change?

At the global level, estimates of the total (aggregate) economic costs of climate change are produced by global economic integrated assessment models (IAMs), the most commonly cited being FUND (Tol, 2002a, 2002b, Tol and Anthoff, 2010); PAGE (Hope, 2006, 2009) and DICE (Nordhaus and Boyer, 2000, Nordhaus, 2009). While these estimates have attracted a great deal of discussion on many issues relating to temporal and spatial weighting (most notably discounting), an important issue which has received less attention has been the coverage of the reported values, i.e. which impacts they actually include. Downing and Watkiss (2003) introduced a risk matrix to assess the coverage of the social cost of carbon in IAMs, see Box 1.

Box 1. A matrix for the coverage of the economic costs of climate change

On the horizontal axis, the matrix includes three categories of effect: market, non-market and socially contingent effects, the latter associated with large scale dynamics that are poorly represented in impact cost estimates, e.g. conflict and migration. The vertical axis includes three categories of climate change. At the bottom are effects that can be relatively well projected such as average temperature and sea level rise; second, more uncertain parameters with more complex bounded ranges such as precipitation and extreme events; and finally, catastrophic climate events, and bio-physical discontinuities or tipping points/elements (Lenton et al, 2008), such as the instability of the West Antarctic ice sheet, where thresholds and subsequent effects are highly uncertain. Watkiss et al. (2005) mapped the coverage in the most prominent IAMs, and Social Cost of Carbon (SCC) estimates against this impact matrix. An updated version is presented below, as published in Watkiss (2011.



Coverage of the social cost of carbon from three of the main economic IAMs. Watkiss (2011).

Most IAMs have good coverage in the bottom left hand area of the matrix, reflecting market damages from relatively predictable changes such as temperature and sea level. All models include some coverage of non-market damages, notably in relation to health, but only limited consideration of biodiversity and natural environments. The rest of the matrix continues to be poorly covered. The original mapping found a poor coverage against major discontinuities and no coverage of socially contingent effects, reflecting the state of knowledge in the supporting literature. The updated matrix shows that the models have advanced, though there remain differences in coverage between the models. However, the lack of coverage – particularly of the catastrophic events – does lead to a systematic under reporting of costs (Watkiss et al, 2005; Warren et al. 2006). Watkiss and Downing (2008) highlighted that some of the missing categories were likely to include both positive as well as negative effects, but considered the missing effects were likely to have potentially large net damages. The omission of major catastrophic events and abrupt climate change is a particular concern. This has been examined more recently in relation to the plausible, if unknown, probability of catastrophic climate change (Weitzman, 2009) and 'fat tails', where uncertainty is so large that the tails of the distribution are likely to dominate any conclusions, as the expected welfare loss is potentially unbounded. The consideration of these outcomes leads to radically different conclusions for policy from the conventional advice from standard economic analysis and formalized CBA.

The UK CCRA offers a partial coverage of this risk matrix. However, the matrix in Box 1 does not fully capture the consideration of risks from a UK perspective. Consequently, we present a new matrix.

A matrix to interpret the CCRA

A number of areas are important in conceptualising the CCRA coverage.

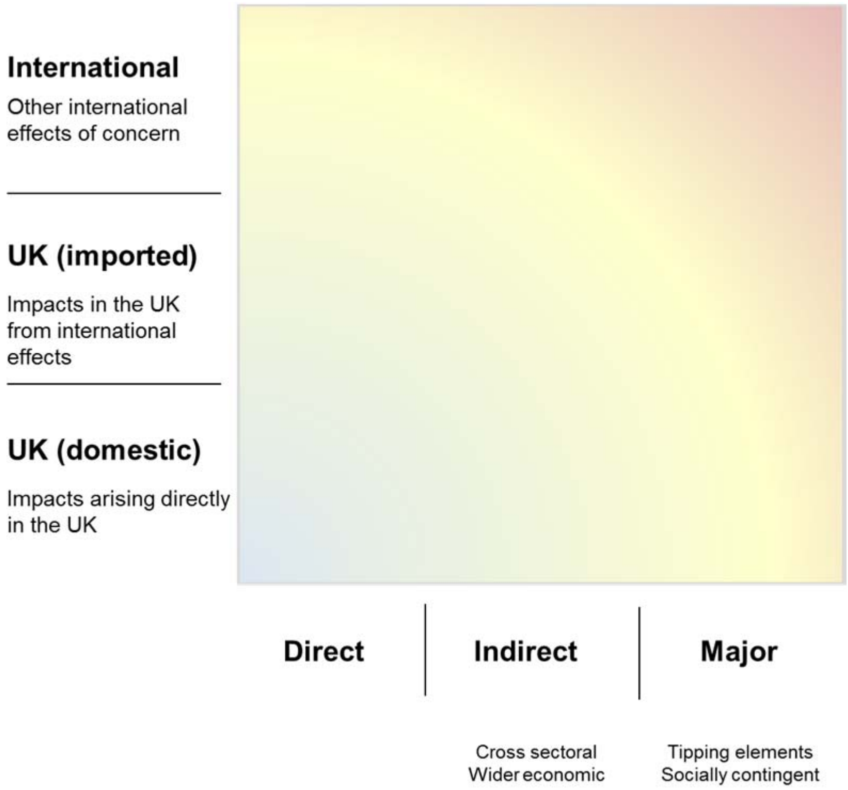
First, when considering the impacts that arise directly in the UK, the CCRA valuation has quantified and valued Tier 2 risks (some 100 risks) out of the full list of over 600 Tier 1 risks. This is not a criticism of the CCRA per se– which has covered a more comprehensive set of risks than many international studies and has addressed the risks of most obvious direct importance – but it is simply a recognition that assessing such a large number of risks is extremely challenging and beyond the available resources. However, it is important to note that the CCRA values reported are therefore only a partial picture. The issues raised in the previous chapter are also highlighted (e.g. in relation to the single climate response functions, and the need to report the range of risks rather than only the central trends).

Similarly, the CCRA systematic mapping did identify possible cross sector linkages, though with the exception of flood linkages, these were rarely quantified. The CCRA also did not consider the wider economic costs of climate change as this was outside the scope of the work. However, the combined omission of these two areas means that the scope of the CCRA was limited in considering the indirect effects of climate change.

The CCRA also did not consider the potential risks of catastrophic events (discontinuities), often known as tipping points or tipping extremes (Lenton et al, 2008). Many of these events are projected as being most likely to occur after 2100, beyond the time-span which the CCRA was asked to cover within the statutory legislation. However, these risks are critical to the case for mitigation, as captured through the CCC's own analysis of the UK's 2050 target (CCC, 2008). They are also being considered in relation to adaptation in the UK in some areas, notably in High + sea level rise scenarios.

Finally, it is also necessary to consider the international effects of climate change and how these might impact on the UK. One example derives from the fact that the UK, as a net food importer, will be affected by global effects of climate change on agricultural production and subsequent prices changes. A second example relates to the potential pressures on migration to the UK which might conceivably arise from future impacts in other countries. These international effects were raised and discussed in the CCRA, but not quantified or valued. This was due to the coverage by the Foresight futures international study on-going at the time.

All of these areas are potentially important when estimating the full aggregate costs of climate change in the UK. Indeed, they are all needed to make an analysis of the full risks to the UK, and the case for adaptation. For this study, a new risk matrix has been developed which captures these issues, shown below.

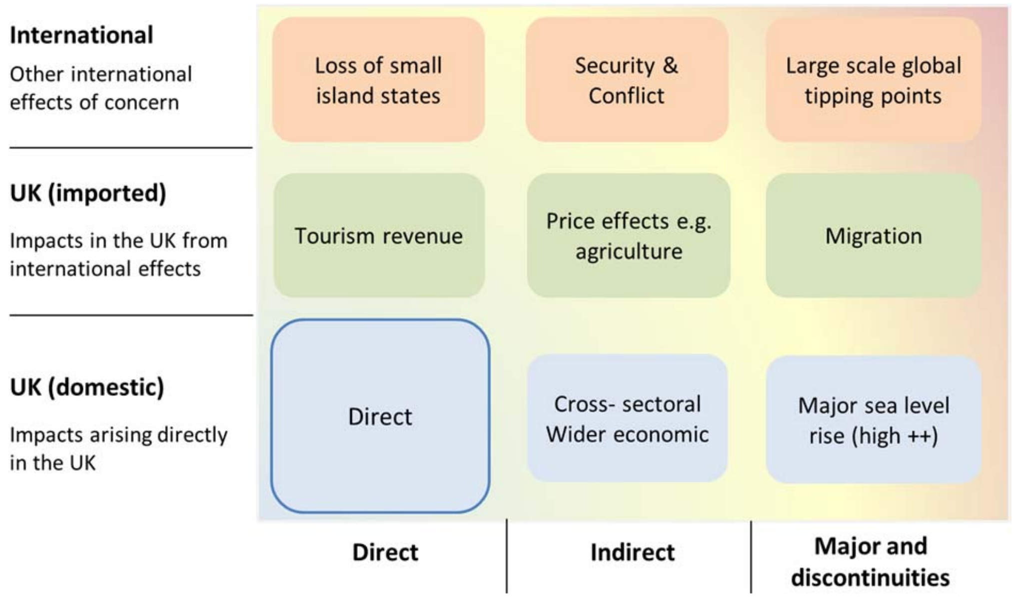


This matrix plots:

- **<u>The type of risks</u>**, distinguishing between the **direct effects**, which were the main focus of the CCRA, the **indirect effects** of climate change, which include cross sectoral and wider economic multiplier effects, and the **major effects**, which include risks not captured by the UKCP09 projections and/or that may arise post 2100.

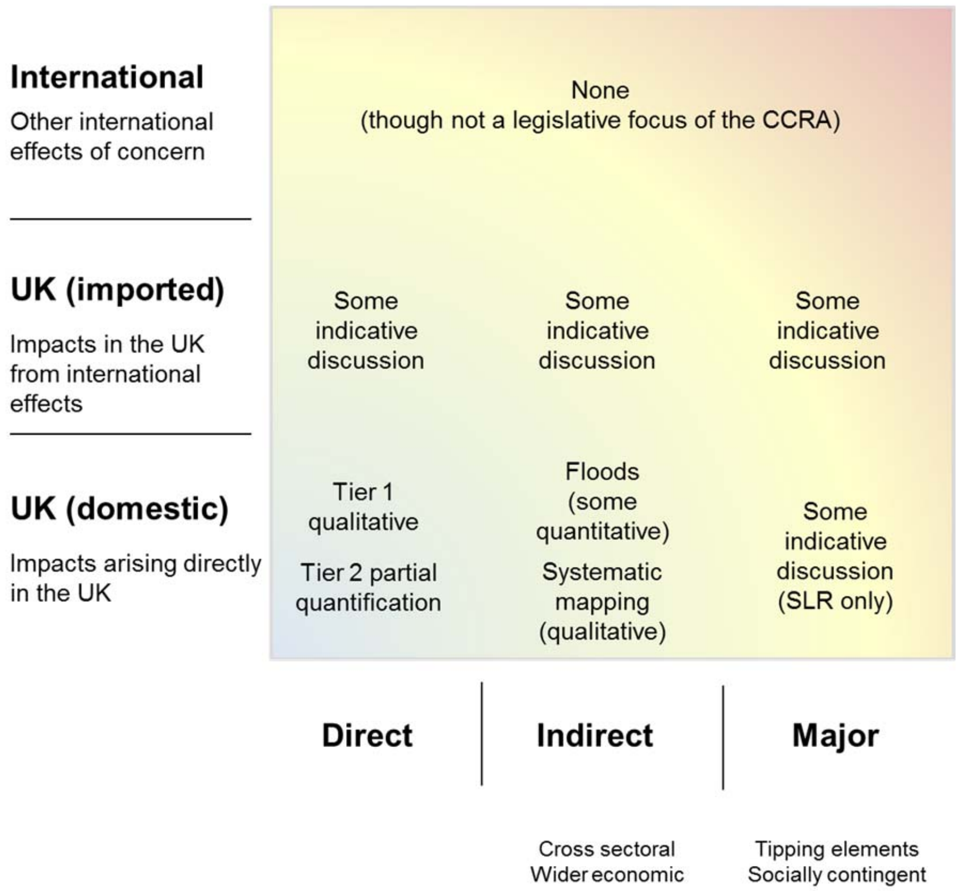
- **<u>The domain of the risks</u>**, i.e. whether the primary effects occurs **within the UK**, or whether it involves **international risks**, that then translate to effects in the UK. The latter is further split into those international effects that will have an effect in the UK (i.e. where the effects are imported to the UK through a cause and effect relationship), and those that might not affect the UK directly, but which will be important in the context of international foreign policy, security and international development aid. It is also stressed that these latter risks, i.e. those that occur in the rest of the world, are relevant from an economic perspective, because they will have been partially caused by UK emissions of GHG emissions (an external cost associated with UK activity). Note that many of these global effects are related to strong ethical or moral issues, such as the loss of sovereign states to sea level rise, irreversible effects (e.g. species extinction), etc. It is stressed that in practice, it can be quite hard to distinguish whether international risks will or will not impact in the UK, and in many ways, the international domain is a continuum.

Examples of the types of categories in each cell are illustrated below.



**Note most major tipping point would have at least some impacts on the UK.

The CCRA has been mapped on this matrix, shown below. **<u>This shows that the CCRA has a partial coverage, particularly when expressed in quantitative terms</u>.**



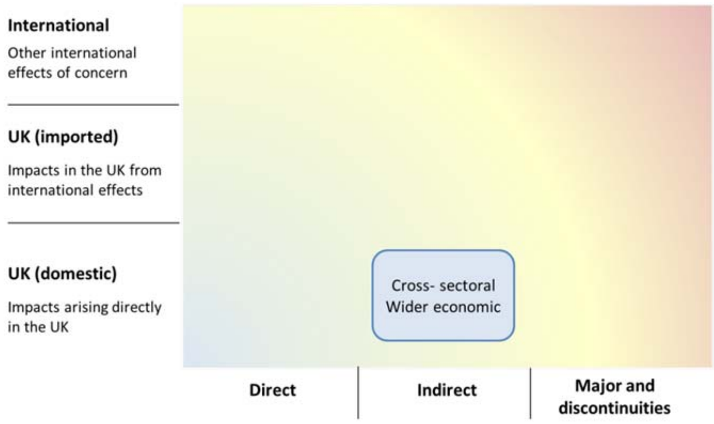
The coverage of the monetary valuation within the CCRA is even narrower, since it is focused solely on the Tier 2 risks in the **bottom left cell** (and even here it is partial), as it requires some form of underlying semi-quantitative or quantitative analysis of the risks in physical terms.

4. Filling the Gaps in the Matrix

Given the discussion above, it is useful to identify and review the potential omissions in the CCRA results, looking across the gaps in the matrix, to consider the relevance of these other potential risks on the UK and its citizens. With this in mind, for each of the boxes or rows in the matrix, we briefly outline findings of the relevant literature and – as far as is currently possible - provide indicative estimates of the potential scale of the gaps.

Indirect and Wider Economy Effects

This section of the review addresses the middle box of the bottom row on the matrix, shown below.



Introduction

The use of sectoral analysis, as advanced in many national studies, does not fully capture the cross-sectional or cumulative impacts of climate change. There is a growing recognition that these cross-sectoral linkages and impact chains are extremely important. However, there is a lack of research and studies in this area.

However, there are a range of different types of indirect effects, which involve different elements.

The first set of indirect effects includes various cross-sectoral linkages and can include the following:

- Where impacts in one sector cascade through to indirect effects in another sector. As an example, the indirect effects on mental health arising from flooding were captured in the CCRA and a semi-quantitative analysis was undertaken. Thus the number of people flooded was taken, and a quantified analysis was made of the possible mental health impacts. Overall, the CCRA was particularly good at capturing this type of cascade effects from flooding (see below). However, the analysis in other sectors was much lower and tended to be limited to identification of possible links in the systematic analysis.
- Where several sectors are linked and are impacted together, leading to cumulative effects that are greater than the sum of the individual effects e.g. the built environment and its inter-dependencies with water resources, building design, transport and energy. The key difference

to the bullet point above is that the processes are synergistic and involve feedbacks and therefore potential amplifications, rather than just an effect in one sector affecting a receptor in another. The effects of an risk acting in multiple areas at the same time involves a much more complex analytical assessment, but potentially it is more important because of possible cumulative effects and amplification effects, which can lead to major events. .

- Where multiple cross-sectoral demands exists, for example, in relation to water, in regions of declining water resource availability where multiple sources of individual sectoral demand need to be considered together. In this case, sectoral demand needs to account for sectoral socio-economic projections (e.g. domestic, tourism, industry, agriculture) rather than assessed individually In the case of water, which is priced these competing demands can be assessed in terms of the effects on market prices (see next section), and the feedbacks this has on demand.

The second main type of indirect effects relates to the impact of a change in price in one market resulting in a change in price in related markets or in the economy more generally. These effects are most precisely captured when economic modelling of the affected markets is undertaken.

The CCRA

One of the most impressive elements of the CCRA was the cross sectoral linkages assessed for flooding. The study assessed both the direct consequences of flooding, as well as recognising the indirect consequences, for example:

- Loss of water supplies to people and business as a result of flooding of water supply infrastructure. Loss of water can then lead to further indirect consequences, for example related to human health.
- The indirect consequences of the loss of other services such as energy supply as a result of flooding.
- The effects of flooding on vulnerable people who may not have property or household contents insurance, and may not have the capacity to recover.
- The effects of flood risk and the increase in the number of vulnerable people becoming dependent on state support if their existing support and coping strategies fail.

The CCRA emphasised that many of these potential indirect consequences could have greater social and economic consequences than the direct consequences of flooding, though it highlighted there is currently a lack of information to support a UK analysis. However increasing information, such as social and economic costs of flooding have been estimated for the July 2007 floods (Environment Agency 2010) are helping to bridge the gap.

The CCRA advanced a process of systematic mapping to identify the main potential indirect consequences of flooding, and progressed a large number of these through the flooding sectoral analysis, and assessments in the other sectoral reports. It categorised effects into:

- Level 1: Direct biophysical effects of climate change;
- Level 2: Direct impacts of flooding;
- Level 3: Indirect consequences of flooding (layer 1);
- Level 4: Indirect consequences of flooding (layer 2), leading to consequences for the economy, society and the environment.

An example is shown below.

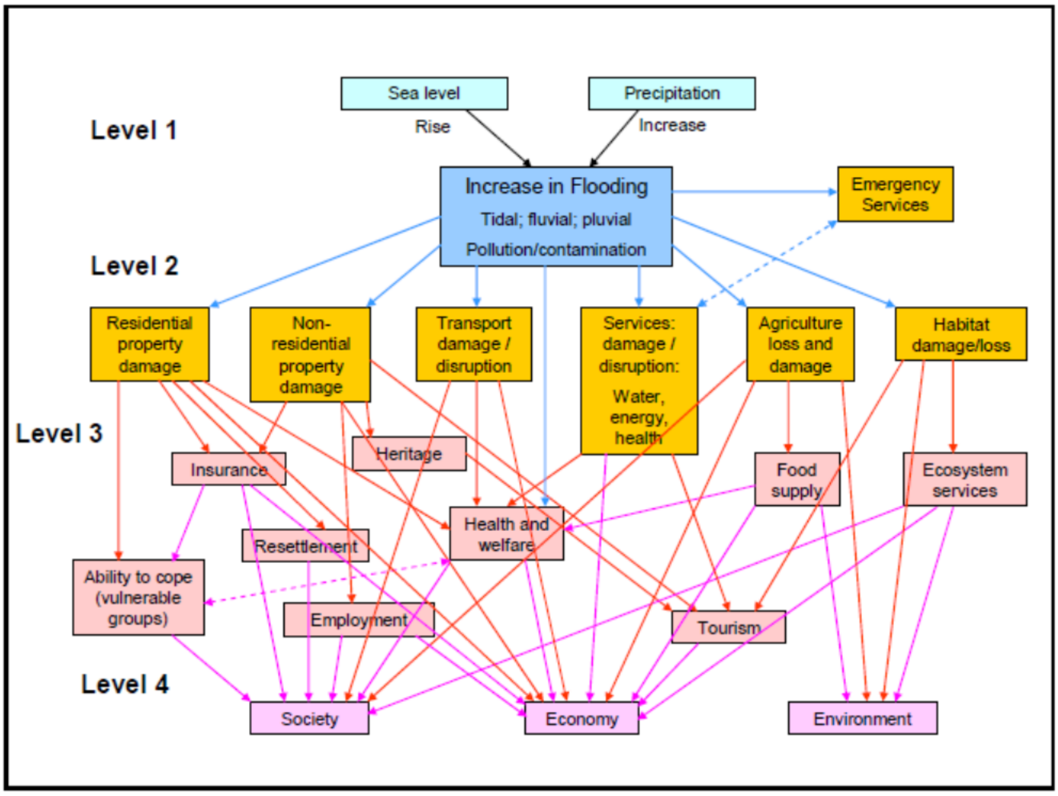


Figure A5.1 Linkages related to flooding

For flooding, the CCRA undertook semi-quantitative or quantitative analysis for direct effects, e.g.:

- Deaths and injuries caused by flooding (Health Sector).
- Flooding of natural and built tourist assets (Business Sector).
- Flooding of business assets (Business Sector) and the indirect consequence of business interruption costs.
- Scour at bridges which can cause bridge failure (Transport Sector).
- Spills from Combined Sewer Overflows, which provide an indication of the potential increase in flood risk from surface water flooding in urban areas (Water Sector).
- Coastal evolution including the combined effects of coastal flooding, coastal squeeze and coastal erosion (Biodiversity Sector).

These are captured in the sector reports – sometimes with quantification and monetisation (e.g. deaths from flooding) and sometimes with more semi-quantitative analysis.

The CCRA also included some indirect consequences of flooding and coastal erosion, e.g.:

- Mental health impacts to people who have been flooded (Health Sector).
- Supply chain disruption to business activity caused by flooding (Business Sector).
- Damage and disruption to road transport as a result of flooding of roads (Transport Sector).
- Effects of the disruption of ICT systems caused by flooding of components of the systems including electricity supplies (Business Sector).
- Flood impacts on mortgage revenues as a result of difficulties obtaining insurance for properties in flood risk areas (Business Sector).
- Increase in insurance payout costs and the potential financial burden on the insurance industry as a result of increases in flooding (Business Sector).

Again, some of these were quantified and monetised.

What is interesting is that for most sectors, the impacts of flooding represent one of the largest impacts when expressed in monetary terms. To illustrate, there were very large flood impacts projected for the transport sector, but also the health, energy and agricultural sector, which in the scoping monetisation were found to be more significant (in terms of economic costs) than many of the direct effects.

This reinforces the conclusion from the wider literature, that indirect effects are extremely important.

A key question is given the importance of these cross-sectoral effects for floods, how large are cross-sectoral and indirect issues for the UK?

This is something that is discussed in the CCRA but not quantified. As examples:

The business theme highlights the importance of indirect risks. This identifies areas that even the floods assessment did not capture (telecommunications and computing), but also lost efficiency from higher ambient temperatures and extreme events. It also identified the issue of supplies (and supply chains), communications or supporting services, particularly with regard to just-in-time supply policy (which was identified to be of sufficient significance that would merit further research).

Similarly, the buildings and Infrastructure theme highlights the issue of interdependencies, whereby resilience in one sector is dependent on the resilience in another. Examples include (but are not limited to) risks to infrastructure and critical elements (including cascade failures).

And critically, in the natural environment, where a new definition was introduced (*indirect impacts are caused by societal responses to climate change rather than by climate change itself*) and a number of indirect effects were identified, including cross sectoral linkages with ecosystem services. However, understandable, the CCRA reported that such impacts are difficult to assess, though it did include a discussion of issues that were identified as being highly important (catchment management, marine management, land use changes, urban environments, provisioning ecosystem services, and cultural ecosystem services).

Finally, in the overall conclusions of the Evidence Report, the report outlined the Connectivity – the causal chain and cross-cutting risks – and the importance of indirect risks. It outlined how the systematic mapping provided an extensive resource to explore and better understand many of the key cause-process-consequence links but that the complexity was such that it could not be easily summarised.

The Current Evidence Base

In the disaster risk management literature, direct effects of natural hazards are often used to capture direct physical impacts of a hazard on humans or economic assets such as the destruction of buildings, or loss of crops (Conhaz, 2011). Indirect damages are then defined as those that occur outside the hazard area, such as on manufacturing profitability when supplies are disrupted. Indirect damages are often cited as resulting in negative feedbacks on the wider economy due to their diversion of scarce economic resources away from other, productive, activities.

Other economic definitions apply a slightly different interpretation, largely based on the modelling framework used. In this case, direct effects relate to the primary effects from climate change on production or consumption, and are generally captured by the sectoral type assessments as in the CCRA. In contrast, indirect impacts reflect changes in production or consumption in one or more sectors on the whole economy, through their effects on relative prices, including factor prices. This requires assessing how climate change impacts will affect sectors or regions that are different from those initially impacted, and the feedbacks between sectors. It usually requires the use of input-output modelling to look at sectoral linkages, or general equilibrium modelling that considers overall macro-economic effects, including effects on GDP, employment, etc.

There are several studies that have looked at these wider economic effects. This includes analysis within sectoral studies (health in Bosello et al, 2007), as part of national climate change studies (in Australia, (Garnaut, 2008); and in Sweden, (SCCV, 2007) and Europe-wide such as in the PESETA study (Ciscar et al, 2011), as well as analysis of individual large-scale extreme events (Kemfert, 2006; Hallegatte, 2008).

It is interesting to note that some of the wider economic effects of large-scale hazards, or the use of CGE models, can lead to results that seem counter-intuitive. Some studies show that natural hazard occurrence may actually increase GDP, at least in the short-term, associated with rebuilding activities (though other authors refute this, see Hallegatte et al, 2009). Similarly, some CGE models show that markets can act as a form of autonomous adaptation, effectively dampening down the economic impacts of climate change through allowing price adjustments (Carraro and Sgobbi, 2008). Clearly, these results are the consequence of using total GDP as the economic metric, and of modelling only market impacts.

In contrast, a number of studies have assessed the wider economic costs of extreme events, and found that indirect costs are more additive and may be comparable in size to direct costs. For example, several studies have been published on the wider economic costs of Hurricane Katrina in New Orleans[7]. The IPCC 4th Assessment Report estimates that the total direct economic costs of Katrina were in excess of US$100 billion (Wilbanks et al, 2007). However, a number of studies have considered the wider economic effects of this event. Hallegatte (2007: 2008) estimated that the full macro-economic costs of Hurricane Katrina in New Orleans were roughly 25% more than direct costs alone, bringing related damage costs for this incident to roughly $130 billion. The significance of these estimates is put in perspective when compared to the size of the Louisiana gross domestic product, which stood at about $168 billion in 2005. Other studies find even larger macro-economic cost. For example, Kemfert (2006) reports that the full macro-economic costs of Katrina were twice as large as the direct costs, from the additional effects of oil price increases, increased energy costs, and other factors). Wilbanks et al (2007) highlight that reconstruction costs have driven up the costs of building construction across the southern U.S., and federal government funding for many programmes was reduced because of commitments to provide financial support for hurricane damage recovery.

[7] Note Katrina did not occur as a result of climate change, though climate change may have influenced the probability of a high intensity storm hitting the area at some point.

At present, therefore, it is difficult to know how important are the cross-sectoral linkages in the UK, and how they translate through to the economic costs of climate change, and the need for adaptation. There does not appear to be national scale indirect coverage of impacts in the UK, even for flooding.

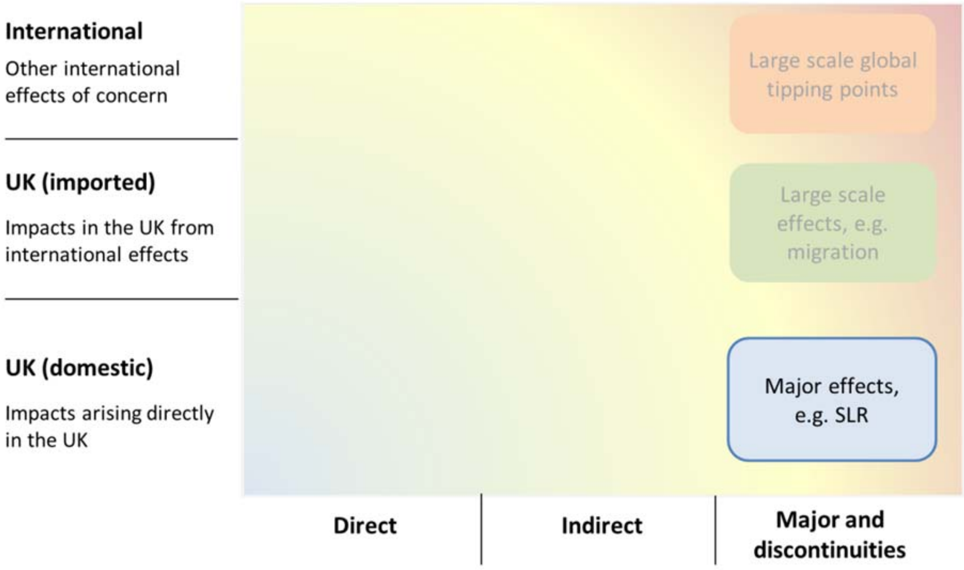
There has been some very thorough UK work looking at cross-sectoral issues at the regional level, notably the RegIS project (Holman et al, 2002: 2007), which assessed the impacts of climate and socio-economic change on water resources, agriculture, biodiversity and coastal zone in two regions and found these linkages to be crucial in planning adaptation. The ECR pilot reported, for many risks, there is a strong element of cross-sectoral impacts, and even for risks that sit clearly within one sector, many of the most promising adaptation options are cross-sectoral. The wider literature, reported above, also suggests that indirect effects are significant. However, analysing such effects at the national scale remains challenging, though addressing these cross-sectoral aspects seems to be one of the key areas where the NAP should add value to the existing programme and analysis.

Summary

As the discussion shows above, the indirect effects of climate change do seem to be an important area, with potentially high economic costs. The initial work in the CCRA (on flooding) seems to indicate large effects, and the additional areas of amplification effects (multi-sector) and wider economic costs are also important risks. However, there is a lack of evidence on these issues, particularly in terms of quantitative and economic analysis, and this makes it difficult to know the potential order of magnitude of these risks – though there are indications that overall, indirect risks could be of the same order of magnitude as direct risks. Further investigation of this area is considered a priority for the next CCRA.

Major Catastrophic Events and Extreme Outcomes

This section of the review concentrates on the right hand column of the matrix.



Introduction

The CCRA – in line with the requirements of the Climate Change Act - focuses on the impacts of climate change up to 2100, and uses the UKCP09 climate projections. It therefore includes minimal discussion of a number of phenomena associated with climate change include:

- Higher climate sensitivity – the equilibrium temperature rise that results from a doubling of CO_2 concentrations;
- Global or regional discontinuities, often termed tipping points, or tipping elements, (Lenton et al, 2008). Tipping points refer to events and processes that would push the climate system into what are regarded as very undesirable states. An example is the repeated failure of the South Asian monsoon, with resulting implications for water supplies to agriculture, etc.

These are critical in considering the justification for UK and global mitigation action. They were identified by the CCC in determining the UK's long-term carbon reduction target (CCC, 2008), i.e. in recommending a level of GHG reductions consistent with a global pathway to limit global temperatures to as close to 2 degrees as possible, and to ensure they do not exceed 4 degrees.

As these major concerns have already been translated into policy in the UK, through the greenhouse gas emission reduction targets set out in the Climate Act, it could be argued that there is no need for the CCRA to reconsider them. However, the omission of them in the CCRA does create the potential for misinterpretation of the overall risks of climate change to the UK, and their possible implications for adaptation planning. Indeed, within the CCRA, there is very little discussion of higher end risks.

The UKCIP09 and CCRA Analysis

<u>Tipping elements</u>

The UCKP09 Climate Projections science report (Murphy et al, 2009) confirms that one sub-system with a potential tipping point – the Atlantic Ocean Thermohaline Circulation (THC) – is considered in the UKCP09 scenarios[8]. Murphy et al (2009), highlight that a shut-down of the Meridional Overturning Circulation (MOC) would have a dramatic effect on the climate of the UK, with modelled analysis suggesting that a THC shutdown would lead to a cooling of around 4°C in terms of daily maximum Central England Temperatures, relative to the pre-industrial climate, and would reduce precipitation by around 20%. The report also states that

Climate models suggest that the MOC will weaken gradually in response to increasing greenhouse gases. The effects of such a weakening are included in the UKCP09 projections. However concerns have been raised that the MOC might undergo a more rapid decline, or pass a threshold beyond which it will eventually shut down effectively irreversibly.

The projections in UKCP09 take account of the reductions in the strength of the MOC. This is consistent with recent literature that suggests that the MOC will weaken gradually in response to increasing greenhouse gases, i.e. between 0 and 50% in the MOC by 2100, rather than shutting down (see below).

The fact that these issues are already taken into account in the CCRA is reassuring, though it is highlighted that there are significant uncertainties in this area due to the way that the models currently represent some of the processes like the MOC. While recognising the existing UKCP09 information base, a comprehensive risk assessment might therefore explore other possible issues or alternative futures, not only relying on current models.

The Marine Chapter of the CCRA (Pinnegar et al, 2012) reports on the melting of arctic sea ice. It used ice projections from the met office[9]. It identified and assessed one Tier 2 metric for this, MA5, Shipping routes: navigable days for north-west and north-east passage per year. Note that this is considered to be a positive effect (for the UK), although though the report does highlight the environmental consequences of sea ice reduction in the Arctic will be severe.

Higher Climate Sensitivity

The UKCP09 frequently asked questions states that the UKCP09 projections do not include the climateprediction.net projections. The full range of climate sensitivity scenarios (from climateprediction.net and the wider literature) is therefore not included.

Sea Level rise

UKCP09 provides two sea level rise scenarios:

[8] The science report discusses the Meridional Overturning Circulation in the North Atlantic (MOC, sometimes less precisely referred to as thermohaline circulation (THC), conveyor belt circulation or Gulf Stream circulation), i.e. the circulation in the North Atlantic that moves warm water northwards from the subtropics and supplies heat to the atmosphere at higher latitudes. The MOC in the North Atlantic is part of the Global Thermohaline Circulation and is sometimes mistakenly confused with the Gulf Stream which plays a role within the MOC but is not the full overturning circulation.

[9] The ice extent projections used were supplied by the Met Office from their HadCM3 model provided projections for the three UKCP09 scenarios (B1, A1B and A1FI) and for 12 months of the year. Projections were provided for three different ice cut off scenarios, 30%, 15% and 5% in line with the Met Office's own assessments of ice extent. These cut offs relate to ice extent in percentage cover of each 1º Latitude by 1º Longitude grid cell. For example, under the 30% cut off it is assumed that vessels are able to navigate through ice conditions of up to 30% coverage per grid cell due to ice breaker capability and therefore vessels will be able to navigate through these conditions more frequently. In terms of commercial transport the most relevant ice cut off is 5% as this requires the least ice breaking capability and therefore has the lowest costs associated with transit.

- A range of sea level projections based on climate modelling from the Intergovernmental Panel for Climate Change's 4th Assessment Report (IPCC AR4)[10];
- A low probability, high impact range for sea-level rise called the High-plus-plus (H++) scenario, which is developed from palaeoclimatic proxy data

The High++ (extreme) scenario range for sea level rise and storm surges accounts for potentially faster melting of ice sheets, and is intended (Murphy et al (2009))

to provide an extreme but physically plausible range of change for users wishing to investigate contingency planning and the limits of adaptation. However, it is thought very unlikely that the upper end of the High ++ ranges for sea level rise and surge will be realised during the 21st century.

For the Thames Estuary in the 21st century, the UKCP09 High++ surge increase range equates to approximately 0.2–0.95 m and the H++ mean sea level increase range is 0.93–1.9 m[11].

Within the CCRA, the use of the UKCP09 projections indicate absolute sea level rise (not including land movement) for 2095 range from approximately 13 to 76 cm. The CCRA did not use the High ++ scenario in the national level flood sector assessment, as it reported that the response functions for flooding shows a levelling off as sea level rises, because there are limited numbers of properties in the floodplains[12]. However, it did note that this did not apply to the Thames Estuary and included a brief analysis of implications for this scenario (see below). Interestingly this showed a doubling of the number of properties at risk, though the analysis did not progress to a quantification of EAD.

High ++ in the CCRA

The CCRA flood sector analysis (Ramsbottom et al, 2012) did not undertake a national level assessment of the High ++ scenario. However, it did provide some limited discussion and results for the Thames Estuary in a short section of the report (section 5.30).

The one exception is the Thames Estuary, where the flood defences provide a higher level of protection than elsewhere in the country. In this case the response function continues to rise. The High++ scenario could potentially inundate the entire floodplain on the Thames Estuary, as tidal water levels for an extreme event may overtop all of the defences.

This was demonstrated in the TE2100 study, where extreme sea level rise scenarios were used to predict the flood extent under extreme conditions. The values used for the High++ sea level rise scenario when this work was carried out in 2006 were higher than those projected in UKCP09 (TE2100, 2007).

Assuming that all properties on the Thames Estuary flood during a High++ event, the total number of properties in England and Wales that might flood during a High++ extreme surge tide event is estimated to be about 1.25 million. This is compared with projections from the CCRA analysis below. This very simple estimate has been carried out to provide an indication of the potential impact of a major tidal event that exceeds current projections.

Properties at risk from tidal flooding: High++ scenario - Climate change only (i.e. no socio economic change)

[10] UKCP09 outlines that sea level rise over the next century is likely to be in a range between 20 and 90 cm, which reflects the IPCC AR4 range of values adjusted for the UK region. The upper bound figure of 90 cm corresponds closely with current Defra guidance on sea level rise allowances but relates it to a stronger scientific basis.

[11] Note that these scenarios are different to the High + scenario defined in the Thames Estuary 2100 project (TE2100, 2007).

[12] It therefore concluded it was reasonable to assume that the High++ scenario would overtop all tidal defences, and the number of properties in each region affected would be the asymptotic value for the response functions. This means that an estimate of the number of properties at risk from a High++ scenario could be estimated from the asymptotic values of the response functions shown for residential and non-residential).

Scenario	Estimated number of properties at risk (thousands) Tidal flooding only
Significant likelihood of flooding: Present day	170
Significant likelihood of flooding: 2080s Low p10	450
Significant likelihood of flooding: 2080s Medium p50	550
Significant likelihood of flooding: 2080s High p90	620
High ++	1250

The CCRA report stated that this highlighted the important need to monitor the causes of sea level rise and update projections on a regular basis, and suggested *that there is a need for coastal managers to keep open a range of adaptation options and to be able to change approach as confidence in the predictions become more robust.*

Current Evidence Base

Tipping Elements

While highly uncertain, tipping points (or tipping elements) provide one of the key motivators for ambitious global climate mitigation policy, yet they are poorly represented in most assessments of the economics of climate change (see Watkiss and Downing, 2008; Watkiss, 2011).

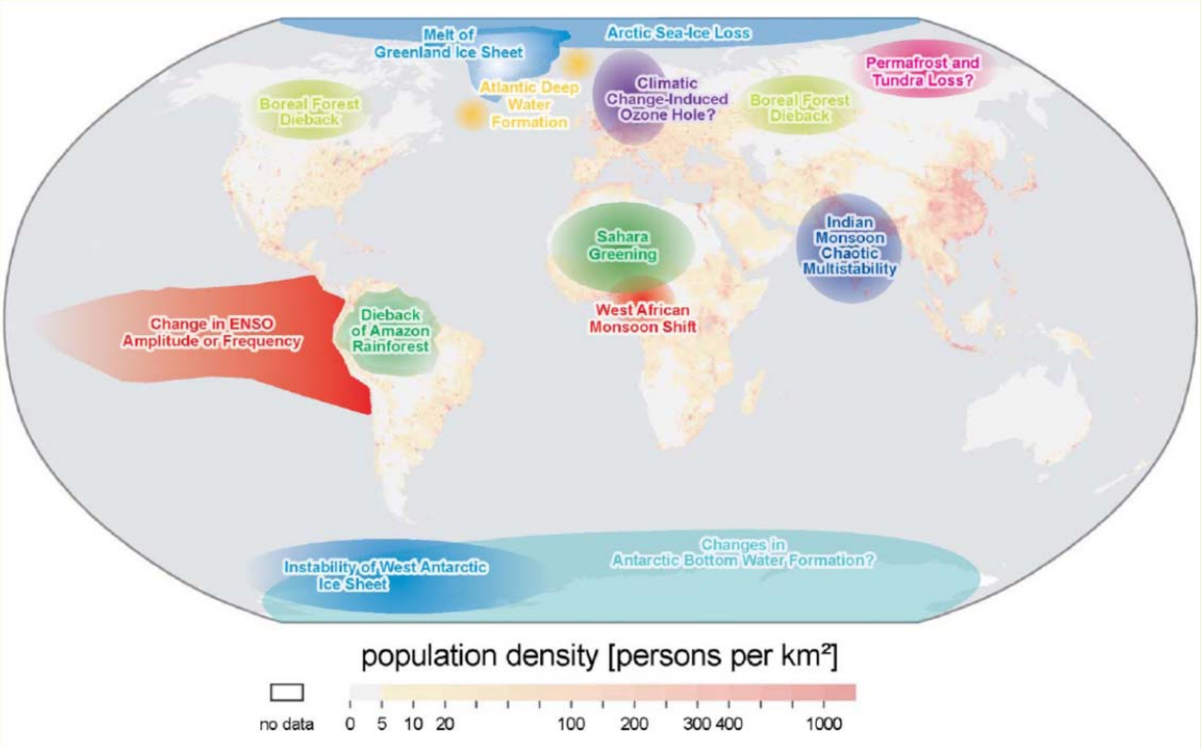
The earlier literature on this subject, expressed in the context of tipping points, was advanced by Schellnhuber et al, 2005, under the Avoiding Dangerous Climate Change Programme/Conference. The results of this analysis was presented as a set of mapped major global extremes, such as the instability of the West Antarctic ice sheet and major sea level rise, which could exhibit threshold-type behavior at a critical point or threshold (such that a small perturbation could alter the state of the system).

This literature was updated by Lenton et al (2008), who renamed as tipping elements, referring to large-scale components of the Earth system that may pass a tipping point. Their definition[13] of a 'tipping element' was: *subsystems of the Earth system that are at least sub-continental in scale and can be switched—under certain circumstances—into a qualitatively different state by small perturbations. The tipping point is the corresponding critical point—in forcing and a feature of the system—at which the future state of the system is qualitatively altered.*

The main graphic from this paper has been widely cited and is presented in the box below.

[13] It should be noted that this definition is broader than for a tipping point, allowing for non-climatic variables; slower transitions; amplification and non-amplification, several phase changes, and includes consideration of reversible or irreversible transitions.

Tipping Elements as Identified by Lenton et al, 2008.



Source: reproduced from Lenton et al, 2008.

Map of potential policy-relevant tipping elements in the climate system, overlain on global population density. Subsystems indicated could exhibit threshold-type behavior in response to anthropogenic climate forcing, where a small perturbation at a critical point qualitatively alters the future fate of the system. They could be triggered this century and would undergo a qualitative change within this millennium. It excludes systems in which any threshold appears inaccessible this century (e.g., East Antarctic Ice Sheet) or the qualitative change would appear beyond this millennium (e.g., marine methane hydrates). Question marks indicate systems whose status as tipping elements is particularly uncertain.

Lenton et. al. also compiled a short list of tipping elements, and investigated where these might lie, using an expert elicitation is used to help rank their sensitivity to global warming and the uncertainty about the underlying physical mechanisms. The summary of key tipping elements, transition timescale, and key impacts was presented in a Table, reproduced below.

Table 1. Policy-relevant potential future tipping elements in the climate system and (below the empty line) candidates that we considered but failed to make the short list*

Tipping element	Feature of system, F (direction of change)	Control parameter(s), ρ	Critical value(s),† ρ_{crit}	Global warming†‡	Transition timescale,† T	Key impacts
Arctic summer sea-ice	Areal extent (−)	Local ΔT_{air}, ocean heat transport	Unidentified§	+0.5–2°C	≈10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (−)	Local ΔT_{air}	+≈3°C	+1–2°C	>300 yr (slow)	Sea level +2–7 m
West Antarctic ice sheet (WAIS)	Ice volume (−)	Local ΔT_{air}, or less ΔT_{ocean}	+≈5–8°C	+3–5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (−)	Freshwater input to N Atlantic	+0.1–0.5 Sv	+3–5°C	≈100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño–Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified§	+3–6°C	≈100 yr (gradual)	Drought in SE Asia and elsewhere
Indian summer monsoon (ISM)	Rainfall (−)	Planetary albedo over India	0.5	N/A	≈1 yr (rapid)	Drought, decreased carrying capacity
Sahara/Sahel and West African monsoon (WAM)	Vegetation fraction (+)	Precipitation	100 mm/yr	+3–5°C	≈10 yr (rapid)	Increased carrying capacity
Amazon rainforest	Tree fraction (−)	Precipitation, dry season length	1,100 mm/yr	+3–4°C	≈50 yr (gradual)	Biodiversity loss, decreased rainfall
Boreal forest	Tree fraction (−)	Local ΔT_{air}	+≈7°C	+3–5°C	≈50 yr (gradual)	Biome switch
Antarctic Bottom Water (AABW)*	Formation (−)	Precipitation–Evaporation	+100 mm/yr	Unclear¶	≈100 yr (gradual)	Ocean circulation, carbon storage
Tundra*	Tree fraction (+)	Growing degree days above zero	Missing‖	—	≈100 yr (gradual)	Amplified warming, biome switch
Permafrost*	Volume (−)	$\Delta T_{permafrost}$	Missing‖	—	<100 yr (gradual)	CH_4 and CO_2 release
Marine methane hydrates*	Hydrate volume (−)	$\Delta T_{sediment}$	Unidentified§	Unclear¶	10^3 to 10^5 yr ($>T_E$)	Amplified global warming
Ocean anoxia*	Ocean anoxia (+)	Phosphorus input to ocean	+≈20%	Unclear¶	≈10^4 yr ($>T_E$)	Marine mass extinction
Arctic ozone*	Column depth (−)	Polar stratospheric cloud formation	195 K	Unclear¶	<1 yr (rapid)	Increased UV at surface

N, North; ITCZ, Inter-tropical Convergence Zone; EEP, East Equatorial Pacific; SE, Southeast.
*See *SI Appendix 2* for more details about the tipping elements that failed to make the short list.
†Numbers given are preliminary and derive from assessments by the experts at the workshop, aggregation of their opinions at the workshop, and review of the literature.
‡Global mean temperature change above present (1980–1999) that corresponds to critical value of control, where this can be meaningfully related to global temperature.
§Meaning theory, model results, or paleo-data suggest the existence of a critical threshold but a numerical value is lacking in the literature.
¶Meaning either a corresponding global warming range is not established or global warming is not the only or the dominant forcing.
‖Meaning no subcontinental scale critical threshold could be identified, even though a local geographical threshold may exist.

Source Reproduced from Lenton et al, 2008.

More recent literature has updated these findings, trying in particular to progress the analysis of when these tipping elements might occur, and what the implications for policy design might be. For example, using a Delphi-type expert elicitation method Kriegler et al (2009) derived potential probability intervals for a selection of tipping extremes. While highlighting profound uncertainty, the authors allocated corridors for the triggering of events for a low (0.5 to 2°C) medium (2–4 °C), and high global mean temperature change (above 4 °C) relative to year 2000 levels. The key assessments for the Thermo-Haline Circulation (THC denoted CMOC), Greenland Ice Sheet, GIS (denoted MGIS) and West Antarctic Ice Sheet (WAIS denoted DAIS) are shown below.

High emission scenarios (right panels) result in probabilities for these events as generally being above 50%. However, even for low warming scenarios (left panels) the tipping potentials are not negligible. The rightmost bar in each panel shows the aggregation of probability intervals from core experts with increasingly restrictive assumptions, thus probability intervals where Red < Yellow < Green.

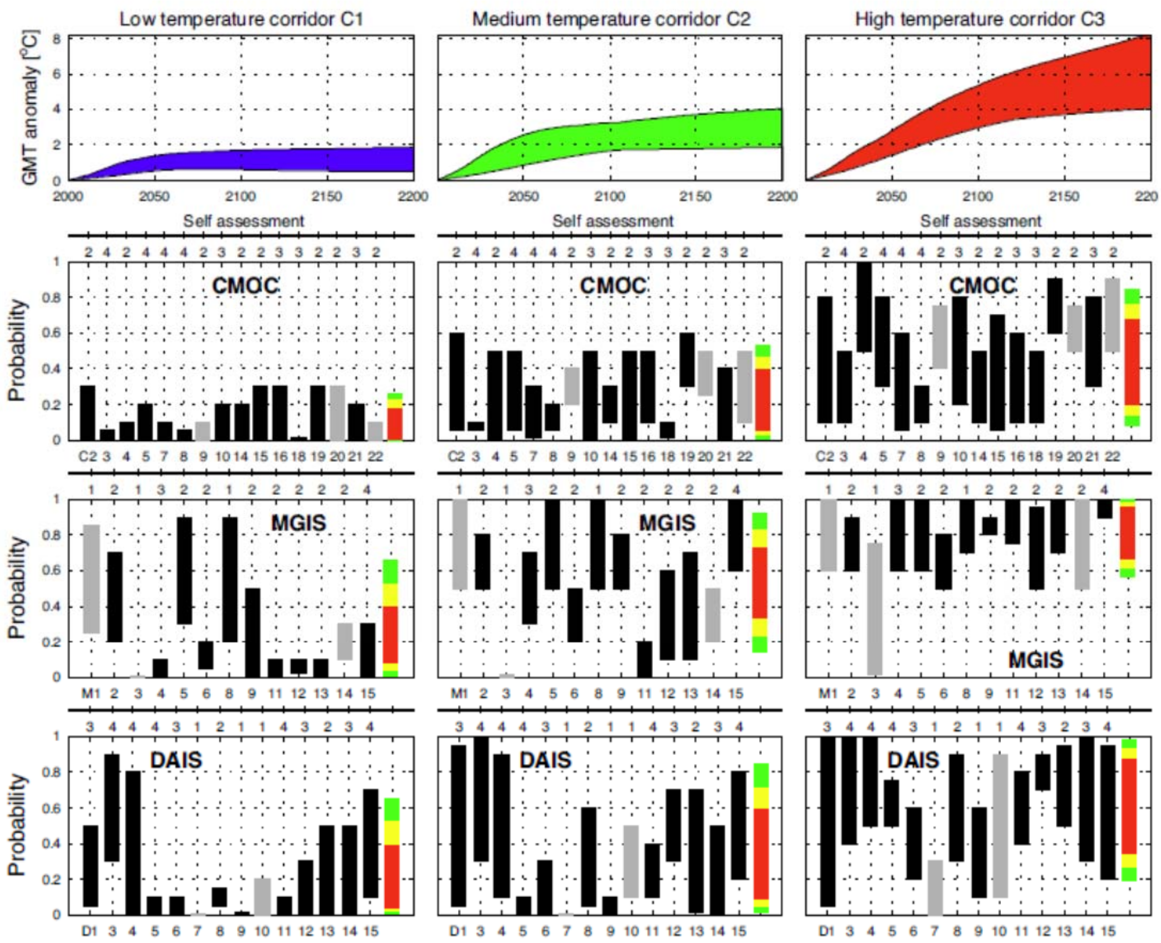


Figure 13 Subjective probabilities provided by experts for the tipping of THC (denoted CMOC), GIS (denoted MGIS) and WAIS (denoted DAIS). The x-axis provides the number of the expert. Coloured bars represent a *core group* of experts for each Tipping Element which are actively publishing on the subject. The upper panel row provides the corresponding climate scenarios as represented by the evolution of the global mean temperature (GMT) during the 21^{st} and 22^{nd} century. High emission scenarios (right panels) yield probabilities predominately above 50% for each system and even for low warming scenarios (left panels) the elicited tipping potentials are not negligible. For details confer (Kriegler *et al.*, 2009).

Source: Kriegler et al (2009)

Core experts (according to self-evaluation) are depicted by black bars. The colored rightmost bar in each panel shows an aggregation of core expert opinions: Red bars indicate the average of all core expert opinions. More conservative aggregations are obtained by allowing the experts' weights to vary up to 50% or 100% around the mean in order to produce the most extreme error bars in the aggregate (yellow and green bars, respectively).

Kriegler et al (2009) reports that the WAIS bears the potential for abrupt solid ice discharge in response to oceanic warming, though currently no direct temperature estimates required for such tipping are available[14]. Further, they caution that estimates of the threshold temperature for GIS of 3.1 ± 0.8◦C might not be robust since they are based on simplified parameterizations of the surface mass balance. Arctic sea ice is therefore the most vulnerable of the current short list of Tipping

[14] Paleo-climatic evidence suggests that abrupt discharge occurred at temperatures 1-2◦C above present levels.

Elements, and many consider even limiting pre-industrial levels to 2◦C is not sufficient to avoid major change in the Arctic region.

Levermann et al. (2012), who looked at the probability of tipping elements for Europe, thus of greatest relevance in relation to CCRA gaps. They use the definition of tipping elements as follows: *Tipping elements are regional-scale features of the climate that could exhibit a threshold behaviour in response to climate change—that is, a small shift in background climate can trigger a large-scale shift towards a qualitatively different state of the system*

Their graphical presentation of key risks is presented below.

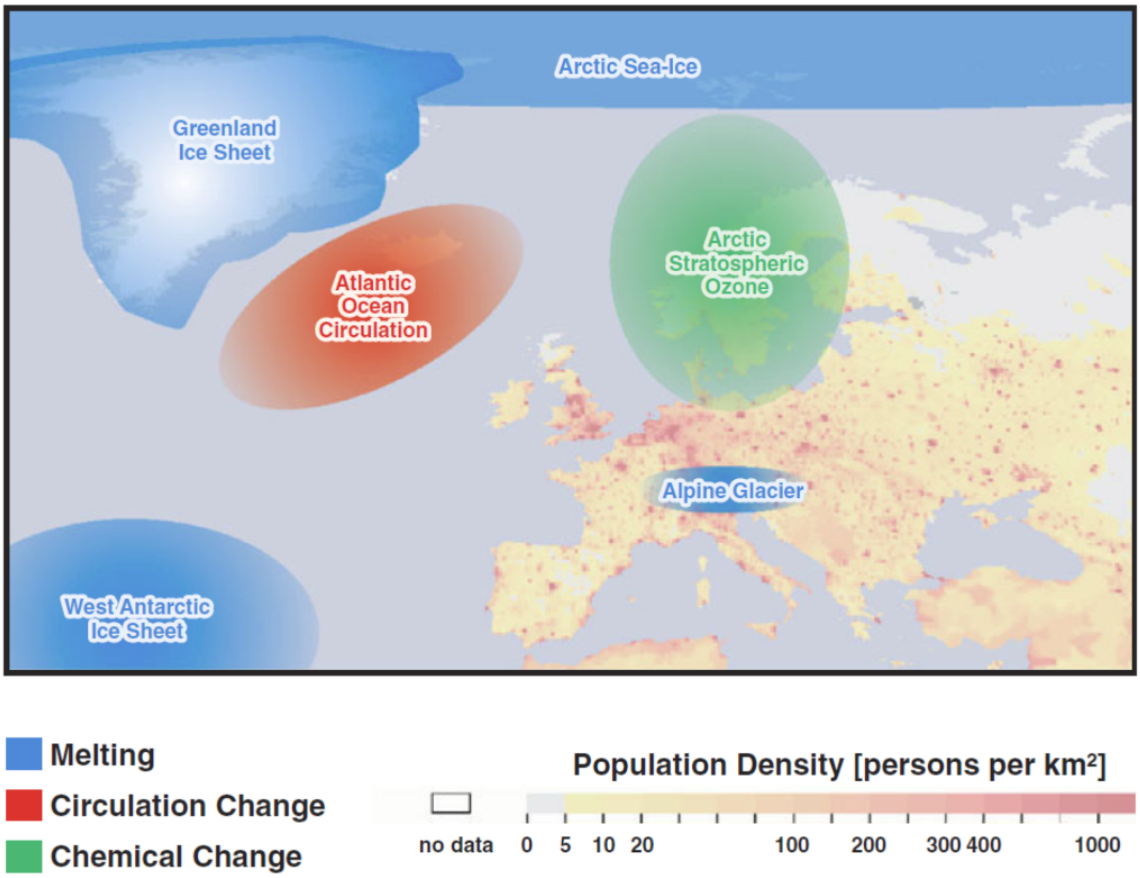


Fig. 1 Potential tipping elements with direct impact on Europe as discussed in this paper

Source: Levermann et al. (2012),

Levermann et al. considered six climatic sub-systems with large-scale potential impacts on Europe: the ice sheets on Greenland and West Antarctica, the Atlantic thermohaline circulation, Arctic sea ice, Alpine glaciers and northern hemisphere stratospheric ozone. Analysis was made of the potential impacts, and the 'tipping' potential for each system was provided as a function of global mean temperature increase.

The paper discusses evidence on the potential major ice sheets and reports that the water stored in Greenland ice sheet is sufficient to raise global sea level by about 7 m. Although WAIS contains enough ice to increase global sea level by approximately 5 m, only about 3 m SLR equivalent are subject to potential self-amplifying ice discharge. These ice-sheets are a concern because of their potentially self-amplifying ice loss mechanisms, and thus there is a concern as to whether there is a critical threshold temperature at which a complete disintegration of GIS is certain. The evidence on this remains highly uncertain. The IPCC-AR4 presented a threshold of global mean temperature of 3.1 ± 0.8◦C (noting it depends on the rapidity of Arctic sea-ice retreat) and polar amplification of warming, thus it could be exceeded within this century.

Levermann et al conclude that temperatures in the Arctic will result in increased mass loss from the GIS, but what is less certain is the temperature at which the fate of the ice sheet is determined, and report that near-complete disintegration is only likely to occur over a millennial time-scale. They cite Pfeffer et al. (2008), who estimated the maximum contribution of GIS to global SLR as constrained by the maximum ice speed possible and the width of potential ice discharge outlets, at 0.54 m within this century.

The tipping potential for the West Antarctic Ice Sheet (WAIS) was also considered, and Levermann et al note the evidence for a previous collapse 400,000 years before present, and that for a complete collapse, it would be necessary to remove the biggest ice shelves - the Filchner-Ronne and Ross (which would require regional warming of 5◦C or more). A partial collapse or retreat of the WAIS is, however, possible, notably for glaciers in the Amundsen Sea (which would be equivalent to a global sea surface elevation of about 1.5 m).

For Atlantic thermohaline circulation (THC), Levermann et al report that a collapse would mean that northern Europe would be several degrees cooler than at present and would suffer from significant drying and reduced precipitation – though varying depending on atmospheric conditions and latitude. It would also change wind directions and potentially increase sea level around European coast lines by up to 1 m. The processes and potential amplification pathways are particularly complex for this effect, and the paper reports there is no clear picture or consensus on the risk of a future THC collapse (citing subjective probabilities of different experts for triggering a breakdown within this century from 0% to 90%).

For Artic sea ice, the polar amplification from melting Arctic sea ice and associated surface-albedo changes, have led to much more pessimistic projections from the earlier literature, though there are complex positive and negative feedback mechanisms. Levermann et al report that the impacts of sea ice retreat can influence Atlantic storm tracks into Europe and has also been associated with anomalously cold Eurasian winters and increased probability of extreme cold events. It will also have major impacts on Artic ecosystems, though with potential benefits in terms of navigation times and access to reserves. Levermann et al report that while model studies suggest that Arctic summer sea ice will vanish at an additional global warming of 1–2◦C, winter sea-ice cover is not likely to be eliminated for a warming of less than 5◦C.

The analysis also includes Alpine glaciers, though these are considered less relevant for the UK, and artic ozone depletion, which is considered unlikely after 2060 due to declining chlorine levels.

The authors summarise their findings using a similar construct to the IPCC TAR burning embers.

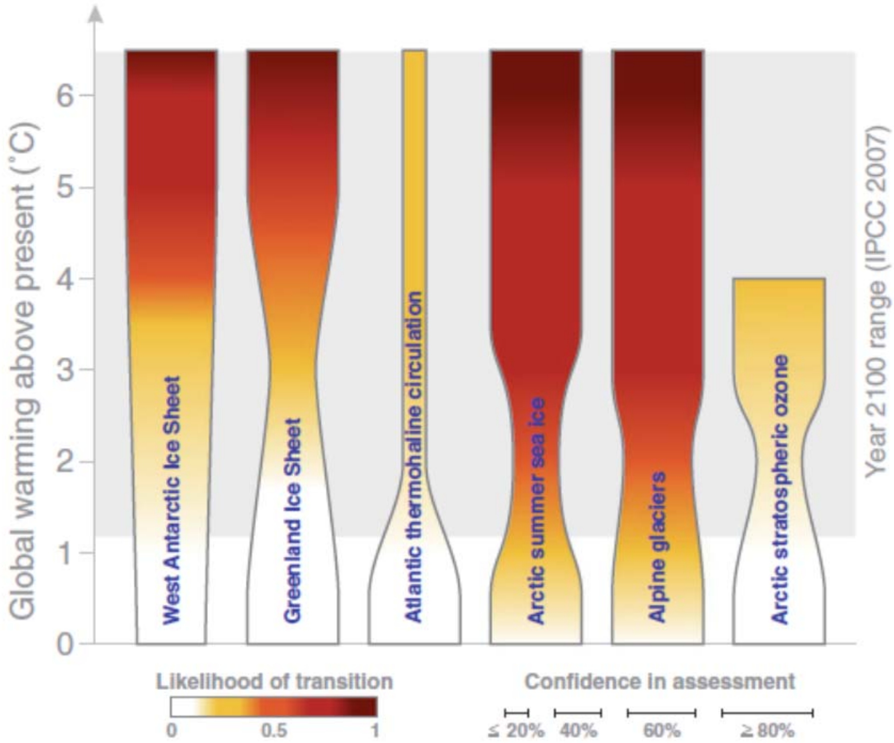


Fig. 15 'Burning rivers' summarizing the authors' general assessment of the potential of a transition of each system into a state that differs qualitatively from their present state. Colour coding represents the authors assessment of the likelihood of a transition for different global temperature increase. The width of the column represents the authors' confidence in their assessment, i.e. the narrower the 'river' the less confident the experts are in their respective assessment. For most systems the risk of tipping increases with temperature along with the confidence in such an assessment. An exception is the potential collapse of the Atlantic overturning circulation. Such a transition depends on the freshwater inflow into the North Atlantic which is only indirectly related to the global mean temperature increase through Greenland melting and precipitation changes. Especially because of uncertainty with respect to future precipitation changes, confidence in the tipping potential for the THC does not increase with temperature. The risk of reaching a tipping point in Arctic ozone depletion will become insignificant when chlorine levels drop below 1980 levels which is projected to occur around 2060 (WMO 2007; SPARC 2010). In the specific case of ozone depletion there exist significant uncertainty on the nature of the state to which the atmospheric circulation might revert to. All other systems are cryospheric and thus the likelihood of a transition increases with temperature. Due to the possibility that a partial disintegration of the WAIS in the Amundson Sea sector might have been already initiated the corresponding confidence that no transition has occurred for zero temperature increase is slightly reduced

Source: Levermann et al 2008

Climate Sensitivity

Many of the integrated assessment models have highlighted climate sensitivity as one of the most important parameters in determining the economic costs of climate change (e.g. Hope, 2006).

The IPCC AR4 2007 reported that "*equilibrium climate sensitivity is likely to be in the range 2°C to 4.5°C, with a best estimate value of about 3°C. It is very unlikely to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement with observations is not as good for those values. Probability density functions derived from different information and approaches generally tend to have a long tail towards high values exceeding 4.5°C. Analysis of climate and forcing evolution over previous centuries and model ensemble studies do not rule out climate sensitivity being as high as 6°C or more*."

The latter numbers capture the range of values from climateprediction net[15]. This is important, as reported later, because UKCIP09 does not include these higher possible outcomes.

Several authors have highlighted that the omission of these higher sensitivities in most of the global economics literature – and the integrated assessment models and social cost of carbon estimates. Again this implies a systematic under reporting of economic costs of climate change, especially when median results are reported (Watkiss et al, 2005; Warren et al. 2006). Note that while some IAMs (PAGE and DICE) include some representation of these major events (being a combination of tipping elements and higher sensitivity), they are still considered partial.

This has been examined more recently in relation to the plausible, if unknown, probability of catastrophic climate change (Weitzman, 2009) and 'fat tails', where uncertainty is so large that the tails of the distribution are likely to dominate any conclusions, as the expected welfare loss is potentially unbounded.

Recent papers (Ackerman et al, 2008; Ackerman et al, 2009) report that the current models project modest changes in damages with temperature, even with very high temperature increases. They argue that such parameterization does not reflect the full range and upper values for uncertainty analysis, not the impacts of the rates of change. They also conclude that even IAMs which employ probability distributions and Monte Carlo analysis to represent uncertain parameters may therefore underestimate the worst-case risks, citing the example from Weitzman (2009) of extreme climate sensitivity, i.e. high temperature increases (10 – 20°C albeit with low probability) and associated impacts such as mass species extinction and biosphere ecosystem disintegration[16].

While this is primarily an issue for mitigation, it does lead to additional uncertainty and the risks of extreme outcomes (i.e. above the range reported in UCKP), and has relevance for adaptation particularly in relation to long lived infrastructure.

<u>Major Sea Level Rise from Tipping Points and/or High Climate Sensitivity: Wider Literature</u>

Brown et al, (2011)

Brown et al (2011) – as part of the EC FP7 ClimateCost study (Watkiss et al, 2011) - used the DIVA model to assess the economic costs of higher sea level rise in Europe, including for the UK. This considered a number of possible higher sea level rise estimates, including Rahmstorf (2007), who projected up to 1.4 m by 2100[17].

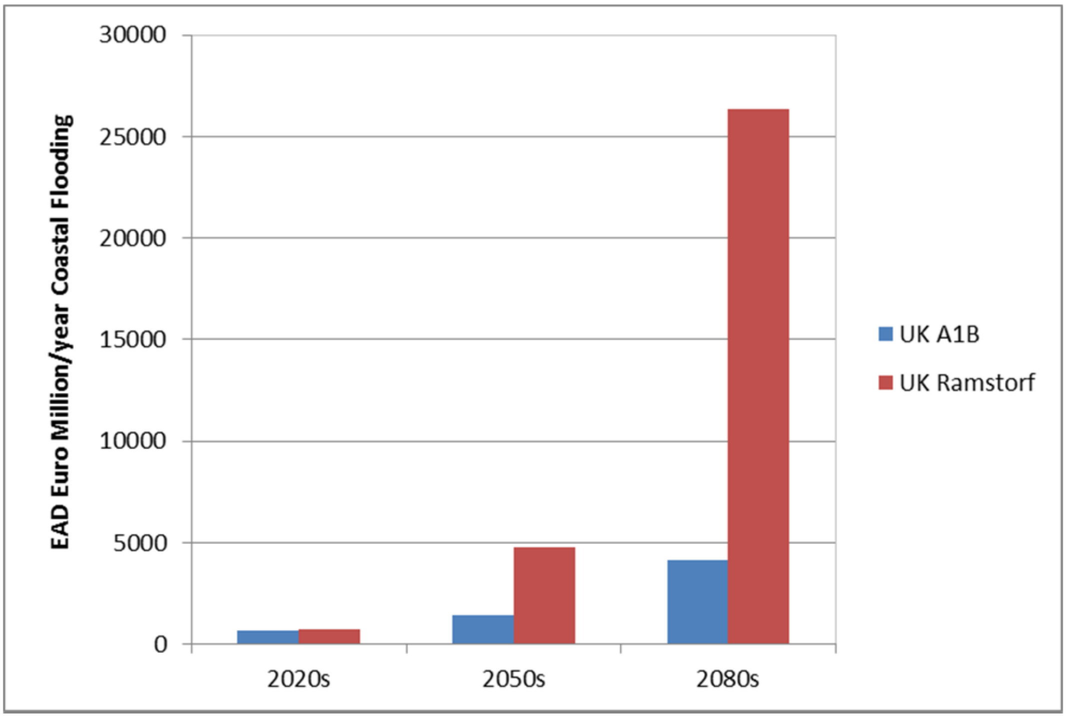
Whilst the uncertainties are high, a comparison of the results do somewhat contradict some of the messages reported in the CCRA, as the CCRA response functions for flooding show a levelling off as sea level rises because there are a limited numbers of properties in the floodplains, and the area of floodplains does not expand significantly with a high ++ scenario combined with storm surge (with

[15] http://www.climateprediction.net/

[16] In the mitigation domain, this a particular concern for the use of aggregated estimates in cost-benefit analysis (CBA) and optimization for mitigation policy. Undertaking a CBA for climate change relies critically on the assumption that marginal costs and benefits, as well as absolute costs and benefits, are finite. This is not necessarily the case as outlined by Tol (2003). As Weitzman identifies, the consideration of these extreme outcomes leads to radically different conclusions for policy from the conventional advice from standard economic analysis and formalized CBA.

[17] The report notes that Pfeffer et al., (2008) projected up to 2 m by 2100 and Lowe et al., (2009) and Vermeer and Rahmstorf (2009) projected upper estimates of up to 1.9 m by 2100.

the exception of the Thames Estuary, described above). The results for the UK as Expected Annual Damage (current prices, no discounting) are shown below, comparing an A1B(Image) scenario against the Rahmstorf projection, assuming no adaptation. Note that these values include the combined effects of socio-economic change (population and GDP) as well as climate change, they are thus not directly comparable to the CCRA results.



Expected Annual Damage Million Euro in the UK from Extreme Sea Level Rise. Combined effects of Socio-economic change and Climate Change.

Source Brown et al (2011) ClimateCost Study.

The figure shows that post 2050, there is a very large difference in the impact estimate, depending on the scenarios. By the 2080s, the annual damage costs in the UK for the Rahmstorf scenario are projected to be €26 billion/year (current prices undiscounted), some five times greater than for the A1B(I) Mid scenario (€4 billion/year). This finding was replicated at the European scale, with reported damage costs of €156 billion/year (Rahmstorf) vs. €26 billion/year (A1B). Note that the socio-economic scenario used for A1B and Ramstorf is similar, thus the marginal increase in the values is due to the additional climate change signal.

Thames Estuary 2100 (TE2100)

The main set of UK specific analysis on major sea level rise is included in the Thames Estuary 2100 (TE2100) project ((EA, 2009; 2011).The resulting TE2100 Plan provides a strategy for protecting London and property adjacent to the Thames estuary from tidal flooding to the year 2100 and beyond, taking account of climate change and the need to maintain and improve the existing system of flood defences.

The Plan was commissioned to provide an overarching strategy for managing the Thames tidal defences and to replace the multiple intermediate strategies. The cost of maintaining and improving current defences[18] was justified by the high value of assets protected, with over 1.25million people living and working in the tidal flood plain and £200bn of property at risk (EA, 2011).

The TE2100 Plan sets out a short-, medium- and long-term programme of investments and other recommended actions to manage tidal flood risk through to the end of this century, and beyond. Most notably it has adapted an iterative adaptive management approach to do this[19].

The TE2100 Plan
The plan examines multiple options to manage flood risk; focussing down on 10 options on which detailed appraisal was undertaken. For the first 25 years of the TE2100 Plan to 2034, the recommendation is for the existing flood defence system to be maintained and improved, at an estimated cost of £1.5bn (2009 prices). From 2035 to 2050, the recommendations are for a £1.8bn programme of renewal and improvement. Around 2050, a decision must be made on the 'end of century' option, to be in place by the year 2070. Current indications are that this might either be a new Thames Barrier in Long Reach, 17km (10.5 miles) downstream of the current Thames Barrier site or a major rebuild of the current barrier at Woolwich. But the decision - to be made in the 2050s - will depend on appraisal of conditions at that time. From 2050 to 2070 the new defence arrangements will be planned, designed and put in place. Beyond 2070, the defences will be maintained, improved and raised to accommodate climate change and other requirements. The cost of this third phase is estimated as £6bn to £7bn - depending on the 'end of century' option adopted. A major new structure such as a barrier commissioned in 2070 will have a design life of 100 years, and the Plan will therefore shape the management of tidal defences for London and the Thames estuary up until the year 2170. The plan reports an average benefit cost ratio[20] of 38.0, thus economic justification of TE2100 investment programme is high although there are some areas with lower benefits identified which are unlikely to justify full exchequer funding. As well as the economic appraisal, the study adopted a wider multi-criteria ranking of options, that implies full economic benefits are more than a factor of two greater than the quantified benefits alone.

In the context of this study, the plan is particularly interesting because it quantified high end and High ++ scenarios as part of the economic appraisal, and compared these to a '*do nothing'* (walk away) and '*just maintain'* current scenario options.

Four TE2100 climate change scenarios, and their associated degree of <u>extreme</u> water level rise by 2100, were considered:
- Low – around 0.5m of rise;
- Defra06 – around 1m of rise;
- Medium High – around 1.5m of rise;
- High Plus – around 2.7m of rise.

Note that it widely cited that TE2100 considered a High ++ scenario. Strictly speaking TE2100 considered a High +, but the levels considered were very similar to the UKCP09 High ++ scenario (up to 1.9 metres of average sea level rise plus storm surge levels of up to 0.95 metres).

[18] The existing Thames tidal defences are extensive. They comprise the Thames Barrier and eight other major moveable barriers owned and operated by the Environment Agency. There are 36 industrial floodgates and over 900 smaller structures in private ownership. The defence system includes over 380km of flood walls and embankments in over 3,500 different private ownerships. The current defences provide a high standard of tidal flood protection to London and property adjacent to the Thames estuary from Teddington in the west to Sheerness/Shoeburyness in the east (EA, 2011)
[19] It is stressed that the international adaptation literature widely reports that TE2100 undertook an economic real options analysis. This was not the case.
[20] B:C Ratio measured as present value benefits/present value costs for first 40 years of TE2100 Plan

Four socio-economic scenarios A-D were also considered. There were key “axes” of change in the scenarios: first, the degree to which the wider macro-economy continues to follow an increasingly market-based “finance capital” path versus a more socially managed approach; and secondly, the degree to which London continues to dominate the Thames estuary as a single “attractor”, versus a situation where more urban centres emerge as rival, multiple attractors. Assumed changes in appraisal variables from these scenarios were used to adjust the present values.

The study assessed the Annual Average Impact (numbers of receptors subject to flooding) under impact-probability curves. Upper and lower percentage bounds were used to adjust central estimates of the appraisal variables, to form “best” and “worst” case Benefit-Cost Analyses. Under the ‘High Plus’ climate change scenario and the ‘Central’ socio-economic change scenario – which assumes no change in social or economic conditions from Present Day, other than Thames Gateway as proposed. Values were presented as present values, through to 2170, using the conventional declining HMT scheme.

Thus the total PV is estimated at £81 billion for the do nothing scenario, and £31 billion for the do minimum (maintain existing) – thus the benefits of the latter are estimated at just over £50 billion. With the various adaptation options, the damages were reduced down very significantly, generally to under £5 billion, revealing very high benefit to cost ratios, thus the ‘do something’ options avert around £83-88bn of property damage. Additional damage costs were also estimated from Fatality and indirect impacts on business, as well as to agriculture and navigation. The estimated costs of these were £69,697 million for the do nothing scenario, leading to a total baseline (do nothing) costs of £151,328 million as a present value (£150 billion PV). The benefits derived from MCA implied values are even larger[21].

£m, PV to 2170	Total Property Damage	Total Other Monetary Dis-benefits
Baseline (walk away)	81,631	69,697
Do minimum	30,782	5,345
With adaptation	1,466 to 5,071	173

With a declining discount rate, an EAD of £1 billion a year over 100 years (i.e. a cumulative undiscounted damage of £100 billion) is reduced to a discounted present value of £29 billion with a standard 3.5% discount rate and £31 billion with the HMT declining discount rate (although the rate declines, values are low in future years, e.g. annual damages are reduced by one third even by the year 30, when the declining factors are introduced).
The values from TE2100 – of £59 billion PV (central) to £82 billion (high +) for property damage from coastal flooding alone (and £128 billion to £150 billion for total damages) therefore imply much higher damage costs than the CCRA. As an example, a PV of £60 billion is equivalent to a constant damage cost of £2 billion each and every year for 100 years.

[21] Note that property damages up to the year 2050 are £29,356 million PV for the do nothing – falling to £3,592 million PV under the do minimum. The increase in higher sea level rise from 2050 – 2170 while large, is reduced significantly because of discounting. Indeed, the results for the High + scenario (2.7 metre of sea level rise by 2100) do not increase that dramatically over the Defra central scenario (around 1 metre of sea level rise), again because of the effect of discounting on the present values. The total baseline costs (do nothing) of the central scenario are £128 billion PV, instead of £150 billion PV, as shown below. However, this level of sea level rise (a range from 0.5 to 1.5 metres with a central 1 metre level) is still much higher than that assessed in the CCRA.

The CCRA estimates that the EAD to residential property at risk in England and Wales due to tidal flooding under the medium scenario including climate change and principal growth in population (£ millions) is £400 million in the 2020s (p50), rising to £800 million in the 2050s (central p50) and £1300 million in the 2080s (p50). The equivalent values for non-residential property at risk of tidal flooding are £350 million in the 2020s (p50), rising to £650 million in the 2050s (central p50) and £1000 million in the 2080s (p50).

Risk Metric FL6b – EAD to residential properties at risk due to tidal flooding (England and Wales)

Table FL6b_02c - EAD to residential property at risk due to tidal flooding including climate change and principal growth in population (£ millions)

		2020s			2050s					2080s				
Nation	2008 baseline	Medium p10	Medium p50	Medium p90	Low p10	Low p50	Medium p50	High p50	High p90	Low p10	Low p50	Medium p50	High p50	High p90
England & Wales	212	350	400	500	550	750	800	900	1,150	850	1,150	1,300	1,450	1,900
Wales	49	60	70	70	80	90	90	100	120	90	110	120	130	150

Risk Metric FL7b – EAD to non-residential properties at risk due to tidal flooding (England and Wales):

Table FL7b_02c - EAD to non-residential property at risk due to tidal flooding including climate change and principal growth in population (£ millions)

		2020s			2050s					2080s				
Nation	2008 baseline	Medium p10	Medium p50	Medium p90	Low p10	Low p50	Medium p50	High p50	High p90	Low p10	Low p50	Medium p50	High p50	High p90
England & Wales	188	300	350	400	450	600	650	700	800	650	850	900	1,000	1,250
Wales	37	50	60	60	60	70	80	80	90	80	90	100	100	120

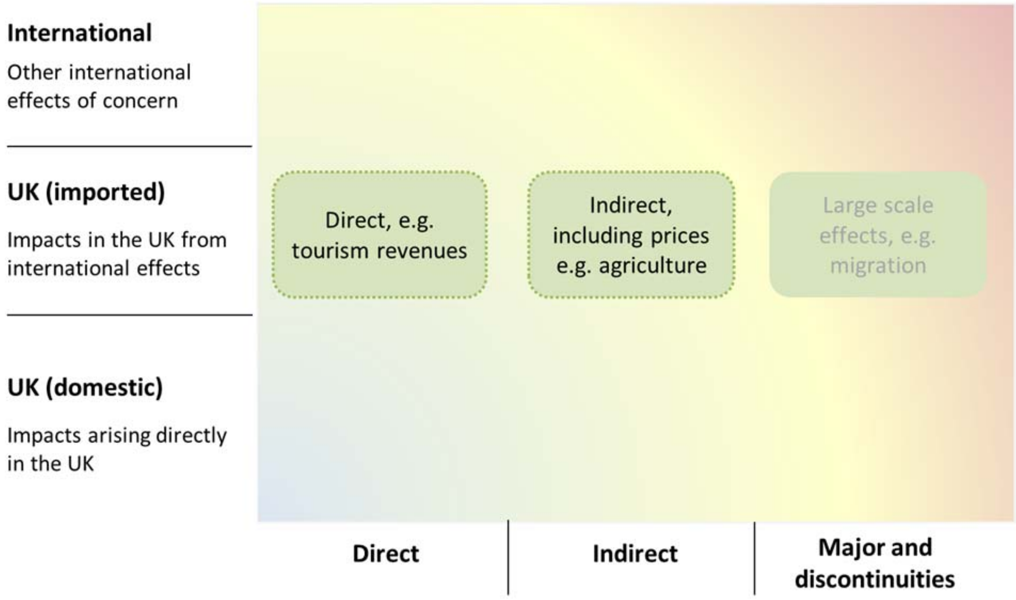
Over 100 years (to 2110), the total EAD for England and Wales for property damage of £700 million in the 2020s (p50), £1450 million in the 2050s (central p50) and £2300 million in the 2080s (p50) gives a total PV (over 100 year) of £33 billion with the declining discount scheme. This is still significantly lower than the estimated costs from the TE2100 analysis for the Thames Estuary corridor alone (59 billion PV (central) to £82 billion (high +) for property damage, and double this when other indirect damages are included. This indicates the potential scale of increase from these higher level scenarios in TE2100, though some care must be taken in directly comparing the two studies due to various methodological differences.

Summary

The sub-section above identifies that the CCRA explores the flooding impacts in the UK associated with a sea-level rise scenario above that projected by the main UKCP09 climate scenarios, but which is broadly consistent with sea-levels that would result from a number of bio-physical tipping points identified. However, potential impacts arising from other tipping points remain un-studied. For example, the direct impacts on the UK from a significant slow-down in the thermo-haline circulation are not yet studied in detail. Similarly, little analysis has been undertaken on the indirect impacts on the UK arising from tipping points occurring in other world regions – though the qualitative assessment of trade effects, migration and conflict, below, implicitly allow for the possibility of these type of events.

International Effects

This part of the review concentrates on the middle row the matrix, shown below.



Introduction

The world is currently characterized by a high degree of international inter-dependence, whether in the form of international trade flows, expanding human diaspora, or other forms of economic, social and cultural integration. Consequently, climate change impacts in one geographical region are likely to be transmitted by these inter-dependencies to other regions. Since the UK is a particularly open economy, with a population comprised of sizeable ethnic groups originating from a number of world regions, the likelihood of it being susceptible to any secondary effects resulting from international climate change impacts is likely to be high. Furthermore, since most global climate change impact assessments stress that the more severe impacts are likely to occur outside of Europe, the international effects of climate change impacts in the UK could be very significant.

On the basis of a survey of the literature, this section summarises the main impacts on the UK that have been identified as resulting from the effects of climate change in other countries. These impacts have been sub-divided in the top two rows of the matrix above. Though these dimensions have not been well researched to date, a recent Foresight study on the International Dimensions of Climate Change undertakes an initial assessment of the potential international climate change impacts, and how these may affect the UK (Foresight, 2011). The Foresight study, together with other recent literature, provides the foundation for this summary.

From the UK perspective, it is the left and middle cells within the second row of the matrix above that have been most investigated, and to which we give the most attention. These cells include the effects of climate change on international trade that affect the UK. In the following sub-section we summarise the existing evidence relating to these effects and place it more directly in its economic context.

The CCRA analysis

The CCRA did not cover the international aspects in detail, due to the on-going work on the Foresight study. It does, however, acknowledge the international effects of climate change and the results of this work, for example in the Evidence Report it notes:

Potential climate risks in other parts of the world are thought to be much greater than those directly affecting the UK, but could have a significant indirect impact here. These risks include effects on global health, political stability and international supply chains.

and
International risks could be as important as those that directly affect the UK and include climate impacts on global health, political instability and international supply chains that we depend on (Foresight, 2011a). Climate may also play a role in environmental degradation and international human migration patterns, which could affect the UK (Foresight, 2011b).

It also has a discussion on the implications for agriculture (including trade effects and food security) and the Foresight Future Food and Farming Project. It also featured considerable discussion on the relevance for business, noting the potential for disruption of supply chains, resources and commodities.

There was also some in the Evidence report on Climate Induced Migration
'Climate change related migration, if it becomes significant, could have an impact on UK demographic and influence the health needs of the population. The evidence, however, weak regarding the extent to which global migration will increase in the future and whether the UK would be significantly affected.' and possible factors that might emerge, citing the Foresight report.

The CCRA summarised the Foresight IDCC study (as below) and highlighted this was likely to influence priorities and urgency of some of UK adaptation actions, for example international water and food security issues may influence UK agricultural and land use policy, but did not explore further. It did, however, stress that

The development of an improved understanding of how international climate risks may disrupt UK society can be addressed by ongoing monitoring and regular review of potential risks. The cyclical nature of the CCRA is well suited to this purpose; there was limited analysis in this cycle but future cycles provide an opportunity for more detailed consideration.

Against this background, this study has explored the potential consequences of these international risks in more detail.

Climate change projections	• Uncertainties are large but do not diminish the need for policy makers to take action now
Geopolitics	• Leading to changes to UK alliances and trading partners
Tipping points in global system	• Catastrophic changes and ecosystem failures
International water security	• Water scarcity may lead to impacts on health, wellbeing, food production and manufacturing
International food security	• The UK imports 50% of its food; wide ranging risks and opportunities for the UK
International finance and trade	• The UK has a high exposure in the finance sector, which may not have fully recognised the risks
Changes in coastal processes	• Low lying coastal cities may be flooded disrupting production, shipping and trade
Oil/gas availability and transportation	• Any disruption to energy production and imports could have major global consequences
Early impacts in vulnerable countries – Africa	• Climate impacts in vulnerable countries may prompt faster action on climate change
Green policies / sustainable development	• International agenda and promotion of green economy in the UK may present opportunities for UK business

Foresight 2011

International Trade Effects

Extreme weather events, as well as changes in the means of climatic variables, are understood to have impacts on supply chains in which UK businesses and customers are a part. These impacts include, inter alia, changing conditions affecting the extraction and/or production of raw materials to be used in food and manufacturing processes and disruption to the transportation of raw materials, labour, capital or finished goods and services. There may also be impacts on the international demand for UK-produced goods if, e.g. climate change impacts on incomes in importing countries, as well as on the production of UK exports – both forms affecting the value of trade flows to and from the UK. These events are likely to have financial and economic costs associated with them that may only be partially mitigated by hedging and other risk management tools.

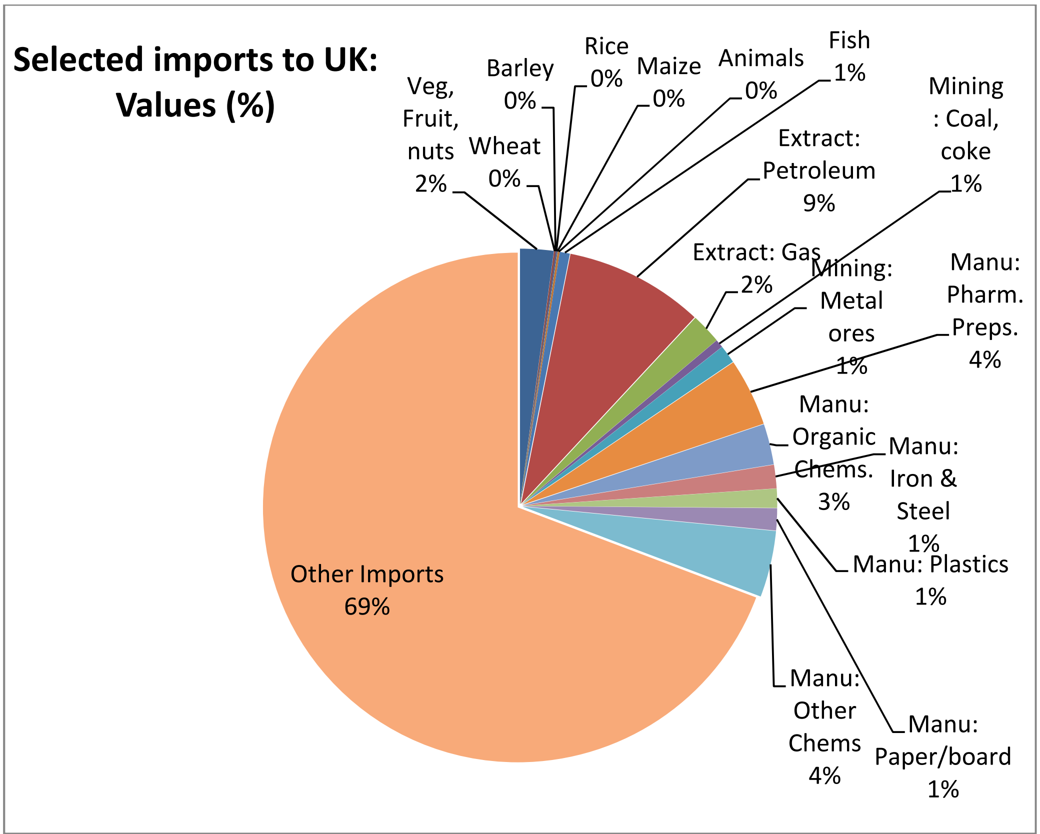
Recent research undertaken by the UK Met. Office, (Lewis et. al. (2010)), for the Foresight International Dimensions of Climate Change project, maps out in matrix form a variety of projected regional climatic changes to 2040 against current commodity patterns of trade between those regions and the UK. An indication of the magnitude of the potential economic impact is given in qualitative terms, along with the degree of uncertainty attached to the climate projections. This sub-section summarises the projected impact data reported in Lewis et. al. and presents it alongside data that shows which countries and regions are currently responsible for the largest export values of each commodity to the UK. This comparison therefore allows a first indication of what imports, and from where, are likely to be most vulnerable to climate change. Possible adaptation responses are also indicated.

Method

Lewis et. al. (2010) identify the sectoral split of UK imports in 2008 on the basis of the UK ONS classification system, and present the respective values of these sectors. These sectors include: Agriculture, hunting & forestry, Fishing, Mining & Quarrying, Manufacturing and Electricity and gas supply. Manufacturing is shown to dominate the total value of imports to the UK, comprising approximately 85% in 2008 (Ref.). Lewis et. al. consider the climate change impacts on a sample of the full list of import sub-categories. This sample was selected on the basis of expert judgement and was principally determined by their perceived relative sensitivity to climate change.

The relative size, in economic terms, of the sample sub-categories are detailed below for which we have up-dated the data to 2010. The figure shows that the sample represents 31% of total import value, of which the main components are Petroleum Extraction (oil) and the six manufacturing categories. The "Other Imports" therefore comprise those that are not selected as being notably climate sensitive.

Sample sub-categories: Economic value as % of total import value – UK, 2010.



The weather and climate sensitivities of these sectoral-based imports are then described on the basis of the available climate impact literature. The future projected trends in climate to 2040 and to 2100 under climate change scenarios are then identified. The SRES A1B scenario is used for the time period to 2040, using the HadCM3 general circulation model. In the period to 2100, by which time the alternative GHG emission paths are more easily distinguished from each other, an E1 scenario is also adopted. These climate change projections are then used to identify how the import climate sensitivities are likely to manifest themselves in future time periods. The climate change impacts that are therefore derived are then plotted geographically against the World regions from which the imports originate. The World regions are defined on the basis of climate, i.e. the similarity of climate across the region, and the resulting nine regions are known as Giorgi regions.

The regionally disaggregated climate change impacts are also given a rating that combines a ranking of the likely magnitude of the impact with a ranking of the degree of uncertainty attached to the impact to 2040 (where changes are unknown, there is some signal, or a clear signal). These two dimensions do not appear to be measured against any pre-existing metrics. Rather, they are each defined on the basis of a small number of categories defined and evaluated by the report authors. The resulting rating matrix is reproduced below.

Impact rating matrix

		Magnitude of Impact			
		Minimal Impact (0)	Low Impact (1)	Medium Impact (2)	High Impact (3)
Degree of Uncertainty	Changes Unknown (A)	A0	A1	A2	A3
	Some signal (B)	B0	B1	B2	B3
	Signal (C)	C0	C1	C2	C3

Source: Lewis et. al (2010)

In order to draw out the potential vulnerabilities of UK imports to climate change, we present the import-sectoral climate impact data derived in Lewis et. al. (2010), alongside the total value of these sectoral imports. Total import values are up-dated to 2010 – the most recent year for which data is currently available. We note however, that whilst this comparison provides a high-level signal of potential vulnerability the total sectoral import values do not necessarily reflect their true importance to the UK. For example, the future strategic importance of the commodities, and their value to wider national security concerns, are not distinguished within this measure. Similarly, their substitutability - domestically or internationally – is not reflected in this economic indicator. The relative importance of individual commodities is also not well-defined in this exercise.

Whilst Lewis et. al. do not consider adaptation responses to the climate risks identified, it is possible to make generic comments as to the implications of the risk type for the form of response. Consequently, as far as is possible, we do provide a broad indication of appropriate adaptation action alongside discussion of the sectoral risks in the following paragraphs.

Results

In the following three tables – we show the results for the ONS categories A1: Vegetables and fruits, nuts, C1a: Extraction of Petroleum and D1: Manufactures, respectively. These three sets of results are selected in order to highlight the climate risks that are projected to potentially impact on the economic sub-categories that are judged to be most vulnerable. Results for other sectors are given in Annex 1.

The first table relating to the import to the UK of vegetables, fruit and nuts, shows that the principal import sources are European countries – most notably Spain (17%) and Netherlands (16%). The grading of the identified climate risks suggest that all risks are expected to have either a medium or high impact, though the level of uncertainty attached to these impacts varies between the risks associated with changes in the means (of temperature, sea-level rise and CO2 levels), which have a strong signal, and the extremes (temperature, precipitation and storms), where the changes are judged to be currently unknown. Consequently, the nature of the adaptation response may be expected to differ between the two groups, with the former having more emphasis on specific adaptation options – for example, to exploit the new growing opportunities and to adjust crops to the changing conditions – and the latter placing more emphasis on flexible responses that exploit low-regret investments and/or that increase capacity to quantify risks of extreme weather events.

The second table presents the results for petroleum extraction. Imports to the UK are dominated by those from Norway and the Netherlands, extracted from the North Sea, as well as those from Russia. The table shows that only the risk of disruption from storms has a potentially high impact, though the uncertainty associated with such extreme events is judged to be very significant. The other identified risks are associated with changes in climatic means and relate primarily to the infrastructure. Adaptation responses are therefore likely to be technical and undertaken primarily in the design phase of new infrastructure investment.

The third identifies the climate risks associated with six manufacturing sub-categories. For all six of the manufacturing sub-categories considered the main source origin is Europe, within which Germany is dominant. The risks are grouped into i) those associated with the transportation of the manufacturing materials or products, and ii) the energy and water used in the manufacturing processes. The transport-related climate risks are primarily those associated with the risk of damage to infrastructure as a result of extreme weather events. Design standards may be expected to dominate adaptation responses if the projected costs of repeated repair are judged as being too great.

The efficiency of energy generation – whether associated with weather-related sources such as wind and hydro-power, or with reduced combustion efficiency – are judged to have moderate impact at most, though with varying degrees of uncertainty. Apart from the flood risk to sub-stations in flood plain – where an obvious response is to site new stations out of flood risk areas – adaptation appears likely to be dominated by technical design methods.

Water security is judged to be most threatened by drought risks that limit the supply of water for manufacturing processes, though potentially counteracted by more seasonal run-off becoming available. Whilst technical responses at individual sites may be expected to be introduced to store available water, such drought are likely to affect many economic and domestic sectors, highlighting the potential need for cross-sectoral responses to effectively and fairly ration water use.

Annex A presents the remaining summary results tables. The four Cereals & Grains sub-categories – wheat, barley, rice and maize – are projected to bear similar risks as the Vegetables, fruits & nuts sub-sector, as outlined above in Europe and South Asia (rice). They therefore benefit from reduced frost risks, and their potential Northwards expansion, whilst being at risk of damage from extreme weather risks. Livestock (A3), predominantly from Ireland, is identified as being potentially vulnerable to a number of risks, the largest judged to be the threat of heat stress to animal health in hot periods. Fish (B1) are currently sourced from a number of world regions. Whilst heat stress is again judged to be a risk to fish stocks, albeit with much uncertainty, ocean acidification is projected to be the most significant risk. Mining, (C2), whether of coal or metal ores, are also judged to have health risks from heat stress – to the mining workforce – and are principally borne outside Europe.

Summary Climate-Import impacts: A1. Vegetables and fruits, nuts

Region/Main countries	**% of UK Imports**	**Climate var.**	**Mean/ Extreme**	**Climate risk**	**Grading**
Europe & Med			M	Reduced frost risk to crop	C3
Spain	17%	Temp.	M	Northwards expansion of crops	C3
NL	16%		M	Crops already at climate thresholds likely to be vulnerable	C3
Belgium	6%		M	Greater risk of pests spreading Northward	B2
Germany	4%		E	Crop vulnerability to hot spells	C3
Italy	7%		E	Water stress from reduced summer rain reduces crop yield	B3
France	6%		E	Flood risk to crops - uncertain	A3
		Precipn.	E	Storm risk to crops - uncertain	A3
			M	Salt water intrusion risk to crops	B2
		Storms			
		SLR			
		CO_2	M	CO_2 fertilisation	C2
Value - Global Impacts to UK £bn	7.7				

Summary Climate-Import impacts: C1a - Extraction of Petroleum

Region/ Countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	M	Dried soil - Subsidence risk to industry infrastructure	A2
Norway	46%	Temp	M	Less ice on off-shore decks	C1
NL	7%	Precipn.	M	Decrease in precipn affects efficiency of extraction	A2
Belgium	1%	Humidity	M	Design consideration for rigs - uncertain	A1
Germany	2%	Storms	E	Potential for disruption - uncertain	A3
North America		SLR	M	SLR combined with storm surge disruptive	B2
USA	2%	Ocean currents	M	Affects rig stability - uncertain	A0
Central & N. Asia					
Russia	8%			As Europe	
Central & S. America					
Venezuela	1%			As Europe	
Africa					
Nigeria	2%			As Europe	
Algeria	1%				
Libya	4%				
Value of Global Impacts to UK £bn	32				

Summary Climate-Import impacts: D: Manufactures

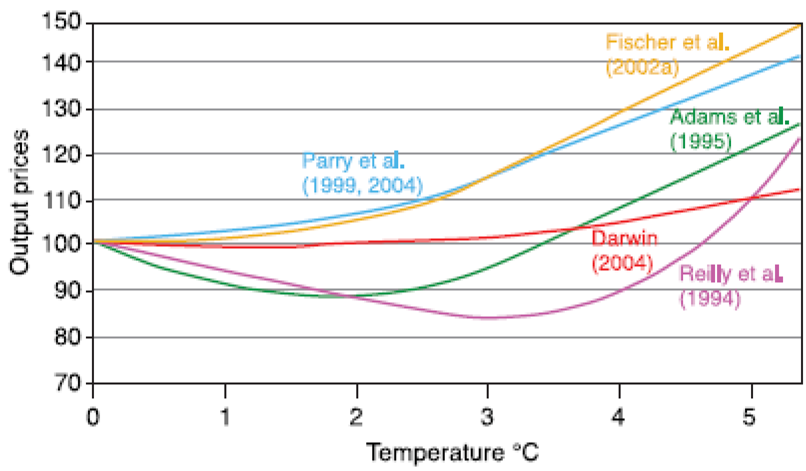
D1. Pharm. preps	D2. Other org. chems	D3. Iron and steel	D4. Plastics	D5. Paper/board	D6. Other Chem.					
% of UK Imports						**Manu. Risk**	**Climate var.**	**Mean/ Extr.**	**Climate risk**	**Grading**
Europe & Med	*Europe & Med*	*Europe & Med*	*Europe & Med*	*Europe & Med*	*Europe & Med*	*Reg. Transp.*	Temp	E	High temps cause infrastructure damage	C2
Germ. 14%	Germ. 10%	Germ. 16%	Germ. 23%	Germ. 20%	Germ. 19%		Precipn	E	Flood & subsidence risk	B1
Fr. 6%	Fr. 8%	Fr. 9%	Fr. 10%	Fr. 9%	Fr. 15%		Storms	E	Damage to transport infrastructure	A2
Sp. 4%	Sp. 2%	Sp. 7%	Sp. 2%	Sp. 2%	Sp. 3%		SLR	M	Risk to coastal infrastructure	C2
Italy 5%	Italy 1%	Italy 8%	Italy 4%	Italy 4%	Italy 5%		Reg. Circ.	E	NAO changes - warmer winters & less disruption	
Switz. 9%	Switz. 3%	NL 7%	NL 17%	NL 6%	Switz. 1%					
NL 11%	NL 11%	Belg. 7%	Belg. 21%	Belg. 4%	NL 10%	*En. Sec*	Temp	M	High temps reduce combustion efficiency; reduces cooling ability of water; affects infrastructure & energy demand	C2
Belg. 11%	Belg. 6%	Ire. 1%	Ire. 2%	Ire. 1%	Belg. 7%		Precipn	M	Changes in precipn may affect hydropower	A2
Ire. 8%	Ire. 28%	Swe. 5%	Swe. 1%	Swe. 12%	Ire. 6%			M	Changes in precipn may affect ability to cool power stations	B2
Swe. 2%	Swe. 1%	Czech 2%		Pol 1%	Swe. 1%			E	Flood risk to sub-stations in flood plain	B2
		Aus 2%		Aus 2%	Pol 2%		Storms	E	Damage to energy infrastructure plus flood risk	A2
N. America	*N. America*	*N. America*	*N. America*	*N. America*	*N. America*		Wind	M	Change to patterns may impact on wind power generation	A1
USA 17%	USA 5%	USA 3%	USA 6%	Can 2%	USA 10%		SLR	M	Risk to coastal infrastructure	C2
				USA 4%						
	East Asia	*East Asia*	*East Asia*	*East Asia*	*East Asia*	*Water Sec*	Temp	M	High temps - greater demand for water & conflict	B1
	China 3%	China 4%	Japan 1%	China 6%	China 4%		Precipn	E	Drought limits production & power generation	B3
		Japan 3%			Japan 2%			M	Greater surface run-off enhances water availability	B1
	South Asia	S. Kor 1%						M	Changes in precipn may result in water stress	A2
	India 2%	*South Asia*					Storms	E	Risk to water storage & availability	A2
		India 2%					SLR	M	Salt-water intrusion to coastal aquifers	C1
Value to UK £bn 15.6	9.4	5.4	4.4	6.1	15.3		Reg Circ	M	NAO changes leading to more precipn. and water availability	

Discussion

The preceding paragraphs summarise and elaborate on a recent assessment by Lewis et. al. of the potential effects of climate change on commodity imports to the UK. Whilst the assessment is essentially qualitative it does provide a rating of the size of potential impact, combined with the level of attendant uncertainty, which we have placed more directly in the context of total import values. The ratings appear to suggest that though the highest import values relate to the manufacturing and oil extraction sectors, the most significant impacts are borne by imported agricultural commodities.

This suggests that – as well as recognising its fundamental role in human well-being – the focus on food in quantitative modelling to date correctly reflects the relative importance of climate in its production. Indeed, quantitative data is likely to be essential in identifying the welfare impacts of changes in the supply of food commodities to the UK, and the scale of response that might be required. The IPCC Fourth Assessment Report (Easterling et. al. 2007) provides a synthesis of the quantitative modelling of world market prices for cereal prices as projected global temperatures rise. These are presented below and show a gradually steepening rate of increase in prices beyond temperature increases of 1^{o}C, reflecting the fact that the relatively benign effects, identified above, of CO_2 fertilisation and northwards expansion of crop areas are found to be outweighed by water constraints and heat stress as temperatures rise. Subsequent studies seem to confirm - and exacerbate - this pattern of increasing prices. For example, Nelson et. al. (2010) find that maize, rice and wheat prices are projected to rise by 18-34% by 2050, depending on population and climate scenarios adopted.

Cereal prices related to global mean temperature change: study findings (% of baseline)



Source Easterling et. al. 2007

Further, it is possible to model these price changes to show how profitability of the food industry might be affected. For example, the changes in food prices identified by Parry et al. (2004) are interpreted in Hunt et. al. (2009) in terms of changes in input costs to the Food and Drink sub-sectors. An own price elasticity – assumed to be of 0.5 – dictates the extent to which the cost increases can be passed on to consumers. The resulting changes in input costs borne by the firms within the sub-sectors are then expressed in terms of the percentage by which they reduce the Gross Operating Surplus (GOS), adopted as a proxy for profit levels – see Table below.

The four sub-sectors whose profitability is most vulnerable under the future climate change-induced price scenarios are highlighted in the table, in bold italics: Production and preserving of Meat and Poultry Meat, Operation of dairies and cheese making, and Manufacture of prepared feeds for farm animals. In these sectors, profitability is reduced by 10-20% in the 2020s and by 20-40% in the 2080s.

Cost increases expressed as % of UK Food & Drink sub-sector GOS in future time-periods

Sub-sector	2020s	2050s	2080s
Production and preserving of meat	***12.4***	***14.3***	***24.8***
Production and preserving of poultry meat	***11.1***	***12.9***	***22.3***
Production of meat and poultry meat products	7.4	8.6	14.8
Processing and preserving of potatoes	1.8	2.1	3.6
Processing and preserving of fruit and vegetables	4.6	5.3	9.3
Operation of dairies and cheese making	***19.5***	***22.5***	***39.0***
Manufacture of ice cream	2.4	2.8	4.9
Manufacture of prepared feeds for farm animals	***19.5***	***22.5***	***39.1***
Manufacture of bread, cakes etc	2.9	3.4	5.9
Manufacture of rusks and biscuits	3.4	4.0	6.9
Manufacture of cocoa; chocolate and confection	1.6	1.8	3.2
Processing of tea and coffee	2.0	2.3	3.9
Manufacture of condiments and seasonings	3.9	4.5	7.9
Manufacture of other food products	3.2	3.7	6.4
Manufacture of beverages	1.6	1.8	3.2

Case Study: 2010 Thai Floods – Supply chain disruption.

The floods that affected Thailand extensively in October and November provide a recent example of the extent to which supply chain disruption in the currently highly integrated global manufacturing and services markets results in economic consequences. The country's role as a leading supplier of manufacturing components – particularly in the automotive and high-tech sectors – resulted in global disruption in these sectors and price increases of 20-40 percent. The country that has been hardest hit is Japan - Toyota, Honda, Hitachi, and Canon all have plants in Thailand that were severely disrupted; profit projections of Toyota were cut by US$2.5 billion. Similarly, Thailand is the world's 2nd largest producer of hard disk drives, accounting for approximately 25% of the world's production. Many of the factories that make hard disk drives were flooded leading to worldwide shortages of hard disk drives in the short-term. The flooding also had serious local economic effects: seven industrial estates close to Bangkok led to 650,000 people being made temporarily unemployed. The World Bank estimated that the total economic cost of flood damage was US$45.7 billion[22].

[22] World Bank, in AON Benfield (2012) 2011 Thailand Floods Event Recap Report Impact Forecasting — March 2012

The concern that manufacturing purchasers might switch to alternative suppliers who are not judged to be at flood risk has prompted the Thai government to seek international finance to make investments in long-term flood prevention projects. This is additional to $10 billion that had already been earmarked for post-flood restoration.

Climate Change Impact on Foreign Demand for UK Exports and Imports

Tourism

A direct effect of international climate change on the UK is that results from changes in tourism numbers to the UK, originating from other countries, and from the UK to other countries. This is because the majority of tourism – particularly summer tourism - is closely associated with climate, in terms of the source of tourists and their preferred destination. For example, at present the predominant summer tourist flows from the UK are to the Mediterranean coastal zone. This region is the world's most popular holiday region: it attracts some 120 million visitors from Northern Europe each year, the largest international flow of tourists on the globe and their spending is in excess of 100 billion Euros (EEA/JRC/WHO, 2008).

With growing income and increasing leisure time, the tourism industry in Europe is expected to continue to grow. However, mean temperature increases are likely to change summer destination preferences in Europe, with strong distributional effects. The effect of climate change is thought likely to make outdoor activities in northern Europe including the UK more attractive, while summer temperatures and heat waves in the Mediterranean, potentially exacerbated by limited water availability, may lead to a redistribution or a seasonal shift in tourism away from the current summer peak, either to a bi-modal distribution either side of the summer peak, or a transfer to other more northerly regions of Europe, which become more attractive, as shown in modelling work within the PESETA project (Amelung & Moreno, 2011). The potential shift in the major flows of tourism within the EU will be important in regions such as some Mediterranean regions, where tourism is a dominant economic sector, though autonomous adaptation responses will be critical.

Analysis by Hamilton and Tol, in Metroeconomica, (2006), models the tourism flows in Europe with and without climate change to 2100. Results are presented in **Error! Reference source not found.** Table below. For all the countries listed here, and all climate and socio-economic scenarios, the number of inbound tourists increases. Population growth and economic growth in the rest of the world cause the shift in the balance. The impact of climate change is either to increase the rate of growth – for example, in the UK– or to decrease the rate of growth – for example, Spain and Italy. The analysis also shows changes in country-specific patterns. For example in the UK, climate change amplifies the shift towards more inbound tourists relative to outbound. This is because the UK becomes more attractive for UK citizens and so holidays abroad are replaced by domestic holidays; in addition, the UK becomes more attractive for tourists from abroad. By the 2050s, for all of the climate change scenarios, there are more tourists arriving from abroad than there are tourists leaving the UK.

A projected increase in the number of visitors to the UK as a result of climate change in the UK and elsewhere, combined, has potential positive effects on the operations of tourism-related businesses in the UK, in terms of increased revenues. There may, however, be associated pressures on e.g. infrastructure provision and water resources in UK regions such as SW and SE England, Wales and Scotland, thought likely to be most popular. Adaptation to cope with increased visitor numbers would then need to be incorporated in the strategic planning process within potentially affected regions (Hunt et. al. 2009).

In-bound tourists - selection of European countries for the High scenarios, with and without climate change for the time slices 2020s, 2050s and 2080s (Millions)

	With climate change			Without climate change			Difference		
Inbound tourists	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
Czech Rep.	46	126	213	51	125	194	-5	1	20
Denmark	2	3	5	2	3	4	-0.2	0	0.4
France	77	109	153	89	123	167	-12	-13	-15
Germany	20	32	48	23	32	44	-3	-0.2	4
Greece	13	18	24	16	23	32	-3	-5	-8
Ireland	6	8	12	7	9	12	-0.9	-0.8	-0.4
Italy	40	56	76	47	67	93	-7	-12	-17
Netherlands	9	12	17	10	13	18	-1	-1	-0.4
Spain	48	67	91	58	81	113	-10	-14	-22
Sweden	4	6	10	4	5	6	0.1	1	4
UK	42	88	176	46	89	163	-4	-0.6	13

Water Stress and Embodied Water

Allan (1998) and more recent analysis by Chapagaina and Hoekstra (2008) have reported that in aggregate, the UK currently is a net importer of water, with approximately 70% of the total water generated in consumption and production in the UK being imported from other countries in the form of water embodied in the production of these imports[23].

Rather surprisingly, this makes the UK one of the more import water dependent countries in the world. This is a striking statistic, particularly given that imports equate to only 15% of total UK output (Office for National Statistics (2011)).

Climate change will affect water availability, and while these effects vary strongly, and involve increases and decreases, it is generally reported that semi-arid and arid areas will be particularly exposed to the impacts of climate change (Kundzewicz et al, 2007), i.e. it will exacerbate problems in existing areas of water stress. Given high embodied water imports in the UK, this therefore seems to be a priority area for consideration.

Climate Change Impacts on UK Overseas Business Interests

Introduction

Additional to the direct impacts of climate change on UK trade identified above, the UK Financial Services sector has been identified as having significant potential exposure to international climate change impacts. Two elements of the financial sector in the UK are thought to be particularly vulnerable to climate change impacts projected internationally (Hunt et. al. 2009). First, the insurance and re-insurance is exposed to the projected increase in frequency of extreme weather events globally to the extent that it provides cover to health and property that is vulnerable to such

[23] "Embodied water" is a term that describes the quantity of water used in the production of a given economic output.

events and whose cost is not internalised in the premiums asked for such cover. Extreme events such as Hurricanes Mitch and Katrina are illustrations of the types of risk that may need to be covered.

Second, the banking and insurance sectors are exposed to the extent that they hold physical assets that may be vulnerable to changing climate – either through extreme events or through changes in mean values. For example, a bank lending to a company that owns a port in a country whose coastal geography makes it particularly susceptible to sea level rise and associated storm surges will have a liability that grows in size over time. Again, the financial sector exposure will be determined by the extent to which the increased risk is captured within the contract agreed between the parties. The principal risks, as well as opportunities, are outlined in the Table below (over the page) along with the implications for the sector.

Summary of Climate Change risks and implications for UK Finance sector

Risk	Global/regional Implications	Implications for UK	
		Direct	**Indirect**
Food scarcity & water stress Ecosystem degradation Increased Increased transport disruption Infrastructure damage Property damage	- Global food rationing, migration & civil unrest. - Civil unrest, - international disputes - worsening international security - Ecosystem collapse or reduction in ecosystem services - Slowdown in global trade Increasing energy & water costs	- Increased insurance claims, - default on loans, - reduced returns on investments - redirection & loss of foreign wealth and capital - reduction in business opportunities - increased commodity price volatility	- Reduction in globalisation and loss of international financial activity - impact on inflation, interest rates and consumer spending - increased uncertainty - reduced access to resources, -reduced international cooperation. - Opportunity for risk management products, low carbon and climate-resilient finance.
Increase in heat related mortality	Increased humanitarian burden	Increased demand for aid and life insurance claims	
Increase demand for low carbon products	High demand for low carbon and low water use products	Increased opportunity for manufacturing, carbon finance and research and development	UK opportunity to be a leader of global low carbon economy
Increased demand for climate risk management	Greater awareness of climate risks and demand for financial products to manage this risk	Innovative insurance and other risk management products and services. Financing for adaptation and climate resilient growth	

Source: Adapted from Silver et. al. (2010)

The UK financial services sector primarily includes insurance services and banking and investment, associated with financial risk and capital management. Thus, the five main functions of the sector are identified as being:

i. transfer and pooling of risk;
ii. provision of access to capital;
iii. asset management;
iv. intermediary services, and;
v. advisory services.

The sector as a whole contributed £129 bn to the UK economy in 2010, equivalent to just under 9% of GDP (Office of National Statistics, 2011) In economic terms, functions i)-iii) are by far the most important, comprising approximately 90% of the total sectoral value. From an economic welfare perspective, these functions may be understood – in the simplest terms - as serving to increase exchange efficiency through providing markets that facilitate net welfare gains from exchange.

Direct overseas exposure to UK financial services is dictated by the degree to which these functions are offered to those in non-UK markets and the degree to which non-UK financial services are offered in the UK.

For (i), total UK overseas insured risk equated to £65 billion in 2008, equivalent to about 25% of the total UK insured risk. Long term insured risk comprises 65% of the UK total. The overseas insured risk is dominated by exposure in mature economies; of long term overseas insured risk, 50% is in the EU whilst 37% was in North America.

For (ii), banking service export earnings from overseas lending equated to £31bn, or 35% of total UK banking lending earnings in 2008 (Office of National Statistics, 2010). Of the overseas lending, approximately 60% was to mature economies – the largest single economy borrower being the US – whilst about 40% was to emerging markets, the five largest being China, South Africa, Brazil, India and United Arab Emirates (TheCityUK, 2011).

For (iii), £1.11 trillion of overseas assets were managed by UK financial services, equivalent to 30% of total UK asset holdings. Around two-thirds of these assets are located in the EU, whilst 16% is in the Americas (IFSL, 2009). These assets can be regarded as similar to those resulting from UK foreign direct investments, (FDIs), where the overseas physical assets are owned by UK companies. In turn, these are related to overseas portfolio investments which comprise of UK ownership of stocks in overseas companies. Income to the UK from FDI and overseas portfolio investments were £82 billion and £47 billion, respectively. In the subsequent assessment, these assets are considered as being equivalent and so are not distinguished from each other.

As noted by Silver et. al. (2010) the UK financial service sector accommodates a significant number of organisations that are foreign-owned. For example, of UK Banking sector assets, around 50% are foreign owned. Of this 50%, one-half are owned by EU companies whilst one-third are US-owned.

Climate Change Impacts

The most thorough assessment of the potential impacts of overseas climate change on the UK financial sector was undertaken by Silver et. al. (2010) as part of the Foresight Futures International

Climate Change Impacts project (Government Office for Science, 2010), and include a overall assessment, together with two more detailed case studies in the European and Indian contexts. The authors undertake a qualitative analysis of the sector's vulnerability to international climate change impacts on the basis of the three functions highlighted above. The impacts are primary, secondary and tertiary impacts occurring in four sectoral groupings, and are considered according to scenarios differentiated on the basis of a pro-active or reactive response by the sector, and society more generally, to limiting climate change through GHG mitigation, as well as the health of the economy, i.e. robust or fragile. These means of disaggregating the impacts are summarised below.

Disaggregation descriptors in Financial sector climate change impact assessment

<table>
<tr><th>Impact assessment: Dimensions</th><th colspan="12">Descriptors</th></tr>
<tr><td>Impact category</td><td colspan="3">Agriculture, forestry and ecosystems</td><td colspan="3">Water resources</td><td colspan="3">Human health</td><td colspan="3">Industry, settlement and society</td></tr>
<tr><td rowspan="2">Impact pathway stage</td><td colspan="4">Primary
Direct impact on sector, e.g. increased water scarcity</td><td colspan="4">Secondary
Social or environmental response, e.g. Introduction of water pricing</td><td colspan="4">Tertiary
Response in global economy, e.g. economic contraction</td></tr>
<tr><td colspan="4">Direct impact on financial services, e.g. insurance claims</td><td colspan="4">Indirect impact on financial services, e.g. inability to do new business in contracting global markets</td><td colspan="4">Impact on wider UK economy, e.g. higher interest rates</td></tr>
<tr><td>Vulnerability

Exposure – Resilience combinations: Most vulnerable where low resilience combines with high exposure</td><td colspan="6">Exposure
Geographical; Propn. of business.

5-point scale: Low - High</td><td colspan="6">Resilience
Business adaptability; Congruity of decision-making time frames

5-point scale: Low - High</td></tr>
<tr><td rowspan="3">Scenario</td><td colspan="6">Pro-active
Business response to climate change based on early internalisation of decarbonisation.

E1 GHG emissions mitigation scenario.</td><td colspan="6">Reactive
Business response to climate change based on "wait-and-see" approach.

A1 SRES GHG emissions</td></tr>
<tr><td colspan="6">Robust
Appropriately regulated and is resilient to shocks</td><td colspan="6">Fragile
High level of volatility and high responsiveness to internal and external shocks.</td></tr>
<tr><td colspan="6">Current Economy
National and regional GDP has current pattern</td><td colspan="6">Future Economy
National and regional GDP projected to 2050 shows relative growth in BRIC countries plus Indonesia, Turkey and</td></tr>
</table>

		Mexico.

Based on an assessment of the exposure-resilience combination judged to be most appropriate, Silver et al. (2010) undertake a vulnerability mapping of the different functions of the UK financial sector against climate change impacts. The findings of this mapping are summarised below.

International Climate Change Vulnerability mapping of UK Financial Sector

	REACTIVE ROBUST		REACTIVE FRAGILE		PROACTIVE ROBUST		PROACTIVE FRAGILE	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
			Primary: Transfer and pooling of risk					
AFE								
WR								
HH								
ISS								
			Primary: Access to capital					
AFE								
WR								
HH								
ISS								
			Primary: Asset management					
AFE								
WR								
HH								
ISS								
			Secondary: Transfer and pooling of risk					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Secondary: Access to capital					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Secondary: Asset management					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Tertiary: UK and Global Economy					
	•	•	•	•				

Legend: green (low vulnerability), yellow (low to medium vulnerability), orange (medium to high vulnerability) and red (high vulnerability), grey (negligible effect); Black dots indicate the potential for low probability high impact events to occur; AFE = Agriculture, Food and Ecosystems; WR = Water Resources; HH = Human Health; ISS = Industry, Settlement and Society.

Whilst the analysis does not attempt to assess the likelihood of the impacts - and therefore the level of industry risk – there are a number of notable findings. These include the following:

- Opportunities for sectoral growth may arise as a response to the need to transfer risks associated with extreme weather events from e.g. agricultural production to insurance markets;
- Whilst human health impacts are significant as a primary impact in insurance markets, they are less likely to result in secondary and tertiary impacts. In contrast, the secondary and tertiary impacts of water resource scarcity are much more important than the primary impacts;
- In the absence of tertiary impacts, access to capital is judged to be the most vulnerable function of the financial sector, reflecting its relatively high exposure to currently emerging economies where climate change risks are projected to be more significant;
- The insurance industry is less vulnerable, due to its relatively low current level of exposure in these economies, and its greater expertise in risk management of weather events, though high levels of interdependence with the banking sector's asset access and management functions ensures continued vulnerability;
- There is little difference in vulnerability from impacts associated with direct overseas business and those associated with indirect business, such as UK clients who have exposure via overseas supply chains;
- As a result of the UK financial sector's eminent role in the international financial system, the severity of risk to the financial sector depends – in part - on the extent to which the climate impact manifests itself more widely in terms of wider and global market disruption and distortion, i.e. through secondary and tertiary impacts;
- The severity of risk to the financial sector also depends on the extent to which the economy is robust in its ability to adapt to climate change and pro-active in its management of GHG mitigation. More opportunities for financial sector growth are evident within a pro-active economy;
- Low probability – high impact events, such as regional ecosystems and bio-physical shifts resulting from THC slowing, are associated with the more severe impacts on the financial sector. These events are judged as possible precursors to significant shifts and contraction in a range of the most important global economic markets and the supporting financial activities;
- Over the next few decades, climate change risks in the principal emerging economies are likely to be significant in shaping their patterns of economic development and the consequent opportunities and risks facing the UK financial sector in these economies;
- Existing markets in currently developed countries will also face more negative climate impacts in more distant future time periods, with greater risks of secondary and tertiary impacts in the UK financial sector (Silver et. al. (2010)).

Other International Effects of Concern

The top row of the matrix signals that there are a further category of climate change impacts that are projected to occur outside of the UK but which are thought likely to affect the welfare of UK citizens. Direct effects include those that occur on the UK's Overseas Territories (OTs) and those that affect UK citizens whilst travelling abroad, most notably health. A wide range of projected international climate change impacts are also envisaged to have repercussions on the mechanisms by which the UK involves itself with the rest of the world, including the management of international security and migration, and the support of international development. These concerns are motivated both by the UK's self-interest, and ethical criteria based on fairness and other altruistic considerations. These areas of concern are outlined in the following sub-sections.

Overseas Territories

The UK has 14 Overseas Territories, and 3 Crown Dependencies. Of these territories and dependencies, all except Gibraltar and British Antarctic Territory are small island states (SISs). As SISs, therefore, they are particularly vulnerable to sea-level rise, and associated problems of salinization of freshwater and soil, as well as damage to coastal infrastructure and loss of land. The IPCC Fourth Assessment Report judges that "Small islands … have characteristics which make them especially vulnerable to the effects of climate change, sea level rise and extreme events (very high confidence)" (Mimura et al, 2007, quoted in Betts, (2010)).

Sears et. al. (2001) report that coral reefs represent the most important coastal system components that are significantly threatened since the coral protection and buffering that they provide will be lost. Nicholls and Kebede (2010) argue that the potential loss of protection to mangroves, sea grasses and other coastal ecosystems will lead to further loss of ecological habitats and coastal erosion problems and combine with additional stresses such as ocean acidification to threaten the wellbeing of the natural and human systems on most of these small islands. Whilst no assessment of the consequent welfare impacts has been made for the OTs collectively, a number of studies in the Caribbean make quantitative estimates of the costs of climate change. For example, the Table presents estimates made by (Bueno et al. 2008) of the impact costs on a number of islands resulting from infrastructure and hurricane damage as well as the loss in tourism revenues, expressed as a percentage of current (2008) GDP. Whilst these estimates are made on the basis of only a partial coverage of the potential impacts, these totals are clearly very significant for the future development of these islands, and the need for adaptation appears to be urgent.

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Costs of Inaction to Climate Change – Caribbean OTs (% of 2008 GDP)

Island	2025	2050	2075	2100
Turks & Caicos	19.0	37.9	56.9	75.9
Anguilla	10.4	20.7	31.1	41.4
Monserrat	10.2	21.7	34.6	47.9
British Virgin Islands	4.5	9.0	13.5	18.1
Cayman Islands	8.8	20.1	34.7	53.4

Health

The international impacts of climate change on health have a number of effects on welfare related to the UK:

1. Changes in the incidence of disease as a result of climate change may affect UK citizens who are travelling in affected overseas areas. Similarly, it is conceivable that certain diseases may spread from other countries to the UK.
2. Health impacts arising from changing patterns, frequencies and intensities of extreme weather events overseas may be significant on affected populations and elicit expressions of sympathy by UK citizens. As a result, a number of initiatives and policies in the context of the United Nation's International Strategy for Disaster Reduction (UNISDR) and the World Health Organisation

(WHO), and contributed to by the UK, are currently being instigated to increase the effectiveness of the international response to such events.

3. In the event of climate-related migration to the UK, there may be increased pressure on health service infrastructures.

The potential international health risks to the UK are surveyed by Grynszpan et. al. (2010) as part of the Foresight International Dimensions of Climate Change project. They found that, as a consequence of the lack of epidemiological modelling of climate-health linkages, combined with a lack of consideration of other important factors such as ecological changes, economic development, changes in land use, population growth, migration and urban expansion and development of public health infrastructures. Little quantitative analysis had been undertaken of the health risks. However, they identified the following groups of risks as being potentially significant to the UK over the next century:

- Changes in conditions for food and water-borne diseases as resources become more scarce, in Sub-Saharan Africa and South Asia. These may result in e.g. malnutrition and diarrhoea, which themselves are likely to give rise to calls for increased, or targeted, development resources from the UK, or through pressures on the UK population to support relatives abroad.
- Changes in conditions for vector-borne diseases such as malaria and dengue may also require UK health care resources, either as part of development aid or domestically as a result of being transported into the UK. For example, tuberculosis is especially prevalent in sub-Saharian Africa and South-East Asia (WHO 2010), and immigration to the UK from these areas would increase health care resources devoted to their treatment.
- Changes in patterns of extreme weather events that result in human health consequences and that therefore justify humanitarian assistance to the victims. These include the short-term consequences such as injuries and water-borne disease resulting from floods, as associated with the Pakistan floods of July 2010, and the longer-term effects on mental health, including depression and post-traumatic stress disorder.

UK in the World

<u>International Development</u>

As a country with relatively high levels of income and wealth, the UK – represented by its Government – recognises an obligation to encourage and facilitate development in other world regions that currently have high levels of poverty. The internationally agreed Millennium Development Goals (MDGs) are concrete representations of what the UK – with other partner countries – aim to achieve in this respect. UK Government policy also has a range of supporting aims including: 1) Introducing greater transparency in aid; 2) Boosting wealth creation; 3) Strengthening governance and security in fragile and conflict-affected countries; 4) Leading international action to improve the lives of girls and women, and; 5) Combatting climate change (Department for International Development (2011).

There is a substantial literature that demonstrates that vulnerability to the impacts of climate change, and the ability to respond to those impacts, are highly correlated with the level of overall social and economic development in a country and region (Schelling, 1992). Therefore as long as the actions of the UK Government and its operating Departments such as the Department for

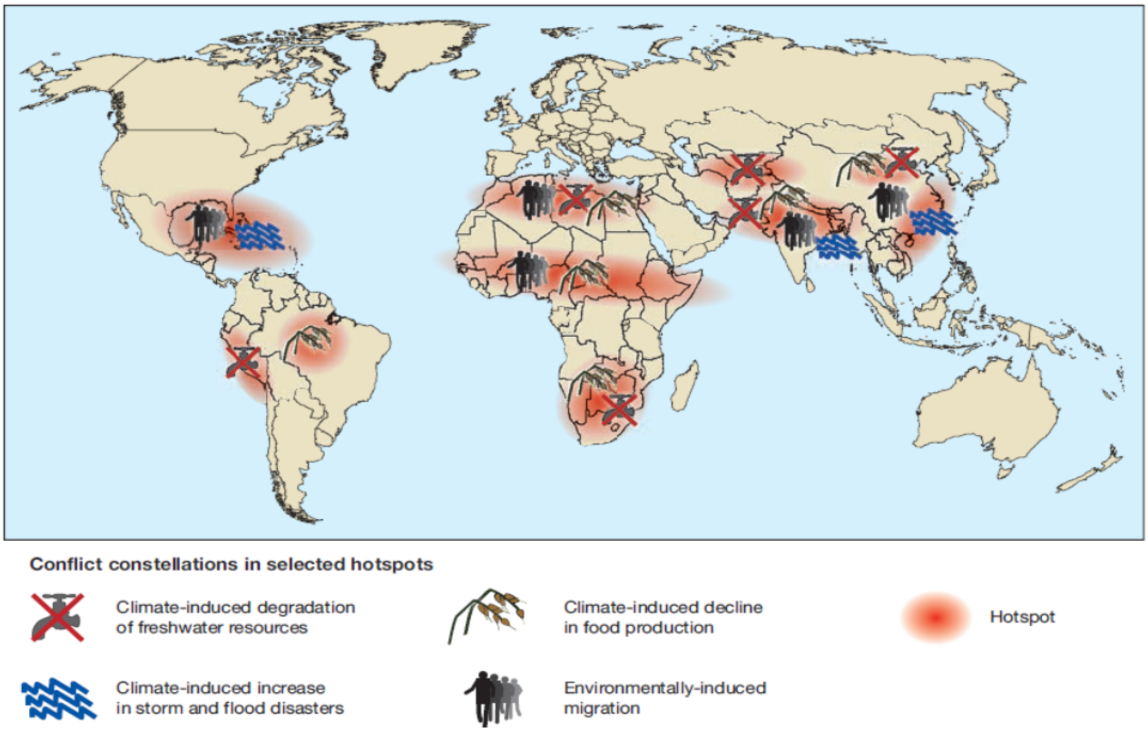
International Development (DFID) and Foreign Office are effective in making progress towards the MDGs and the supporting aims listed above, it is likely that the severity of climate change impacts will be diminished over time. The fifth supporting aim – combatting climate change through supporting adaptation and low carbon growth in developing countries – explicitly recognises this linkage and a dedicated DFID budget line is intended to help meet this aim.

Since it resulted from a public policy commitment this budget line, administered by the International Climate Fund (ICF)[24], can be interpreted as expressing a societal willingness to pay to avoid current and future international impacts from climate change[25]. Its value of £1.5 billion over the three years 2010-2012 therefore represents an annual expenditure of £500 million by the UK as part of the Fast Start finance[26] of $100 billion (£63 billion) pledged by a number of developed countries in the Copenhagen Accord to continue to 2020. Approximately 50% of the funds committed by the UK ICF are dedicated to climate change adaptation to address the international impacts of climate change.[27] These funds should be placed in the context of the total Gross Public Expenditure on Development (GPEX), of £9 billion in the 2010/2011 financial year, which itself could be expected to raise adaptive capacity.

In the manner described above, development expenditure can be seen to be contributing, in some measure, to the reduction of climate change impacts and their consequences. These impacts, however, are unlikely to be entirely mitigated by such expenditures. Consequences of these impacts, including those resulting from migration and conflict, have additional dimensions that are of cause for concern to the UK; these are outlined in the following sub-sections, and a map presenting the potential geographical origins of such risks is presented in Schubert et. al. (2008).

Security risks associated with Climate Change: Selected Hot-Spots

[24] http://www.dfid.gov.uk/What-we-do/Key-Issues/Climate-and-environment/
[25] Note that this interpretation does not account for private and non-governmental commitments to reduce these impacts.
[26] www.faststartfinance.org
[27] http://www.dfid.gov.uk/Documents/publications1/fast-start-climate-change.pdf



Source: Schubert et. al. (2008)

<u>Migration</u>

Migration may be regarded as a cause of concern for the UK for a number of reasons.

First, migration resulting from displacement as a result of extreme weather event-related disasters is understood to have great consequences for human welfare in terms of the associated suffering and hardship. A strong sense of empathy with populations affected in these ways is consequently felt by UK citizens, and this feeling may be expected to determine the levels of finance available from the overall development budgets for humanitarian assistance (£351 million in 2010/11 (DFID 2011)).

Second, the practical consequences of migration on neighbouring host companies may be negative in terms of the resulting pressures on economic and other resources, in the worst case potentially resulting in the threat of conflict (Raleigh (2011). For humanitarian as well as commercial reasons such consequences may be undesirable for the UK.

Third, there may be a possibility of immigration to the UK that is not perceived as being in the national interests, for example because of potential resource-based or culture-based disputes.

The notion of climate change-induced migration is a specific example of the phenomenon of environmental migration, defined by the International Organisation for Migration (IOM) as being the result of "persons, or groups of persons, who for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or chose to do so, either temporarily or permanently, and who move either within their country or abroad."[28] Thus, for example, forced climate migration may result from a diminishing water and food supply brought about by increased variability in rainfall patterns, migration of local fish stocks, or flooding from sea-level rise that inundates scarce productive

[28] IOM, "Discussion note: Migration and the Environment;, Ninety-fourth session, MC/INF/288, 2007, p1-2.

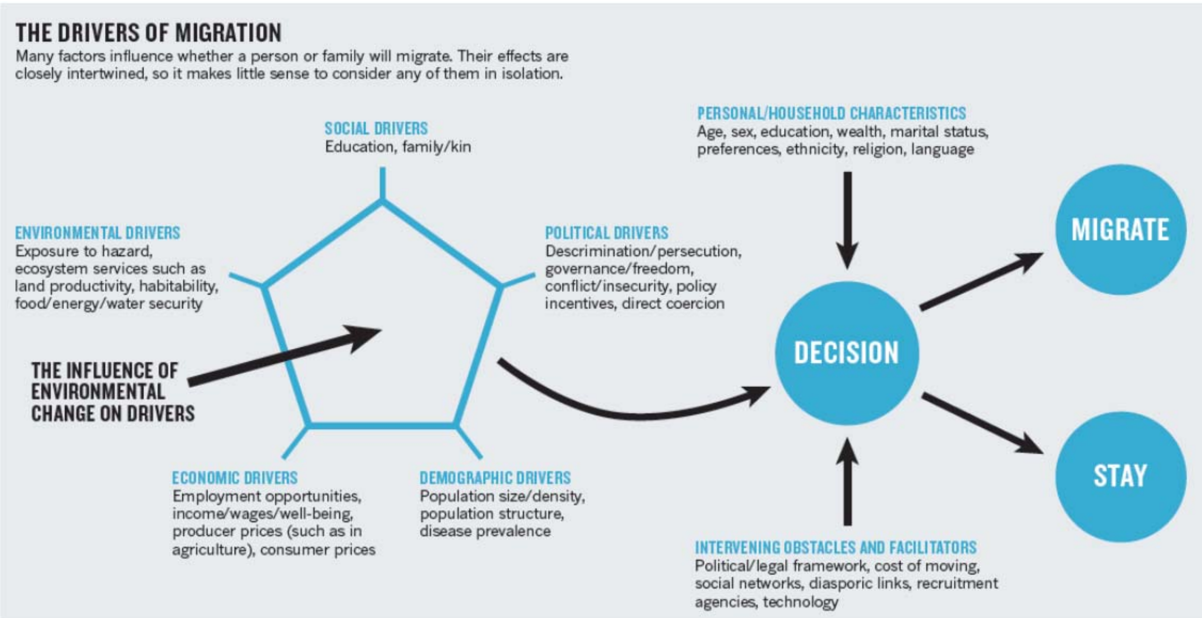
agricultural areas along coastlines. Attendant health risks from malnutrition and diarrhoeal diseases, as well as changing distributions of vector-borne diseases may also be significant. Historical data has been used to argue that 25 million people globally had migrated by 1995 primarily as a result of climate (Myers (2002))

Under future climate change scenarios, these threats are most relevant for many African countries, Small Island States, and Central, East and South Asia, (Parry et. al., 2007). The same world regions are also expected to be particularly vulnerable to extreme weather events such as windstorms, intense precipitation or droughts that may damage, disrupt or destroy property and infrastructure and so lead to shorter term displacement. It is also possible to envisage mean temperatures rising to levels that physiologically prohibit many human activities and plant or livestock growth in Equatorial regions, leading to migration.

Using simple algorithms that relate climate impacts to migration, Myers (2005) projected a global total of 200 million forced climate migrants by 2050, later up-dated to 250 million (Christian Aid, 2007). Similarly, Brown (2008) estimated that under the SRES B1 scenario, falling crop yields in Africa of 5-10% would result in a 5-10% increase in migration, with attendant pressure on the EU to accommodate some proportion of these migrants.

However, more recent research – notably the Foresight-led project: Migration and Global Environmental Change[29] - is more cautious about the validity of making quantitative estimates of climate migrant numbers. It is argued that it is inappropriate to model climate-migration linkages in a linear, causal way since in reality the determinants – or drivers - of migration are numerous and their relative importance highly context-specific. Rather, it is more useful to recognise the complexity of decisions relating to migration, as well as the climate and socio-economic uncertainties about the future that further limit the scope for reliable and useful quantification. These dimensions are characterised below.

A Schematic of the Complexities in Migration decision-making



29 http://www.bis.gov.uk/foresight/our-work/projects/published-projects/global-migration

Source: Black et. al. (2011)

The Foresight work and other recent literature draw a number of additional conclusions relevant to our assessment of risks to the UK from climate-related migration.

- The scale of any potential migration to the UK will be constrained primarily by the cost and the legality of entry. As the Figure shows, the main geographical areas from which climate migrants may originate are sub-Saharan Africa and the Indian sub-continent, implying significant journey distances and associated costs. The numbers of non-EU immigrants to the UK is currently limited to 21,700 per annum and are determined primarily by a points-based system that rations by job market skills.[30] People with UK ancestry are also eligible to apply for work visas, and subsequently citizenship, though they need to show that they can adequately support and accommodate themselves and their dependents without help from public funds.[31]
- In this regard, it might be expected that the UK will be increasingly susceptible to migratory pressures from former Commonwealth countries in South Asia, the Caribbean, and East Africa that – as noted above - are vulnerable to climate change and that have large diaspora populations in the UK. This pattern reflects the pattern of migration applications that have arisen from conflicts in these regions. It is conceivable that greater migration to the UK will originate from within the EU if climate change results in prolonged drought over the Northern Mediterranean (de Haas, 2011).
- There is a view that any such migratory pressure from LDCs to DCs should be accommodated on the basis of equity; a form of compensation for the greenhouse gas emissions resulting from historical development (NEF, 2007). Moreover, there is some evidence (see e.g. McMahon, 2003), though disputed by e.g. Coleman and Rowthorne, (2004), that large-scale in-migration to the UK may have net economic benefits.
- The function of migration as a means to adapt geographically to climate change risks implies that resources may be effectively targeted at facilitating such movement from resource-poor to resource-rich regions within or between countries. To this effect, it is argued that the UNFCCC Adaptation Fund, which is part-financed by the UK ICF, should be able to support this form of response (Black et. al. 2011).
- In facilitating migration of this form, adaptation finance would be well-targeted at developing the infrastructure in the urban areas of these countries and its resilience to climate change. At present there is a widespread trend towards greater urbanisation as a result of migratory movement. However, these areas may themselves be vulnerable to climate change risks – most notably sea level rise and flooding. Such cities include the coastal capitals of Dhaka and Rangoon in South Asia, and Lagos and Abidjan (Hanson et. al. 2011)
- Complementary development support – as well as humanitarian assistance - needs to be targeted at those population groups that have insufficient capital to finance moving from an area in the face of climate-induced resource scarcity. Indeed, climate change may further reduce the value of existing capital. An example of this occurred in Mali during the droughts of 1983–85, when emigration decreased whilst rural poverty was exacerbated (Findley, 1994).

[30] http://www.ukba.homeoffice.gov.uk/visas-immigration/working/
[31] http://www.ukba.homeoffice.gov.uk/visas-immigration/working/uk-ancestry/

Conflict can be seen as an alternative response to migration when resources integral to a community, or other grouping of people, become more scarce, leading to fighting over the resources remaining in an area, rather than moving elsewhere. Related to this, migration may result from conflict, as has occurred in Pakistan and Kenya (Raleigh (2011). For example, Nyong, Fiki and McLeman (2006) find that drought conflicts in the Western Sahel have been increasing and that climate change could exacerbate such conflicts. Similarly, rising food commodity prices that are projected to be associated with climate change futures have led to civil disturbance in the last five years (Feakin, 2011)

As such, international climate-related conflict will have a number of impacts on the welfare of UK citizens:

1. First, and as with migration, conflict is understood to have substantial consequences for human welfare in the immediately affected local population, in terms of the associated suffering and hardship. The development budget for humanitarian assistance, (£351 million in 2010/11), currently allocated by the UK Government to some extent reflects this concern felt by UK citizens, but military intervention may also be felt to be justified in order to bring the conflict to an end.

2. Second, conflict in a foreign country or region may threaten or disrupt the lives and livelihoods of UK citizens who are travelling or working in the area.

3. Third, there may be wider strategic interests – based on commercial and/or geo-political concerns – that justify threatened or actual military intervention by UK.

A recent paper sponsored by the UK Ministry of Defence (DCDC, 2010) underscores these risks, recognising that “climate change will amplify existing social, political and resource stresses, shifting the tipping point at which conflict ignites, rather than directly causing it”. This accords with the prevailing view of climate-forced migration and highlights that relationships between climate and conflict are likely to be context-specific, indirect and mediated through the existing governance systems.

Indeed, whilst empirical evidence shows that conflict might in principle occur in various forms (non-state or state, armed or not), either in the location where the climate impact on resources is greatest, or at the destination of a migrant population, historical evidence shows that co-operation is much more likely than conflict (Nordås and Gleditsch (2007)). This has been witnessed in the context of competition for water resources in various international contexts (Yoffe, Wolf and Giordano, (2003)). Certainly, where conflict does result it seems often to reflect pre-existing ethnic divisions (Reuveny, 2007). Similarly, it has also been argued that conflict may result from resource abundance as much as from resource scarcity (Collier et. al., 2009).

The complexity in determination of climate-conflict linkages therefore does not allow quantification of the risks of conflict and their impacts on the UK. However, the possibility of – for example - increased desertification in regions bordering the Sahara, and changing patterns of rainfall distribution within the Monsoon belt in the Arabian Sea and South Asia, leading to climate-induced instability and conflict gives cause for concern for UK security. Such risks lead DCDC (2010) to state that “out to 2040, there are few convincing reasons to suggest that the world *will* become more peaceful. Pressure on resources, climate change, population increases and the changing distribution of power are likely to result in increased instability and likelihood of armed conflict".

Although no defence resource projections for future years are available, the DCDC appraisal suggests that required resources will become greater. It seems likely therefore that, as suggested by Mabey (2008), there needs to be a more explicit trade-off made between adaptation and development financing on the one hand that pre-emptively reduces the risks of climate-related conflict, and defence resourcing that reactively reduces security risks.

International Effects: Conclusions

The effects on the UK of climate change impacts occurring internationally are summarised on a sectoral basis in the table below (updating Hunt et al, 2009). The table maps current and future international climate risks against their effect on UK economic activities. For each climate risk identified, the table also provides an indication of the possible forms of adaptation response that might appropriately be undertaken by UK stakeholders.

Overview of International Climate Change Impacts and Effects on the UK

Climatic variable(s) leading to climate impact	Potential Sectoral Climatic Impact(s) Identified	Potential Adaptation Actions by UK	Cross-Sectoral linkages	Key Uncertainties
Agriculture and forestry				
Higher global mean temperatures	Permanent changes in global crop production patterns leading to: a) changes in UK trading patterns with primary product suppliers; b) higher food prices faced by UK consumers	Autonomous responses by UK consumers in response to changes in food prices; Trade negotiation positions influenced by changing food supply conditions	Water resources; Ecosystem services	Pattern of climatic change (extent and timing) and impacts interaction with socio-economic change e.g. technological changes in production
Extreme weather events: precipitation or temperature	Temporary changes in food output for domestic population leading to food poverty and associated population movements and/or conflict. Migration pressures and security concerns for UK	Targeting of current and future international development support to most vulnerable food producing areas and in production practices & technologies most suited to projected regional climatic changes	Water resources; Ecosystem services.	As previous.
Fisheries				
Higher global mean temperatures	Permanent changes in global patterns of fish stocks leading to changing relative prices of fish in UK	Regional economic diversification strategies for ports etc reliant on fishing.	Tourism; General economic development.	Impacts may be dominated by fish resource pressure, and attendant regulatory regimes, not associated with climate change
Energy				
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to energy infrastructures and their operation internationally that prevent energy transmission to UK. Damage to energy infrastructure assets owned by UK companies.	Energy security diversification strategies in line with wider energy security policies, including supply of domestic renewables. Encouragement and adoption of defensive measures to protect critical infrastructures.	General economic development.	Technological change and geo-political changes may over-ride climate considerations.
Transport Infrastructure				
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to transport infrastructures and their operation internationally that impact adversely on product supply chains to UK or to UK-owned businesses operating abroad.	New infrastructure to be built in less vulnerable locations. Relocation and adjustment of UK business operations. Encouragement and adoption of defensive measures to protect critical infrastructures.	General economic development.	Socio-economic change, including shifting patterns of consumer demand, may over-ride climate considerations.

Tourism				
Higher global mean temperatures	Changes in regional and global patterns of tourist movements intra-annually.	Tourism-related infrastructure including transport and water resources to be provided in areas of growing tourist numbers. Economic diversification strategies in areas currently reliant on tourism.	General economic development.	Socio-economic change, including changes in income levels may dominate climatic factors.
Industry				
Higher global mean temperatures; changes in precipitation	For UK-owned industry: Adverse impacts on labour force productivity in hot weather. Availability & quality of raw materials for manufacturing may decline	Relocation or adjustment of industrial operations e.g. changes in working practices, product design etc.;	General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan. Consumer demand patterns dominate.
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to industrial infrastructures and their operation internationally that impact adversely on product supply chains to UK or to UK-owned businesses operating abroad.	New infrastructure built in less vulnerable locations. Relocation / adjustment of UK business operations. Encouragement and adoption of defensive measures to protect infrastructures. Demand for UK services.	General economic development.	Socio-economic change, including shifting patterns of consumer demand, may over-ride climate considerations.
Financial Services				
Higher global mean temperatures; changes in precipitation	Adverse impacts on financial services sector are indirect and are determined by the extent that physical assets and business operations overseas are effectively owned by banks through their lending policy to UK-owned companies.	Adapting lending policies to reflect changing patterns of exposure in international business operations.	Construction; Planning; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan.
Extreme weather events: precipitation, wind or temperature; storm surge.	Adverse impacts on financial services sector are indirect and are determined by the extent that physical assets and business operations overseas are given insurance coverage.	Adapting insurance coverage policies to reduce projected international exposure.	Construction; Planning; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan.
Health				
Higher global mean temperatures; changes in precipitation	Decline in agricultural productivity and/or supply of water resources may lead to fall in public health in some regions leading to increased need for international development assistance.	Increase in ODA, targeted at regions most vulnerable to adverse climate change impacts.	Water resources; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan, exacerbated by uncertainties in socio-economic change.
Extreme weather events:	Extreme events may lead to malnutrition, starvation, and associated need for	Increase in ODA, targeted at regions most vulnerable to adverse climate change impacts.	Agriculture; General economic	Pattern of climatic change (extent and timing) uncertain

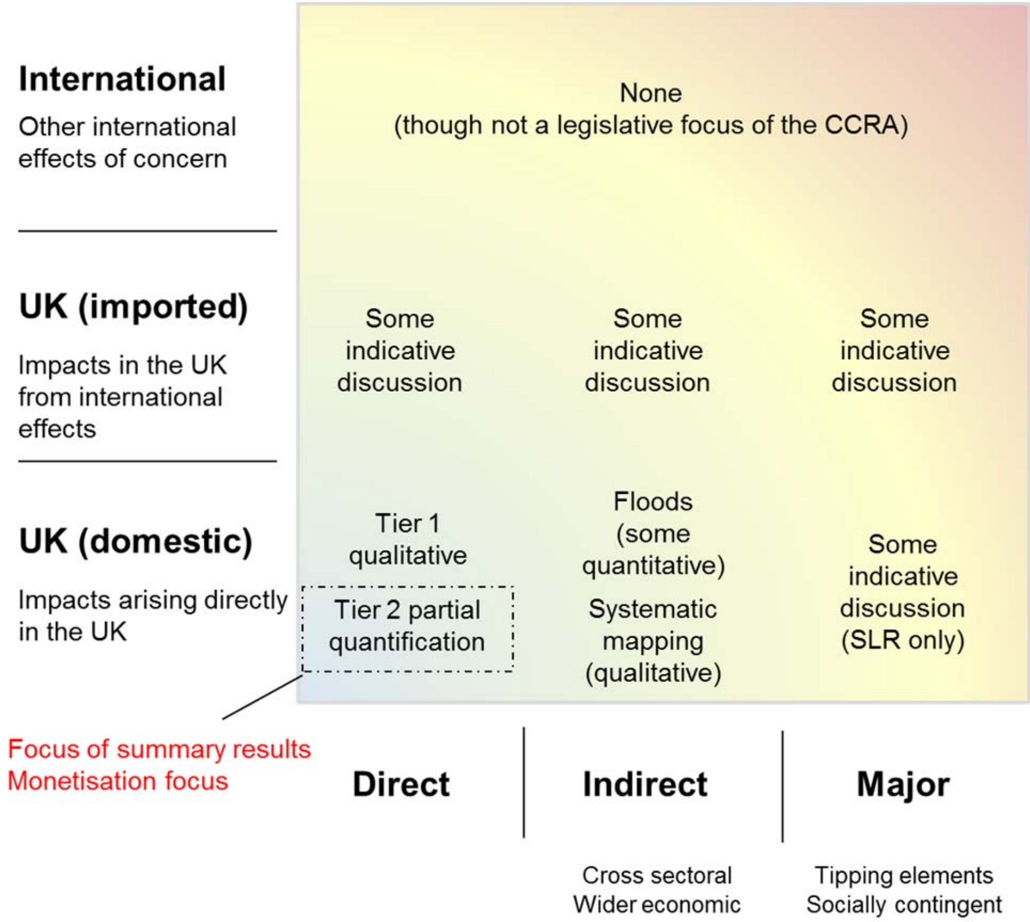
precipitation, wind or temperature; storm surge.	emergency aid.		development.	so difficult to plan, exacerbated by uncertainties in socio-economic change.
Ecosystem Services				
Higher global mean temperatures; changes in precipitation	Provisioning services of ecosystems e.g. as supplier of raw materials and waste management processes overseas may decline and affect UK-owned business operating in these areas or that make use of such resources. Support functions may deteriorate leading to migration or resource conflict and associated impacts on UK.	Support for international conservation treaties; international development assistance that supports diversification away from extensive or intensive use of ecosystem resources.	Water resources; General economic development.	Socio-economic change, including population growth and technological change, may result in increased demand for ecosystem services that dominate climate factors.
Water resources				
Higher global mean temperatures; changes in precipitation	Declines in water availability lead to changes in a number of sectors, as indicated in other parts of the table, and including many aspects of human livelihood.	Increase in ODA, targeted at regions most vulnerable to adverse climate change impacts. Support for water efficient and storage technologies.	Ecosystem services; General economic development.	Socio-economic change, including population growth and technological change, likely to exacerbate climate factors.
Sea-Level Rise				
Higher global mean temperatures; storm surges	Sea-water inundation may lead to loss of land and associated socio-economic activity, with pressures to relocate/migrate away from coast. Associated impacts on UK.	Coastal management strategies including hard and soft defences and accommodation.	General economic development.	Socio-economic change, including population growth, likely to exacerbate climate factors.

Source: Up-dated from Hunt, Watkiss and Horrocks (2009)

5. Conclusions and Next Steps

This report has presented a summary of the range of climate change impacts projected to result in potential consequent impacts on the UK, additional to those included in the first UK Climate Change Risk Assessment.

The coverage of the CCRA quantitative and economic results have been mapped against a matrix developed in the study. The results are shown below.



In summary, most of the quantified analysis (and the summary results) are focused on direct UK domestic impacts, shown in the bottom left corner of the matrix, and the monetisation exercise is almost exclusively focused on this area. This focus is to be expected: the direct risks are an obvious priority for the first CCRA, and are the main area of focus identified in the Act. They are also likely to represent many of the priorities for early adaptation in the UK. Indeed, it is stressed that the UK CCRA has assessed a very large number of direct risks compared and this has been one of the major advances of the study.

Nevertheless, even here the assessment and monetisation is inevitably partial: the quantified analysis could not cover all the 600 or so Tier 1 risks (though many of these would be expected to be low); the analysis has often used single rather than multiple climate parameter functions; it has not been able to fully take account of all possible threshold effects (due to lack of underlying evidence); and the assessment has not factored in the influence of the speed of change for higher scenarios.

These might all be expected to increase the economic costs of climate change for the UK, though it is difficult to know how important these omissions might be (note also that the estimates do not include autonomous adaptation and, in general, planned adaptation measures, which would reduce costs). These omissions are not a criticism of the CCRA per se– which has covered a more comprehensive set of risks than many international studies and has addressed the risks of most obvious direct importance – but it is simply a recognition that even assessing a large number of direct risks is extremely challenging and involves large resources.

It is also stressed that in interpreting the CCRA results for this left hand corner of the matrix, there is a danger of focusing on the central trend (the p50 from the medium scenario), when in practice many of the key threats to the UK (and the high economic costs) are associated with upper ends of distribution. This is a concern because the CCRA summary and synthesis reports tend to focus on central trends, i.e. they tend to present the risks as being more modest than the mean or analysis of the distribution of effects (e.g. the p90) would suggest. While this additional risk and distributional information is included in the main sector and evidence reports, it would be useful for future CCRA to bring out these aspects into the main summary

Looking to the rest of the matrix, the coverage is much lower. It is acknowledged that all of the other areas of the matrix involve very complex issues, which are difficult to assess quantitative, and which reflect emerging evidence in risk assessment and climate modelling. It is also stressed that the CCRA did acknowledge many of the wider risks identified across the matrix above, but found quantification was more challenging or that there was a low evidence base to make quantitative (and economic) analysis on. It is not expected that the first CCRA would be able to address all of these issues. However, it is important that the other areas of the matrix are not overlooked when interpreting the CCRA results. Indeed, much of the wider literature highlights that these other areas of the matrix could be a very large risk driver for a temperate country such as the UK.

The study has gone on to review the potential gaps. This review has outlined the many forms in which additional climate change impacts may manifest themselves. They include:

- Indirect effects including cross-sectoral and wider economic effects;
- Changes in the prices of raw materials and final products to UK-based businesses and consumers;
- Disruptions to the overseas supply chains and operations of UK businesses;
- Changes in patterns of human movements, in the form of tourism and migration, and their effects of business and infrastructure in the UK;
- Implications for UK Overseas Territories, many of which are vulnerable to sea-level rise and storm surges, given that they are small islands;
- Implications for humanitarian and development aid as a result of changes in resource scarcity and extreme weather events.
- The risk of consequences resulting from large-scale bio-physical tipping points, most notably sea-level rise associated with disintegration of the Greenland Ice Sheet and the West Antarctic Ice-Sheet, etc.

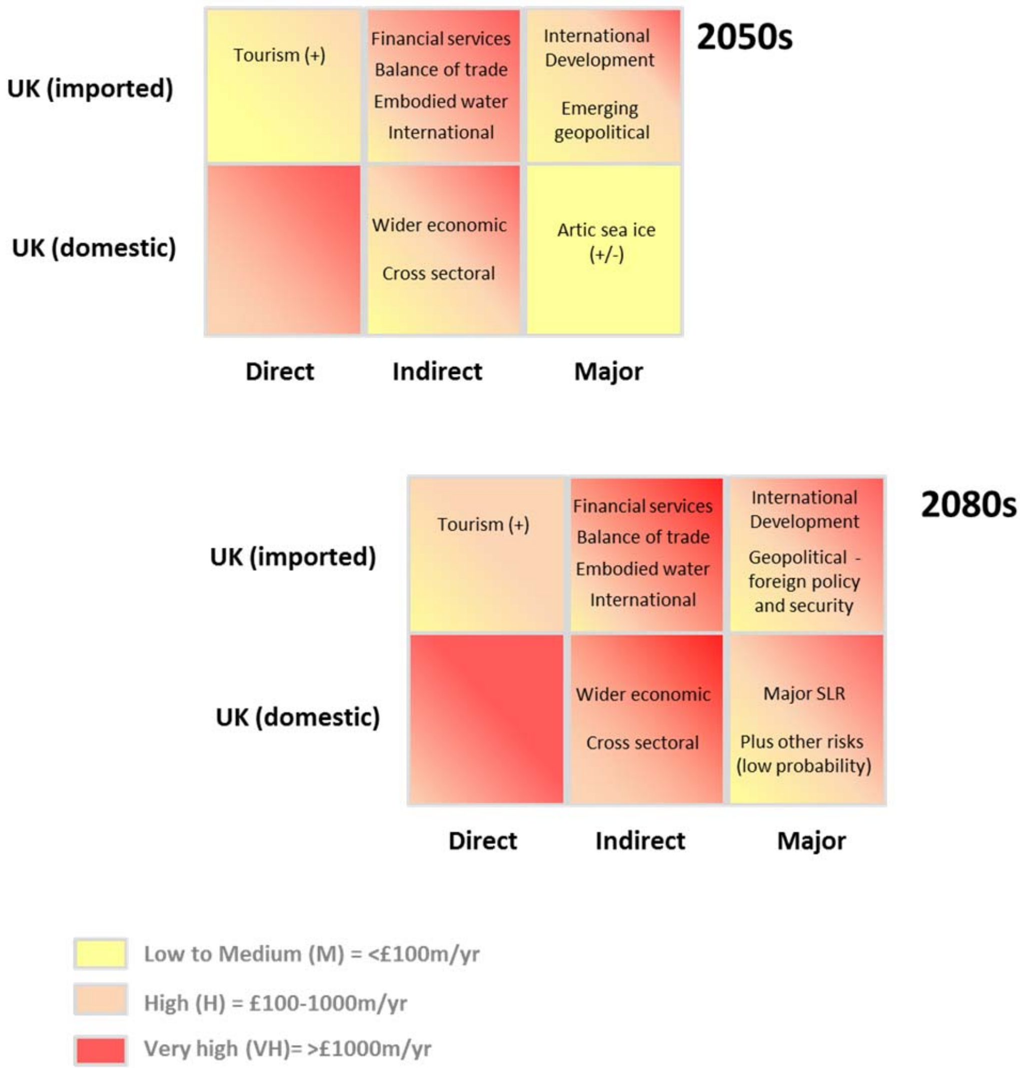
The review has found that quantitative estimates of the size of these impacts is very difficult, because of the complexities in the causative pathways from greenhouse gas emissions to direct and indirect impacts and the relatively high levels of uncertainty attached to each part of these pathways. Nevertheless, a first and very indicative estimate of the potential relative importance that might be attached to the risks in the rest of the matrix has been considered in this paper.

- For indirect (cross-sectoral) effects the available literature indicates significant additional economic costs are likely, and may be of a similar order of magnitude to direct effects. At the same time, there is also the potential for some dampening effects from autonomous market driven adaptation that have the effect of reducing aggregate economic costs measured by GDP.
    - As well as highlighting their potential economic importance, these indirect effects are important because cross-sectoral adaptation responses may be both more effective and efficient than sectoral-based responses only.
    - In relation to international effects, the available literature indicates that in certain contexts, these risks are likely to be very important. The increasingly globally integrated nature of UK economic activity, for example in commodity trade and financial services, exacerbates these risks particularly where the most significant global climate risks coincide with areas of current and planned market expansion, such as South and East Asia, Africa and South America. A particular issue on embodied water has also emerged.
    - As well as greater attention to risk management in these areas, pre-emptive international development support is likely to reduce risks associated with regional political and strategic stresses resulting from migration and conflict. National level adaptation strategies need to ensure these risks are considered.
- For major (catastrophic) events, the very limited analysis suggests that major sea level rise is an important long-term risk for the UK. These risks involve more uncertain elements, but they involve high economic costs. As an example, the economic costs of >1 m of sea level rise would significantly increase flood costs (the largest direct cost reported in the CCRA) to potentially > £10billion/year. Moreover, these risks are beginning to be considered in adaptation planning, thus they warrant a more explicit consideration with the CCRA as a whole. For other major effects, the major short-term risk is from the melting of artic sea ice. While the available evidence suggests modest effects to the UK, there are important unknowns involved, and given the much earlier time-scale for this tipping element, this warrants more investigation (and underlying research) to inform a comprehensive risk assessment.

To try and visually present these findings, the study has considered the estimated scale of the welfare costs of these additional risks. This is summarised below, adopting a semi-quantitative rating. The figure shows the possible size of future risks across the risk matrix, focusing on UK-specific elements. It is stressed that the estimates are indicative only, and reflect the limited available evidence found in this study. The relative size of the economic costs is indicated by the colour shading, the gradient reflecting the fact that effects will vary across the UKCP09 projections and will vary in likelihood and magnitude.

The matrix emphases the well-established fact that climate change risks are likely to be more severe towards the end of the current century compared with the near-term. This is exacerbated in the case of a number of the risks where – whilst they are characterised as “low probability-high impact” – the probabilities are judged to increase significantly during this time period. The review findings indicate that each of these categories is likely to comprise a significant portion of the total risks affecting the UK and – combined - would be at least as large as the direct domestic effects captured in the CCRA.

Possible Severity of Climate Change Risks to the UK: "Indicative Estimates"



Note the existing CCRA economic estimates are included in the bottom-left hand cell. Other cells present indicative estimates for the relative economic importance of the additional areas not captured in the CCRA.

Some additional notes are provided in the table below on the effects in each cell of the matrix. The right-hand column indicates that there are research or adaptation measures that can, and should, be undertaken with immediate effect. They are not comprehensive in any sense but serve to highlight the need to better understand these risks, as well as the mix of investment in adaptive capacity measures to better incorporate these risks more fully into sectoral and strategic planning.

Additional notes

Risk	Notes	Immediate adaptation research / options
Indirect and macroeconomic		
Indirect effects - cross sectoral (UK)	Already very large for flooding.	Analysis and quantification of cross-sectoral linkages.
Wider (macro) economic costs	Possible risks associated with major extreme events. Note some possible benefits possible also.	Macro-economic modelling to complement existing partial equilibrium approach.
International direct		
Tourism in UK	Likely net benefits	UK Regional development strategies including infrastructure provision and water resource management.
International indirect		
Balance of Trade	Very uncertain. Depends on substitute products/sources & Soc-Ec. Change	Scenario-based quantitative modelling of potential size of impacts to inform national and regional development strategies
Financial Services - International	Depends on possibility of system-wide shocks from extreme events.	Stress-testing to incorporate climate change risks.
Embodied Water Stress	UK already large water importer (embodied) and water stress could affect indirectly	Scoping analysis of the embodied water currently and future threat from climate change
International major and socially contingent		
Overseas Territories	Based on Bueno et. al. (2008)	Incorporation of CC in all inputs to strategic development plans.
Health - International	Very uncertain. Depends on disease vector spreads and degree & pattern of Soc-Ec development in LDCs.	Incorporation of CC in design of development support and aid.
International Development (inc. Migration & Conflict)	International "coefficient of concern" assumed to be sizeable.	Incorporation of CC in design of development support and aid.
Major		
SLR ("Rahmstorf scenario")	Based on Brown et. al. (2011), TE2011 (EA, 2009)	TE2100 experience suggests need for flexibility to be incorporated into coastal & flood management plans
Dramatic slow-down of THC	Some decrease already in UCKP09, but no quantitative basis for more severe effects.	Need for continued research.
Arctic Sea Ice retreat	Balance of sizeable costs and benefits	

Overall, the key conclusion from the work is that the other areas of the matrix include risks to the UK that should be included in the next CCRA (i.e. CCRA2). Indeed, taken as a whole, these other risks could be as important as the direct effects considered in the first CCRA.

However, in order to allow these risks to be assessed, there is a need for early research to provide the evidence base to allow a more considered, and especially a quantitative analysis, of these risks.

A number of detailed research priorities have been highlighted in the sub-sections above, and in reviews such as the Foresight projects, and so are not repeated here. However, in general terms research priorities could include:

- The development of a consistent set of impact scenarios applied to international areas of concern for the UK to allow quantitative risk assessment;
- The consistent application of impact modelling in non-linear, global and regional bio-physical systems to, in order to better incorporate tipping points in risk assessments;
- Investigation of the limits to adaptation and the resulting relative roles of adaptation and mitigation in UK, given new knowledge of the risks associated with tipping points.
- There also remains a need for research – for application to all the risks highlighted in this paper - into generic techniques that allow better understanding, and integration, of climate data projections in decision-making contexts, such that uncertainties can be more effectively evaluated and communicated.

References

Aaheim & Schjolden (2004) An approach to utilise climate change impact studies in national assessments. Global Environmental Change 14 147-160.

Ackerman, F., Stanton, E.A, Hope, C., and Alberth, S. (2008). Did the Stern Review underestimate U.S. and global climate damages? October 2008. Stockholm Environment Institute. Working Paper WP-US-0802.

Ackerman, F., Stephen J. DeCanio, S.J., Howarth, R.,B., Sheeran, K. (2009). Limitations of Integrated Assessment Models of Climate Change. Climatic Change. Volume 95, Numbers 3-4, 297-315, DOI: 10.1007/s10584-009-9570-x

Allan, J.A. (1998) "Virtual water: a strategic resource. Global solutions to regional deficits." Groundwater, 36, 545-546.

Bas Amelung B. and A. Moreno (2011) Costing the impact of climate change on tourism in Europe: results of the PESETA project. Climatic Change. Published online on 25/11/2011. At: http://www.springerlink.com/content/y066787444511477/fulltext.pdf

Betts R. (2010) Synthesis Report International climate change issues. Project deliverable number D.1.2.1. March 2010. UK Climate Change Risk Assessment. Defra. London

Black, R., Bennett, S. R. G., Thomas, S. M. and J. R. Beddington (2011) Migration as Adaptation. Nature (478) pp 447-449.

Bosello F, Roson, R. and R. S. J. Tol4, (2007) Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise. Environmental and Resource Economics, Vol. 37, No. 3, pp 549-571

Brown, O. (2008) Migration and Climate Change. IOM Migration Research Papers No 31. International Organization for Migration, Geneva.

Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011). The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

Bueno, R., Herzfeld, C., Stanton, E., Ackerman, F., 2008: The Caribbean and Climate Change: The Costs of Inaction. Tufts University, Medford

Carraro C and Sgobbi A. 2008. Climate Change Impacts and Adaptation Strategies in Italy: An Economic Assessment. Available at www.feem.it/userfiles/attach/Publication/NDL2008/NDL2008-006.pdf

CCC (2011). Household energy bills – impacts of meeting carbon budgets. Committee on Climate Change I December 2011. Published 2011 by the CCC, London. Available at: http://downloads.theccc.org.uk.s3.amazonaws.com/Household%20Energy%20Bills/CCC_Energy%20Note%20Bill_bookmarked_1.pdf

Chapagain, A.K. and Hoekstra, A.Y. (2003) Virtual Water Flows between Nations in Relation to Trade in Livestock and Livestock Products; Value of Water Research Report Series 13; UNESCO-IHE, Institute for Water Education: Delft, The Netherlands, 2003.

Chapagain, A.K. and Hoekstra, A.Y. (2008) "The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products". Water International, 33, 19-32.

Chapagain, A.K. and Orr, S. (2008) UK Water Footprint: The Impact of the UK's Food and Fibre Consumption on Global Water Resources. WWF, Godalming, UK, Vol. 1.

Christian Aid (2007) Human tide: The real migration crisis. London. Christian Aid.

Juan-Carlos Ciscar, Ana Iglesias, Luc Feyen, László Szabó, Denise van Regemorter, Bas Amelung, Robert Nicholls, Paul Watkiss, Ole B. Christensen, Rutger Dankers, Luis Garrote, Clare M. Goodess, Alistair Hunt, Alvaro Moreno, Julie Richards, and Antonio Soria (2011). Physical and Economic Consequences of Climate Change in EUROPE. PNAS. Proceedings of the National Academy of Sciences. Physical Sciences - Environmental Sciences. PNAS January 31, 2011. www.pnas.org/cgi/doi/10.1073/pnas.1011612108Coleman D. and R. Rowthorne, (2004) The Economic Effects of Immigration in the United Kingdom, Population and Development Review, Vol. 30, No. 4 (Dec., 2004), pp. 579-624

Collier, P., Hoeffler, A. and D. Rohner (2009). Beyond greed and grievance: feasibility and civil war. Oxford Economic Papers Volume 61, Issue 1. Pp. 1-27

DCDC (2010) Global Strategic Trends – Out to 2040. Ministry of Defence. London.

Dawson, R.J., J.W. Hall, P.D. Bates and R.J. Nicholls, 2005: Quantified analysis of the probability of flooding in the Thames Estuary under imaginable worst case sea-level rise scenarios. Int. J. Water. Resour. D., 21, 577-591.

Dawson R.J., Dickson M, Nicholls R. J., Hall J, Walkden M, Stansby P K, Mokrech M., Richards J., Zhou J., Milligan J, Jordan A, Pearson S, Rees J, Bates P.D., Koukoulas S, Watkinson A., (2009). "Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change." Climatic Change, in press.

H. de Haas (2011) Mediterranean migration futures: Patterns, drivers and scenarios. Global Environmental Change. Volume 21, Supplement 1, December 2011, Pages S59enc9

Delta Commissie (2008) Working together with Water. A living land builds for its future. Findings of the Deltacommissie. DeltaCommissie, The Netherlands. http://www.deltacommissie.com/doc/deltareport_full.pdf Accessed March 2011.

Department for International Development (2011a) Business Plan 2011-2015. May 2011. At: http://www.dfid.gov.uk/Documents/DFID-business-plan.pdf

Department for International Development (2011b) Statistics on International Development 2006/07 – 2010/11. October 2011. National Statistics. UK. At: www.dfid.gov.uk/documents/publications1/sid2011/SID-2011.pdf

Downing, T., and Watkiss, P. (2003). The Marginal Social Costs of Carbon in Policy Making: Applications, Uncertainty and a Possible Risk Based Approach. Paper presented at the DEFRA International Seminar on the Social Costs of Carbon. July 2003.

Environment Agency (2011). TE2100 Strategic Outline Programme (Environment Agency, 2011)

EA (2009). TE2100 Plan Technical Report. Appendix H. Appraisal in TE2100.

Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, 2007: Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, (eds) M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273-313.

Feakin T. (2011) International Dimensions of Climate Change Discussion paper 6: The Ramifications of Climate Change – the security perspective. Foresight Project. BIS. London

Findley, S. E. (1994). Does Drought Increase Migration? A Study of Migration from Rural Mali during the 1983-1985 Drought. International Migration Review 28, (3) 539–553

Foresight (2011) International dimensions of climate change, Foresight Horizon Scanning Centre, Government Office for Science.

Garnaut Review (2008). The Garnaut Climate Change Review: Final Report Commonwealth of Australia 2008. http://www.garnautreview.org.au/CA25734E0016A131/pages/garnaut-climate-change-review-final-report

Grynszpan, D., Murray, V., Kreis, I., Zenner, D., Vardoulakis, S., Caldin, H., Morgan, D., Heaviside, C. and D. Heymann (2010) International Dimensions of Climate Change Report 1.1.1: The implications for the UK health sector of the International Dimensions of

Climate Change, 2010 to 2100. Foresight, Government Office for Science, November 2010

Hallegatte, S., Hourcade, J.-C. and P. Dumas. (2007). Why economic dynamics matter in assessing climate change damages: illustration on extreme events. Ecological economics 62 (2):330-340.

S. Hallegatte, V. Przyluski (2010). . The economics of natural disasters. CESifo Forum 2/2010, pp. 14—24. http://www.cesifo-group.de/pls/guestci/download/CESifo%20Forum%202010/CESifo%20Forum%202/2010/forum2-10-focus2.pdf

S. Hallegatte (2008). An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina. Risk Analysis 28(3), 779-799, June 2008

S. Hallegatte, P. Dumas. Can Natural Disasters have positive consequences ? Investigating the role of embodied technical change. Ecological Economics, Volume 68, Issue 3, 15 January 2009, Pages 777-786

Hallegatte, S. A Roadmap to Assess the Economic Cost of Climate Change with an Application to Hurricanes in the United States. S., forthcoming in "Climate Change and Hurricanes", edited by J. Elsner and T. Jagger

Hanson, S., Nicholls R., Ranger N., Hallegatte, S., Corfee-Morlot J., Herweijer C. and J. Chateau (2011) A global ranking of port cities with high exposure to climate extremes. Climatic Change (2011) 104:89–111

Hinkel J (2005) DIVA: An iterative method for building modular integrated models. Adv Geosci 4:45-50.

Hinkel J, Klein RJT (2009) The DINAS-COAST project: Developing a tool for the dynamic and interactive assessment of coastal vulnerability. Global Environ Change 19 (3):384-395.

Hope, C., (2006). The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern. Integrated Assessment 6 (1), 19–56.

Hope, C., (2006b). The social cost of carbon: What does it actually depend on? Climate Policy 6 (5), pp. 565-572.

Hope, C. (2009). PAGE Optimisation The social cost of CO2 and the optimal timing of emissions reductions under uncertainty. Prepared for the Pew Center Workshop on Assessing the Benefits of Avoided Climate Change 16 -17 March 2009 by Dr Chris Hope Judge Business School University of Cambridge. Available at http://www.pewclimate.org/docUploads/Hope_0.pdf

Hope, C. (2009b). The Costs and Benefits of Adaptation. Chapter 8. In. Parry, M.L. et al (2009) Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates, International Institute for Environment and Development and Grantham Institute for Climate Change, London.

Hope, C (forthcoming). The PAGE09 model: A technical description. Submitted.

HMT (2007). The Green Book. Appraisal and Evaluation in Central Government Treasury Guidance. Her Majesty's Treasury. London:TSO.

HMT 2008. Intergenerational wealth transfers and social discounting: Supplementary Green Book guidance July 2008, http://www.hm-treasury.gov.uk/d/4(5).pdf.

HMT, 2009. Accounting for the Effects of Climate Change. June 2009. Supplementary Green Book Guidance, Available at

http://www.hm-treasury.gov.uk/data_greenbook_supguidance.htm#Adaptation_to_Climate_Change Accessed Jan 2010

Holman, I.P., Loveland, P.J., Shackley, S., Berry, P.M., Rounsevell, M.D.A., Audsley, E., Harrison, P.A. and Wood, R., 2002. RegIS - Regional Climate Change Impact Response Studies in East Anglia and North West England. UKCIP Technical Report. UKCIP, Oxford.

Holman IP, Berry PM, Mokrech M, Richards JA, Audsley E, Harrison PA, Rounsevell MDA, Nicholls RJ, Shackley S, Henriques C (2007). Simulating the effects of future climate and socio-economic change in East Anglia and North West England: the RegIS2 project. Summary Report. UKCIP, Oxford 2007.

HRW (2012). The UK Climate Change Risk Assessment 2012 Evidence Report. Presented to Parliament pursuant to Section 56 of the Climate Change Act 2008. Project deliverable number D.4.2.1 Release 7. January 2012. Available at http://www.defra.gov.uk/environment/climate/government/risk-assessment/

Hunt, A., Watkiss, P. and L. Horrocks (2009) International Impacts of Climate Change on the UK. Report to Defra. Report no. GA0208_8177_FRP (1)

IFSL, (2009) Fund Management 2009.

Kemfert, C., Truong, P.T., Brucker, T. (2006): Economic Impact Assessment of Climate Change: A Multi-Gas Investigation. In: The Energy Journal, Multi-Greenhouse Gas Mitigation and Climate Policy, Special Issue 3, S. 441-460

Kemfert (2006). Costs of Action and Inaction Prof. Dr. Claudia Kemfert Deutsches Institut für Wirtschaftsforschung Humboldt Universität Berlin Berlin, 10. April 2006. http://www.diw.de/deutsch/dasinstitut/abteilungen/evu/aktuelles/Kemfert_Claudia_CostofInacation_2006.pdf

Elmar Kriegler, Jim W. Hall, Hermann Held, Richard Dawson and Hans Joachim Schellnhuber (2009). Imprecise probability assessment of tipping points in the climate system. PNAS March 31, 2009 vol. 106 no. 13 5041-5046

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007: Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

Lenton, T.M., Held, H. Kriegler, E.. Hall, J.W., Lucht, W., Rahmstorf S. and Schellnhuber H.J. (2008). Tipping elements in the Earth's climate system, Proceedings of the National Academy of Sciences USA 105(6), 1786–1793.

Levermann, A et al. (2012) Potential climatic transitions with profound impact on Europe: Review of the current state of six 'tipping elements of the climate system'. Climatic Change (2012) 110:845–878. DOI 10.1007/s10584-011-0126-5

Lewis K., Witham, C. and R. McCarthy (2010) Physical Resources and Commodities and Climate Change. Report for Foresight International Dimensions of Climate Change. June 2010.

Lonsdale,K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W.Hall (2005), Plausible responses to the threat of rapid sea-level rise for the Thames Estuary, FNU-77, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. http://www.fnu.zmaw.de/fileadmin/fnu-files/publication/working-papers/waislondonwp.pdf

Lowe JA, Howard TP, Pardaens A, Tinker J, Holt J, Wakelin S, Milne G, Leake J, Wolf J, Horsburgh K, Reeder T, Jenkins G, Ridley J, Dye S and Bradley S (2009) UK Climate projections science report: marine and coastal projections. Exeter, UK: Met Office Hadley Centre. See http://ukclimateprojections.defra.gov.uk/images/stories/marine_pdfs/UKP09_Marine_report.pdf. Accessed March 2011.

McMahon, M. 2003. "Eastern European boost to UK trend growth?," Lombard Street Research Monthly Economic Review (July): 8.

Mabey, N. (2008), Delivering Climate Security: International Responses to a Climate Changed World. RUSI Whitehall Paper No. 69, Routledge, London.

Marbaix, P. and J.P van Ypersele (ed.), 2004. Impacts des changements climatiques en Belgique. www.climate.be/impacts

Martin, R., Muûls, M and A. Ward (2011). The sensitivity of UK manufacturing firms to extreme weather events. Report prepared for the CCC.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao Z-C (2007) Global climate projections. In: Solomon S, Qin D, Manning M et al., (eds) Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 433-497.

Metroeconomica (2004). Costing the impacts of climate change in the UK: overview of guidelines. UKCIP Technical Report. UKCIP, Oxford.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. http://www.maweb.org/en/index.aspx

Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A. (2009), UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

Myers, N. (2002) Environmental Refugees: A Growing Phenomenon of the 21st Century. Philosophical Transactions of the Royal Society B, 357, pp 609-613

Myers, N. (2005) Environmental Refugees: An Emergent Security Issue. 13th Economic Forum. Prague, June 23-27.

NEF (2007) Up In Smoke? Asia and the Pacific. New Economic Foundation. London.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray , I., Ingersoll, C., Robertson , R., Tokgoz, S., Zhu, T., Sulser, T.B, Ringler, C., Msangi, S. and You, L. (2010). Food security, farming, and climate change to 2050: Scenarios, results, policy options. Washington, DC: International Food Policy Research Institute.

Nicholls, R et al (2006). Metrics For Assessing The Economic Benefits Of Climate Change Policies: Sea Level Rise. OECD. Environment Directorate. ENV/EPOC/GSP(2006)3/FINAL.

Nicholls, R. J. and A. S. Kebede (2010 International Dimensions of Climate Change R 6.1: The Implications on the UK of the Impacts of Climate Change and Sea-level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100. Foresight, Government Office for Science, July 2010

Nicholls, R.J.(1), Hanson, S. (1), Herweijer, C.(2), Patmore, N. (2), Hallegatte, S.(3), Corfee-Morlot, J.(4), Chateau, J.(4), and Muir-Wood, R. (2)Screening Study: Ranking Port Cities With High Exposure And Vulnerability To Climate Extremes Interim Analysis: Exposure Estimates. ENV/EPOC/GSP(2007)11

Nordås R., and N.P. Gleditsch (2007) Climate Change and Conflict, Political Geography 26 (2007) 627-638.

Nordhaus, W.D. and Boyer, J.G. (2000) Warming the World: Economic Models of Global Warming, Cambridge: The MIT Press.

Nordhaus, W.D. (2006) The Stern Review on the Economics of Climate Change. Journal of Economic Literature. Yale University, http://nordhaus.econ.yale.edu/stern_050307.pdf.

Nordhaus, W.D. (2006) "The Economics of Hurricanes in the United States," Presented at the Annual Meetings of the American Economic Association, Boston, Massachusetts, January 5-8, 2006, available online at http://www.econ.yale.edu/~nordhaus/homepage/hurr_010306a.pdf,

Nordhaus, W. D. (2008) The challenge of global warming: Economic models and environmental policy. New Haven, Connecticut: Yale University.

Nordhaus, W. D. (2009) DICE 2009. Available at: http://nordhaus.econ.yale.edu/DICE2007.htm

Nyong, A., Fiki, C., and R. McLeman (2006) Drought-related conflicts, management and resolution in the West African Sahel: considerations for climate change research, Die Erde, 137(3), 223-248.

Office of National Statistics, (201) Unted Kingdom National Accounts - The Blue Book. Palgrave MacMillan, London

Parry, M. and Carter, T. (1998) Climate Impact and Adaptation Assessment. London: Earthscan Publications Limited.

Parry M. L. Rosenzweig, C., Iglesias, A., Livermore, M. and G. Fischer (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change 14 (2004) 53–67

Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors 2007: Technical Summary. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F.Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78.

Pardaens AK, Lowe JA, Brown S, Nicholls RJ, de Gusmão D (2011), Sea-level rise and impacts projections under a future scenario with large greenhouse gas emission reductions, Geophysical Research Letters, 38:L12604.

Pfeffer W, Harper J, O'Neel S (2008) Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321 (5894), 1340-1343 (DOI:10.1126/science.1159099).

Pinnegar, J., Watt, T. and Kennedy, K (2012). Climate Change Risk Assessment for the Marine and Fisheries Sector. Sector Report of the Climate Change Risk Assessment (CCRA). Published January 2012. Available at: http://randd.defra.gov.uk/Document.aspx?Document=CCRAfortheMarineandFisheriesSector.pdf

Raleigh, C. (2011) The search for safety: The effects of conflict, poverty and ecological influences on migration in the developing world.. Global Environmental Change. 21, (1), pp S82ERL3

Ramsbottom, D., Sayers, P. and Panzeri, M. (2012). Climate Change Risk Assessment for the Floods and Coastal Erosion Sector. CCRA sector report. January 2012. Available at: http://randd.defra.gov.uk/Document.aspx?Document=CCRAfortheFloodsandCoastalErosionSector.pdf

Rahmstorf S (2007). A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science, 315, 368-370.

Reuveny, R. (2007). Climate change-induced migration and violent conflict. Political Geography 26 (6), 656-673.

Schelling, T. C. (1992) Some Economics of Global Warming. The American Economic Review , Vol. 82, No. 1 (Mar., 1992), pp. 1-14

Schellnhuber et al (2005). Avoiding Dangerous Climate Change. Editor in Chief Hans Joachim Schellnhuber Co-editors Wolfgang Cramer, Nebojsa Nakicenovic, Tom Wigley, Gary Yohe. Cambridge University Press, 2005. ISBN: 13 978-0-521-86471-8

SCCV (2007). Sweden facing climate change - threats and opportunities (2007) Final report from the Swedish Commission on Climate and Vulnerability Stockholm 2007. http://www.regeringen.se/sb/d/574/a/96002

Schubert, R., Schellnhuber, H.J., Buchmann, Epiney, A., Griesshammer, R., Kulessa, M., Messner, D., Rahmstorf and J. Schmid (2008) Climate Change as a Security Risk. Earthscan, London

Silver, N., Cox, M. and E. Garrett (2010) Foresight International Dimensions of Climate Change: The Impact of Climate Change Overseas on the UK Financial Services Sector. 6th March 2010 . Government Office for Science, London.

Stanton, E. A., Ackerman, F. and Kartha, S. (2009) Inside the integrated assessment models: Four issues in climate economics, Climate and Development 1 (2009) 166–184

Stern . N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmondson, N., Garbett, S., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H., and Zenghelis, D. (2006). The Economics of Climate Change. Cabinet Office – HM Treasury. Cambridge University Press.

TheCityUK, (2011) Financial Services in Emerging Markets. Economic Trends Series. June 2011.

Tol, R.S.J. (2002a) New estimates of the damage costs of climate change, Part I: Benchmark estimates. Environmental and Resource Economics 21 (1): 47-73.

Tol, R.S.J. (2002b) New estimates of the damage costs of climate change, Part II: Dynamic estimates. Environmental and Resource Economics 21 (1): 135-160.

Tol, R.S.J. (2003), 'Is the uncertainty about climate change too large for expected cost-benefit analysis?', Climatic Change , 56, 265-289.

Tol, R.S.J. (2005). Energy Policy, The Marginal Damage Costs Of Carbon Dioxide Emissions: An Assessment Of The Uncertainties. Energy Policy 33 (2005) 2064–2074.

Tol, R.S.J. (2008). The Social Cost of Carbon: Trends, Outliers and Catastrophes. Economics: The Open-Access, Open-Assessment E-Journal, Vol. 2, 2008-25. http://www.economics- journal.org/economics/journalarticles/2008-25

Tol, R.S.J., and Anthoff, D (2010). Climate Framework for Uncertainty, Negotiation and Distribution (FUND) version 3.5 Available at http://www.fnu.zmaw.de/FUND.5679.0.html

Vafeidis AT, Nicholls RJ, McFadden L, Tol RSJ, Hinkel J, Spencer T, Grashoff PS, Boot G, Klein RJT (2008) A new global coastal database for impact and vulnerability analysis to sea-level rise. J Coastal Res 24:917-924.

Vermeer M, Rahmstorf S (2009).Global sea level linked to global temperature. Proc. Natl Acad. Sci. USA 106, 21 527–21 532. (doi:10.1073/pnas.0907765106).

Watkiss, P., D. Anthoff, T. Downing, C. Hepburn, C. Hope, A. Hunt and R. Tol, (2005): The social costs of carbon (SCC) review: methodological approaches for using SCC estimates in policy assessment. Final Report, Defra, UK, 124 pp.

Watkiss, P. and Downing, T. E (2008). The Social Cost of Carbon: Valuation Estimates and their Use in UK Policy. The Integrated Assessment Journal, Vol 8, Issue 1 (2008),

Watkiss, P. (2011). Aggregate Economic Measures of Climate Change Damages: Explaining the Differences and Implications. Wiley Interdisciplinary Reviews - Climate Change. Vol 2, Issue 3, start page 356. Published online. 2 May 2011. DOI: 10.1002/wcc.111

Weitzman, M. L. (2009). "On Modeling and Interpreting the Economics of Catastrophic Climate Change." The Review of Economics and Statistics 91(1): 1-19.

Wilbanks, T.J., P. Romero Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-P. Ceron, M. Kapshe, R. Muir-Wood and R. Zapata-Marti, 2007: Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 357-390.

Yoffe, S., Wolf, A. T., and M. Giordano, (2003). Conflict and cooperation over international freshwater resources: indicators of basins at risk. Journal of the American Water Resources Association, 39(5), 1109-1126.

Annex 1. Summary Climate - Import impacts: Other Sub-Categories

A2. Cereals and grains: Wheat

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temperature	M	Reduced frost risk to crop	C3
France	9		M	Northwards expansion of crops	C3
Germany	13		M	Crops already at climate thresholds likely to be vulnerable	C3
			M	Greater risk of pests spreading Northward	B2
			E	Crop vulnerability to more frequent hot spells	C3
		Precipn.	E	Water stress from reduced summer rain reduces crop yield	B3
		Precipn.	E	Flood risk to crops - uncertain	A3
		Storms	E	Storm risk to crops - uncertain	A3
		SLR	M	Salt water intrusion risk to crops	B2
		CO2	M	CO2 fertilisation	C2
North America				As Europe	
USA	5			Possibility of increased drought risk, though uncertain	A2
Canada	25			Possibility of increased precip or drought risk - uncertain	A2
Central & North Asia				As Europe	
Kazakhstan	2				
Value of Global Impacts to UK	£314m				

A2. Cereals and grains: Barley

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp.	M	Reduced frost risk to crop	C3
France	16%		M	Northwards expansion of crops	C3
NL	6%		M	Crops already at climate thresholds likely to be vulnerable	C3
Germany	12%		M	Greater risk of pests spreading Northward	B2
			E	Crop vulnerability to more frequent hot spells	C3
		Precipn.	E	Water stress from reduced summer rain reduces crop yield	B3
			E	Flood risk to crops - uncertain	A3
		Storms	E	Storm risk to crops - uncertain	A3
		SLR	M	Salt water intrusion risk to crops	B2
		CO2	M	CO2 fertilisation	C2
North America					
Canada	3%			As Europe	
			E	Possibility of increased drought risk, though uncertain	A2
			E	Possibility of increased precip - uncertain	A2
Value of Global Impacts to UK	£16.8m				

A2. Cereals and grains: Rice

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med					
Spain	12%	Temp.	M	Higher minimum temps harm rice yield	C3
Italy	13%		E	Crop vulnerability to hot spells	C3
NL	4%	Precipn.	E	Risk of summer drought results in reduced yield	A3 -It/Sp
Belgium	3%				B3 - NL/B
			E	Flood risk to crops - uncertain	A3
		Storms	E	Storm risk to crops - uncertain	A3
		SLR	M	Salt water intrusion risk to crops	B2
		CO2	M	CO2 fertilisation	C2
			M	Large-scale circulation effects - uncertain	
North America				As Europe	
USA	7%	Precipn.	E	Possibility of increased drought risk in growing season reduces yield - uncertain	A3
Southeast Asia				As Europe	
Thailand	9%	Precipn.	E	Possibility of increased drought risk in growing season reduces yield	A3
South Asia				As Europe	
India	25%	Precipn.	E	Possibility of increased drought risk in growing season reduces yield	A3
Pakistan	14%				
Value of Global Impacts to UK	£348m				

A2. Cereals and grains: Maize

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp.	M	Reduction in frost days & increase in number of days > 10C in growing season	C2
Germany	2%		M	Beyond 36C, yields are reduced	C2
France	56%	Precipn.	E	Risk of summer drought results in reduced yield	B3
			E	Flood risk to crops - uncertain	A3
		Storms	E	Storm risk to crops - uncertain	A3
		SLR	M	Salt water intrusion risk to crops	B2
			M	Large-scale circulation effects, e.g. El Nino	
North America				As Europe	
USA	5%	Precipn.	E	Increased drought risk reduces yield	A2
Central & S. America					
Brazil	2%	Precipn.		As Europe	
Argentina	14%		E	Increased drought risk reduces yield	A2
Value of Global Impacts to UK	£167m				

A3. Animals

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	E	Heat stress negatively impacts on animal health/productivity	C3
NL	3%	Temp	M	Warmer winters may result in disease & pests surviving	B2
Germany	1%		M	Reduced frozen water reduces hypothermia and dehydration risks	C2
France	9%	Precip	M	Lower summer rain may reduce pasture growth for cattle	B2
Ireland	62%		E	Risk of flooding/feeding difficulties	A2
		SLR	M	Salt water intrusion risk to grazing pastures	B2
			M	Large-scale circulation effects, e.g. El Nino	
North America					
USA	12%			As Europe	
Value of Global Impacts to UK	£457m				

B1. Wild & Farmed fish

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	E	Greater risk of mass stock death	C0
Spain	1%	Temp	M	Higher winter temps decrease mortality	C0
NL	4%	Precipn.	M	Inland lake water levels may change - uncertain	A0 - DK, NO
Norway	5%		M	Inland lake water levels may lower	B0 - NL, Sp, Mo
Denmark	7%		E	Risk of poor water quality & algal blooms - uncertain	A1
		Storms	E	Storms affect ability to fish - uncertain	A1
		SLR	E	Harbour infrastructure vulnerable	C1
		Temp	M	Warmer water ecosystem effects (-ve)	C2
		Wind	M	Patterns affect ecosystems - uncertain	A1
		Acidity	M	Acidification affects ecosystems - uncertain	B3
North America					
USA	3%			As Europe	
Canada	4%				
Iceland	13%				
East Asia					
China	6%			As Europe	
Southeast Asia					
Thailand	7%			As Europe	
Value of Global Impacts to UK	£2.3bn				

C1. Extraction of crude petroleum and gas: Gas

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	M	Dried soil - Subsidence risk to industry infrastructure	A2
Norway	41%	Temp	M	Less ice on off-shore decks	C1
NL	22%	Precipn.	M	Decrease in precipn affects efficiency of extraction	A2
Belgium	4%	Humidity	M	Design consideration for rigs - uncertain	A1
		Storms	E	Potential for disruption - uncertain	A3
		SLR	M	SLR combined with storm surge disruptive	B2
		Ocean currents	M	Affects rig stability - uncertain	A0
Africa					
Algeria	2%			As Europe	
Value of Global Impacts to UK	7bn				

C2. Land-based mining: Coal, coke and briquettes

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	M	Higher temperature is risk to miners health	C2
Poland	2%	Precipn.	M	Risk of less water available for operations	A2
North America			E	Flood risk	A3
USA	19%	Humidity	M	Design consideration for rigs	A1
Canada	3%	Storms	E	Potential for disruption	A3
		SLR	M & E	SLR combined with storm surge disruptive	B2
Central & N. Asia					
Russia	28%			As Europe	
Southeast Asia					
Indonesia	1%			As Europe	
Central & S. America					
Colombia	19%			As Europe	
Australia & NZ					
Australia	21%			As Europe	
Africa					
S. Africa	3%			As Europe	
Value of Global Impacts to UK	1.9bn				

C2. Land-based mining: Metalliferous ores and metal scrap

Region/Main countries	% of UK Imports	Climate var.	Mean/ Extreme	Climate risk	Grading
Europe & Med		Temp	M	Higher temperature is risk to miners health	C2
Poland	1%	Precipn.	M	Risk of less water available for operations	A2
			E	Flood risk	A3
		Humidity	M	Design consideration for rigs	A1
		Storms	E	Potential for disruption	A3
		SLR	M & E	SLR combined with storm surge disruptive	B2
North America					
USA	21%			As Europe	
Canada	17%				
Central & N. Asia					
Russia	4%			As Europe	
Africa					
S. Africa	8%			As Europe	
Value of Imports to UK £bn	4.2bn				