Government Office for Science

Foresight

International Dimensions of Climate Change

FINAL PROJECT REPORT

International Dimensions of Climate Change

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Foreword

This Report has identified for the first time how international climate change is likely to affect the UK through its global dependencies and networks. It concludes that the impacts of climate change overseas could be as important as the direct impacts within UK shores over the next few decades. There are a range of important implications for the UK, both threats and opportunities.

Whilst the extent of future greenhouse gas emissions will strongly influence longer term risks, some level of further global warming is already projected as past emissions continue to take effect, changing the climates to which societies and ecosystems have become adapted.

The most serious and earliest direct impacts from climate change are expected in other parts of the world, often in developing countries. However, interconnected global networks of governance, finance, business, communications and communities will mean that impacts will be felt across international borders. The UK is a member of many leading international institutions, and a nation at the centre of world finance and trade. These linkages, together with vital international interdependencies in energy and resources will mean that the UK cannot isolate itself from the overseas impacts of climate change.

This Report aims to encourage UK policymakers to consider the international impacts of climate change alongside domestic impacts. It is timed to feed into the UK's first Climate Change Risk Assessment, as well as other government initiatives currently underway. While it is shorter than some previous Foresight Reports, over 100 academics and stakeholders from diverse fields of science and policy have contributed to and peer-reviewed the evidence base. I am most grateful to them, the core team of lead experts who have provided advice throughout the process, and also to the Foresight project team for the work that has led to this Report.

The issue is not whether the world, and hence the UK, will experience climate change over the coming decades, but how its impacts will be felt. I am hopeful that this Report will encourage policymakers and other interested communities to act decisively to address the future implications for the UK from climate change overseas.

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Chief Scientific Adviser to HM Government, and
Head of the Government Office for Science

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Executive Summary

This Foresight Report has used available evidence and expert opinion to consider the effects of climate change that could occur *outside* of the UK, but which could give rise to threats and opportunities that need to be considered by UK policymakers. It complements other reports which have considered both the direct impact of climate change within UK borders[1] and the consequences of various mitigation strategies for the UK[2]. These assessments, however, do not consider the political, economic and social impacts on the UK from changes taking place elsewhere in the world. This Report aims to fill that gap.

Climate change is expected to act as a 'risk multiplier', interacting with other trends. It is likely to make it even more difficult to address poverty, disease, and food and water insecurity. In particular, rising temperatures and changing patterns of precipitation may affect the availability of food (including crops and livestock) and water, leading to more hunger and increased volatility in food prices, and heightened regional tensions, affecting international stability and security. An increased frequency of extreme weather events may adversely affect human health, disrupt the flow of natural resources and commodities, and threaten global infrastructure for transport and energy. Moreover, the inherent uncertainty of these various impacts is likely to increase risks significantly in the business and financial sectors.

The top level message of this Report is that the consequences for the UK of climate change occurring in other parts of the world could be as important as climate change directly affecting these shores. The UK will inevitably be affected by these global impacts, and will need to give careful consideration to the implications for diplomacy and foreign policy, security, resources and commodities, finance and trade, human health and social values.

This is not an argument for the UK to become more insular. The UK is closely connected to the global economy and has an important role in addressing international risks. There are significant opportunities for the UK in business, finance and international leadership to help tackle global climate change through investment, innovation and collaboration. To realise these the UK will need to maintain its networks of trade and diplomacy, and its role on the global stage.

Five key messages

- **The diversity of risks to the UK from climate change impacts overseas (including diplomacy and foreign policy, security, resources and commodities, finance and trade, human health and social values) underlines the need for a broad approach to possible responses.**
- **It is vital for policymakers to develop strategies to mitigate these risks, to plan for unavoidable consequences, and to understand better how such consequences may increase other pressures on the UK. In many cases, action taken now or in the near future will address future problems for significantly less resource than action at a later date.**
- **That climate change is taking place, and projected to continue for at least several decades, is well supported by the evidence[3]. Uncertainties in specific areas of climate science, along with the inherent uncertainty of considering the future over several decades, particularly beyond 2040, do not diminish the need for policymakers to take action now. Rather, they imply the need to develop policies which are resilient to future uncertainties by taking a risk-based approach.**
- **UK business has significant strengths which could help other countries to mitigate and adapt to climate change. They include low-carbon technologies, coastal engineering, finance and**

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1 For example, the "Climate Resilient Infrastructure" report published by the UK Government in May 2011, the "Infrastructure, Engineering and Climate Change Adaptation" report published by the Royal Academy of Engineering in February 2011, and the UK Climate Impacts Programme (UKCIP).

2 For example, the Carbon Budgets and other mitigation reports published by the UK's independent Committee on Climate Change, and the Department for Energy and Climate Change's "Pathways 2050" programme.

3 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

insurance expertise, and climate and weather science. There will be growing demand for these skills as the world adapts to climate change, although the UK is not alone in having industries capable of providing such expertise. Positioning UK business for these opportunities would be beneficial.

- **UK policymakers should consider how to factor in the assessment of risk where climate change effects overseas may have an impact. Acting as a risk multiplier, threats from climate change cannot be treated in isolation, and should be considered alongside threats across the wider policy spectrum.**

This Report focuses on four questions:

A. Why are the international dimensions of climate change important for the UK?

Three critical factors are highlighted:

- **The UK's international role** may be affected by changes associated with a warming world. As a member of the UN, NATO, the Commonwealth, the G20 and other bodies, changes to the structure of international institutions, the balance of global power and economic relationships in the world economy will all affect the way in which the UK is able to influence international affairs.
- **The UK is part of a highly interdependent global economic system**. UK firms were responsible for over £1 trillion of direct investment abroad at the end of 2009, with direct investment by foreign companies in the UK standing at £654 billion[4]. If there is disruption and change in the world economy, the UK, with its significant trading and investment links will be affected.
- **A warming world may have internal implications for the UK.** These may be the result of changes in the international economic, social and political environment – for example, global threats which affect the health of UK citizens, or through the influence of global climate change on social attitudes in the UK. The impacts of climate change on the UK Overseas Territories also bring an inherent international dimension to managing the risks to the UK.

The risks to the UK owing to climate change are not necessarily far in the future. We already live in a warming world, and this trend will continue over the next 30 years. **So while policymakers rightly need to develop robust mitigation strategies to limit future greenhouse gas emissions, complementary strategies to adapt to a warming world will be essential**. Global average temperatures rose by approximately 0.7°C over the 20th century[5], and climate model projections, under a range of representative scenarios, suggest that by 2040 the world could have warmed by around 2°C relative to the pre-industrial baseline[6]. Associated with this warming trend is the expectation of other global, regional and local environmental changes. These include sea level rise, changes in water availability due to altered rainfall patterns and glacial melt, more frequent drought and flood conditions in some areas of the world, and an increased severity of extreme weather events.

B. What are the threats and challenges to the UK from international developments in this warming world?

Several threats and challenges are identified in this Report:

1. **International instability** could increase as a consequence of climate change, either directly through extreme weather events and water system stresses, or indirectly as social and political systems in vulnerable parts of the world come under increasing strain. In the most vulnerable areas, governance at the state level is already overstretched, and there will be a limited capacity to adapt to climate change. These regions may stretch the UK's ability to provide international aid, humanitarian assistance and peacekeeping interventions. The UK provided £435 million for humanitarian assistance in 2009/10, and £600 million to the UN peacekeeping budget. Pressure on these budgets may increase if future climate change triggers regional conflict or more severe extreme weather. In severe cases, climate change may be the risk multiplier which pushes countries

4 Office for National Statistics (2010). Available from: http://www.statistics.gov.uk/pdfdir/fdinr1210.pdf

5 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

6 *ibid.*

into becoming failed states, leading to wider global implications for national security, international terrorism and organised crime.

2. There may be shifts in the UK's **international role and global influence** as international institutions, for example the UN, G20 and the Commonwealth, are affected by the new geopolitical challenges posed by climate change. Seemingly localised climate change effects may have wider global implications, affecting, for example, access to resources, stability of infrastructure, borders, international law and security. There is the potential for significant political and social change and the introduction of new interests into the geopolitical calculations of states, for which current global governance structures were not designed.

3. The **financial sector and business** generally may fail to evaluate and take account of changes in the balance of risks associated with climate change overseas. UK firms managed worldwide assets of £1.2 trillion in 2008[7], and the accurate assessment of their level of exposure to climate change effects will be required to ensure that these assets are properly insured or protected. This exposure will increase if international business and financial policy frameworks do not adequately assess the risks of climate change, leaving institutions exposed to additional risks and uncertainties. If an international agreement on limiting global emissions is not achieved, UK businesses may be prevented from taking decisive action on investment in green technologies.

4. Adverse economic impacts could affect overseas **resources and infrastructure** on which the UK depends. A wide range of potential threats are identified including disruption to vital infrastructure serving global markets, disruption to energy supplies, global food production, the extraction of vital raw materials, the impact of extreme weather events on communications networks and data centres, and a growing threat of protectionist responses from countries adversely affected by climate change. For example, the UK is a net energy importer and had an energy trade deficit of £8.2 billion in 2009. Climate change may disrupt critical infrastructure (for example pipelines, ports and overseas refineries) affecting the price and security of UK energy imports.

5. There may be impacts on **global health** arising from temperature change, water stresses and extreme weather events. The UK could be affected in a number of ways: through its citizens living in diaspora communities, by UK citizens travelling overseas, and through provision of aid overseas (in 2009/10, the UK spent £683 million on health aid and £106 million on water supply and sanitation[8]). Also, changing distributions of disease vectors may precipitate an increased occurrence of certain infectious diseases in Northern Europe, and hence the UK.

C. How do the UK's strengths and capabilities help address the challenge of a warming world?

Three broad areas of opportunity are identified:

1. There will be opportunities for the UK to **influence** on the global stage, by playing a leading political role as international institutions and individual countries grapple with the challenges of climate change. The adoption of the Fourth Carbon Budget in May 2011 makes the UK the first nation to agree legally-binding emissions limits beyond 2020, requiring a 50% reduction from 1990 levels by 2025, and is an example of the UK's commitment to tackle climate change and provide leadership at the global level. Furthermore, the UK is pioneering new climate risk analysis methods in the first UK Climate Change Risk Assessment, reporting in early 2012.

2. **Business and financial services** are key sectors of the UK economy, and opportunities will arise in areas of UK strength: science and engineering, in insurance and in climate forecasting, and where there is a need to reduce emissions or adapt to climate change. Investment opportunities include a wide range of green technologies, particularly in the energy sector, such as wind power, and carbon capture and storage. The global environmental and low-carbon market was estimated to

7 Section 3.2.1.
8 Section 3.1.2.

be £3.2 trillion in 2008/09 with a predicted 4% growth rate to 2013/14, with the UK predicted to achieve up to 3.9% growth in these areas by 2016[9].

3. There will be an opportunity to influence and prompt **behavioural change** within the UK by raising awareness of the impacts of climate change overseas, and therefore highlighting the necessity for domestic mitigation and adaptation strategies.

D. How should UK policymakers respond to these threats and opportunities?

The project's analysis of future challenges and areas of opportunity for the UK's strengths and capabilities highlights important strategic issues for policymakers. Managing the associated areas of risk will require a high degree of international co-operation. Also, mitigating risks affecting the business and financial community will require a high degree of co-operation between the public and the private sectors. There is therefore a need for the UK to maintain and strengthen its networks of international influence, and for government to work constructively with business and financial organisations.

The following strategic issues for policymakers are highlighted:

- **To address the risks to the UK from climate change impacts overseas, it is crucial that government departments work across existing boundaries between domestic and international policy, and between climate change mitigation and adaptation.**
- **The long-term nature of climate change combined with the uncertainties that exist in projections (for example, on the pace of change, and regional effects), is acting as a significant barrier to decision-making on climate change policies (and policies affected by climate change) and may lead to inappropriate adaptation or inaction when it is needed most**.
- **Climate change risks cannot be assessed or treated in isolation from other global threats. The impacts of climate change will need to be factored in across all areas of government policy which have an international dimension.**
- **While policymakers need to recognise the high degree of uncertainty in climate projections, and future emissions profiles, the challenges of a warming world will arise in one form or another. The uncertainty is not *whether* the world will experience climate change but *how* its impacts will be felt**.
- **There will inevitably be interactions and interdependencies between the impacts of climate change as they develop and the threats and opportunities associated with them.**
- **Managing the risks associated with climate change will require a high degree of international co-operation. It will be important to strengthen the UK's networks of international influence and to work constructively with business and financial organisations.**

This Report identifies the diverse and substantial ways in which overseas impacts of climate change will affect the UK's political, economic and social interests. Crucially, it highlights the urgent need for policymakers to develop policies and strategies to address the future challenges and opportunities. In view of the broad scope of the work, it has not been feasible to make a detailed assessment of every aspect. The Report aims instead to provide a robust foundation for further work and for prioritising adaptation strategies.

9 Innovas (2010), Low Carbon and Environmental Goods and Services: an industry analysis. Update for 2008/09. Report available at: http://www.bis.gov.uk/assets/biscore/business-sectors/docs/10-795-low-carbon-environmental-goods-analysis-update-08-09.pdf (last accessed 21/06/11).

1 Introduction

Chapter 1 introduces the Project and its aims and objectives.

1 Introduction

1.1 Background

Like many countries, the UK is currently undertaking a major exercise to understand the level of risk posed by climate change, to inform the policies and measures that will need to be adopted over this century. This initiative is currently being led by government through the UK's first Climate Change Risk Assessment and its findings will be laid before Parliament in January 2012. While considerable attention has been focused on the direct effects of climate change on the UK mainland, there may also be significant impacts on the UK from the effects of climate change on other countries around the world. This Report provides a comprehensive analysis of these impacts, and shows that the potential implications for the UK are substantial.

Like many other middle- and high-income countries, the UK's position within (and dependence upon) the rest of the world has many facets. It is an influential member of many leading international institutions, and has strong international links on a range of security issues. The UK is a leading centre for global trade and finance with multiple interdependencies relating to energy and commodity flows. It also has wide-ranging international transport connections, and many diaspora communities. Whilst this connectedness brings substantial advantage, it also means that the many direct and indirect impacts of global climate change will be transmitted to the UK through these diverse international links. Understanding the nature and scale of these possible threats and opportunities is essential for the UK to anticipate and prepare effectively for climate change.

This Report[1]:

- draws out key threats and challenges to the UK that are likely to arise from the impacts of global climate change;
- highlights where the UK can build on its strengths to respond accordingly; and
- sets out possible implications for UK policy in a world affected by climate change, so that the country remains competitive, secure and able to protect the wellbeing of the nation.

This analysis will contribute to the UK's first Climate Change Risk Assessment (CCRA)[2], required under the Climate Change Act (2008)[3]. It will enable the UK's national adaptation policy programme to take appropriate account of the potentially significant risks for the UK arising from impacts occurring beyond national borders. These risks will be considered alongside the evidence from nationally focussed and/or sector-specific studies[4].

1.2 Why international climate change impacts are important for the UK

The UK has extensive economic, political and cultural ties to other parts of the world. It is through these connections that the impacts of global climate change are most likely to be felt in view of:

- the UK's **international role** – its ability to influence global issues and direction may be affected;
- the UK's **interdependencies** – what it relies upon from other nations, and international demand for its services and goods may be impacted;
- the UK may be affected **internally** – in terms of its economy, its security, and the health, demographics and behaviour of its communities.

1 This Report is based on an 18-month project, the 'International Dimensions of Climate Change'.

2 DEFRA are leading the development of the CCRA which will draw together evidence and analysis which will enable all UK Administrations to understand the level of risk posed by climate change for the UK; prioritise adaptation policy; and assess the costs and benefits of adaptation actions.

3 The Act may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

4 Most previous studies on the impacts and adaptation challenges for individual countries have focused on more direct effects and impacts within national borders.

The average temperature around the world during the decade 2001-2010 was, on average, almost 0.5°C warmer than the 1961-1990 average, and 0.21°C warmer than the previous decade[5]. Northern Europe, along with eastern parts of North and South America, and northern and central Asia, became significantly wetter over the 20th century, while precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia[6]. The frequency of heat waves[7] and heavy precipitation events over most areas is also likely to have increased over the last 50 years[8]. Over the course of this century the world's poorest countries are expected to experience more severe impacts on people's welfare and livelihoods, for example from rising sea levels, increased hunger due to crop failure and negative health impacts from increased frequency of extreme weather events. These countries are also more vulnerable and have a limited capacity to adapt[9].

Many of these effects[10] are expected to be much greater than those experienced directly by the UK within its borders. The UK, compared with many other parts of the world, is not expected to experience significant adverse direct climate change effects over the next two decades[11], although evidence of change already taking effect is apparent. Temperatures in central England are now approximately 1°C higher than in the 1970s[12], and spring arrives on average 11 days earlier[13].

Because of the potentially severe effects of global climate change and because of the many ways in which these could affect UK interests, it is critical that the UK's adaptation planning does not focus exclusively on risks driven by domestic climate change effects. Impacts arising from global climate change which will affect the international networks, dependencies and relationships upon which the UK relies will need to be included.

1.3 Project scope

This Report focuses on global climate change, defined here as changes to the climate of countries and regions of the world other than the UK and its coastal waters. Climate change effects (and impacts) directly affecting the UK mainland are not considered[14]. The Report encompasses those issues that will require the UK to respond, either by intervention to prevent or minimise potential damages, or to manage the consequences.

5 World Meteorological Organization (2011), *WMO statement on the status of the global climate in 2010.* WMO-No. 1074, available at: http://www.wmo.int/pages/publications/showcase/documents/1074_en.pdf (last accessed 21/06/11).

6 Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. & Zhai, P. (2007), *Observations: Surface and Atmospheric Climate Change.* In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

7 Specifically over land areas.

8 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

9 *ibid.*

10 For the purpose of this report, climate change effects are defined as long-term (typically decades or longer) physical changes to the state of the climate. Climate change impacts are defined as the impacts of climate change on social and economic systems.

11 See Chapter 2 for more information on the scenarios used in this Report.

12 Jenkins, G.J., Perry, M.C. & Prior, M.J. (2008), *The climate of the United Kingdom and recent trends.* Met Office Hadley Centre, UK. Report available at: http://ukclimateprojections.defra.gov.uk/images/stories/trends_pdfs/Trends.pdf (last accessed 21/06/11).

13 Thackeray, S.J. (2010), *Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments.* Global Change Biology, **16**: 3304-3313.

14 The UK and its coastal waters are considered in the Government's UK Climate Change Risk Assessment. However, it has not considered the effects of climate change on the UK Overseas Territories. This Report has considered impacts to the Overseas Territories where possible – see Section 3.1.3.

The following time horizons are considered:

- up to 2030[15] (medium term), where the uncertainties in the projection of climate change effects (e.g. changes in temperature and rainfall) are considerably less than those in later decades, and where greater confidence can be given to the analysis of potential impacts[16]. On this timescale, the uncertainty in modelling of global temperature change is lower due to the level of inevitable climate change; and
- up to 2050, and where possible beyond to 2100, in so far that these longer timescales have potential consequences for decisions today, whilst noting the increasing uncertainty about climate change effects (see Section 2.3) and social, political or economic drivers[17] which may develop on these timescales. A fundamental uncertainty on this timescale is the future level of greenhouse gas (GHG) emissions, and the extent to which international attempts to limit future emissions[18] are successful.

These time horizons are consistent with other policy developments across the UK Government, such as the forthcoming Climate Change Risk Assessment, as well as international assessments such as the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change Assessment Reviews (see Chapter 2) which look out to 2100.

The Report considers impacts of global climate change driven by both:

- physical effects on climate (e.g. temperature increase and changing precipitation patterns) that will require adaptation measures to adjust, moderate or cope with the consequences; and
- the political, economic and social effects of responses to adaptation and mitigation, for example those arising from international actions to reduce GHG emissions.

For the purpose of this analysis, adaptation and mitigation are viewed as complementary rather than alternative strategies for addressing climate change. There is a growing awareness that adaptation and mitigation strategies need to be considered together, as "*even the most stringent mitigation efforts cannot avoid further impacts of climate change over the next few decades… which makes adaptation unavoidable*"[19]. In other words, due to the level of "locked in" change in the climate system as a result of past and present emissions of greenhouse gases (see section 2.3), implementing policies to mitigate climate change will not prevent further changes for which adaptation may be necessary. Furthermore, some policies may have the potential to achieve both adaptation and mitigation, despite having different aims. For example, the possible establishment of new forests as part of an adaptation strategy to increase local water availability would also aid mitigation[20].

15 For some areas of analysis it was more appropriate to consider a timescale up to 2040 to ensure consistency with existing modelling and evidence.

16 Even within this timeframe, the level of uncertainty does vary for different climate change effects (e.g. between temperature rise and precipitation change).

17 These drivers may (for example) include technology, demographic and land use changes, resource scarcity, energy security and global migration. Other Foresight reports (such as UK Land Use Futures, published February 2010; Global Food and Farming Futures, published January 2011; and Global Environmental Migration, due to be published in autumn 2011) have explored some of these key drivers.

18 Efforts to achieve international agreement on emissions reduction are primarily through the UN Framework Convention on Climate Change process and its supreme body, the annual Conference of Parties (COP).

19 Klein, R.J.T., Huq, S., Denton, F., Downing, T.E., Richels, R.G., Robinson, J.B. & Toth, F.L. (2007), *Inter-relationships between adaptation and mitigation.* In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. (Eds), Cambridge University Press, Cambridge, UK, 745-777.

20 *ibid.*

1.4 Project approach

A multidisciplinary approach was used in the project to:

- **Identify important areas of potential impact:** academics, experts from the private sector, and policymakers were consulted to help identify areas for analysis. Nine broad areas were selected: global governance and institutions, financial services and insurance, legislation, global infrastructure, physical resources and commodities, science and technology, health, migration[21], and human behaviour[22].
- **Base the analysis on scientific and other evidence:** a wide range of existing research, articles and reports from academia, government and other sources were used to inform the project, including international studies on direct impacts of climate change carried out by countries with strong links to the UK. Reviews were also commissioned from leading academics and private sector experts to provide in-depth and independent analysis in the areas listed above, including climate modelling carried out by the UK Met Office Hadley Centre[23].
- **Identify areas of uncertainty:** on the time horizons considered, many factors (including climate change projections, demographic change and economic and social trends) are subject to considerable uncertainty. In some instances the range of uncertainty can be described. In others, experts may disagree, or there will be more fundamental gaps in the evidence. Where uncertainties exist, their nature and extent are highlighted. It is important that they should not be seen as a limitation to the analysis but as an inevitable feature of the longer term. However, understanding the uncertainties ahead is crucial in understanding where policy development needs to be flexible and where new policies need to be robust to a range of possible outcomes.

1.5 How to read this Report

This Report takes a broad view across many sectors and areas of interest to allow policymakers to consider the wide range and impacts of risks for the UK associated with the potential impacts of global climate change. Where relevant, policymakers should consider the threats and opportunities identified here alongside other subject-specific analysis and other significant political, economic and social drivers[24] not directly attributed to climate change that may have impacts on the UK over the next century.

The Report structure is as follows:

- **Chapter 1: Introduction** – provides an overview of the purpose and scope of the project, and why global climate change is important for the UK.
- **Chapter 2: Global Climate Change** – introduces the evidence for climate change, along with potential future effects and the uncertainties that exist. *Readers familiar with climate science and global climate change impacts may wish to pass straight to Chapter 3.*
- **Chapters 3 & 4: UK Threats and Challenges**– two chapters outlining the threats and challenges to the UK that may result from the impacts of global climate change.
- **Chapter 5: Building on UK strengths** – outlines the potential role for the UK to use its strengths to respond to the challenges, threats and opportunities arising from the impacts of global climate change.

Chapter 6: Directions for the UK in a Warming World – considers the nature of the risks identified and how they may be treated by policymakers.

21 Migration, while identified as a key area, will not be specifically covered in this Report. How environmental change will interact with migration will be investigated in the forthcoming Foresight report on Global Environmental Migration, due to be published in autumn 2011.

22 Biodiversity was also identified as a key area of impact. However, given the extremely wide scope of impacts on global biodiversity associated with climate change, it was not considered feasible to include the implications for the UK within the limits of this project. The Climate Change Risk Assessment, due to be published early in 2012, will discuss the impacts of climate change on UK domestic biodiversity and ecosystems services.

23 These reviews are listed at Annex B and may be accessed at: http://www.bis.gov.uk/foresight.

24 These drivers are highly specific to different countries and individual risks, but may (for example) include national energy or food security, trade policies and social inequality.

A word of caution

This Report conveys the threats and opportunities to the UK from particular outcomes related to climate change, but does not attempt to assess the likelihood of such events. Projections of climate change are subject to considerable uncertainty (see section 2.3.2). It would therefore not be feasible for a project of such broad scope to carry out an exhaustive assessment of every risk identified, as well as the inherent uncertainty around the timing, scale and location of climate change impacts and other relevant global drivers of change. The Report combines peer-reviewed analysis, quantitative modelling, expert judgement and elements of futures techniques in the process of risk identification and analysis. A variety of terms are therefore used to reflect the different approaches to communicating expert judgement, uncertainties and confidence (both statistical and relating to expert judgement).

While this Report does not provide a formal or quantitative risk assessment, it does identify a range of threats and opportunities that should be considered as signposts for action, and a basis for further, more detailed analysis.

2 Global climate change

Chapter 2 provides background on the evidence for climate change. Projections of potential effects of climate change in the future are presented and areas of uncertainty are highlighted.

2 Global climate change

The first decade of the 21st century was the warmest since records began in 1850[1]. It was on average 0.2°C warmer than the previous record for the warmest decade (1991-2000) and approximately 0.4°C warmer than the 1961-1990 average[2]. Observations show that both atmospheric and ocean temperatures are rising[3]. Effects of global warming that are already apparent are declining sea ice extent and sea level rise[4], changes to weather patterns, including indications of more frequent and more intense extreme weather events[5], and changes to precipitation[6]. Some impacts of climate change are already apparent in, for example, altered distribution patterns of infectious disease vectors, such as ticks and mosquitoes[7], and the extension of crop growing seasons[8]. But the impacts of climate change cannot be considered in isolation from other human influences on local environments, such as land-use change, land degradation, population growth and rising urbanisation. Understanding how climatic change interacts with other environmental, economic and societal pressures is fundamental to improving our ability to assess what the future nature and scale of climate change impacts may be, and how we should respond.

2.1 Human activity is changing our climate

There is a robust and diverse body of scientific evidence which suggests that the global climatic changes observed over the past 50 years are largely attributable to human activities, predominantly through the burning of fossil fuels, land use changes and agricultural practices, all of which increase atmospheric concentrations of greenhouse gases (GHGs)[9]. Inherent natural variability in the climate system, variations in solar irradiance and volcanic activity are other factors which influence climatic conditions over a range of timescales. However, assessments of their relative influences over the past century conclude that natural factors alone cannot account for the observed warming, particularly in the latter half of the century[10].

In 2009, global atmospheric concentrations of GHGs reached the highest levels ever recorded, with carbon dioxide (CO_2) at 386.8ppm, methane (CH_4) at 1803ppb and nitrous oxide (N_2O) at 322.5ppb – which equate to 38%, 158% and 19% above pre-industrial values respectively[11]. Levels of CO_2 in the atmosphere are at their highest concentration for at least 800,000 years[12], primarily due to burning of fossil fuels but also as a result of land-use change, including degradation of the world's forests[13]. Changing land use and agricultural activities have also significantly increased the levels of methane and nitrous

1 World Meteorological Organization (2011), *WMO statement on the status of the global climate in 2010*. WMO-No. 1074, available at: http://www.wmo.int/pages/publications/showcase/documents/1074_en.pdf (last accessed 21/06/11).

2 *ibid.*

3 Arndt, D.S., Baringer, M.O. & Johnson, M.R. (eds) (2010), *State of the climate in 2009*. Bulletin of the American Meteorological Society, **91**: S1-S224.

4 *ibid.*

5 Trenberth, K.E., Jones., P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. & Zhai, P. (2007), Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

6 Zhang X. *et al*. (2007), *Detection of human influence on twentieth-century precipitation trends*. Nature, **448**:461–465.

7 Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B. & Woodward, A. (2007), *Human health*. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. (Eds). Cambridge University Press, Cambridge, UK, 391-431.

8 Rosenzweig, C., Casassa, G., Karoly, D.J., Imeson, A., Liu, C., Menzel, A., Rawlins, S., Root, T.L., Seguin, B. & Tryjanowski, P. (2007), *Assessment of observed changes and responses in natural and managed systems*. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. [eds], Cambridge University Press, Cambridge, UK, 79-131.

9 These include (in order of abundance in the atmosphere): water vapour, carbon dioxide, methane and nitrous oxide.

10 IPCC (2007), *Summary for Policymakers*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

11 World Meteorological Organization (2010) Greenhouse Gas Bulletin, November 2010. Available at: http://www.wmo.int/pages/prog/arep/gaw/ghg/documents/GHG_bull_6en.pdf (last accessed 21/06/11).

12 Luthi, D. *et al.* (2008), *High-resolution carbon dioxide record 650,000-800,000 before present*. Nature **453**: 379-382.

13 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

oxide emissions[14]. The Intergovernmental Panel on Climate Change (IPCC) has concluded that most of the observed changes in global average temperatures since the middle of the 20th century are very likely due to the observed increase in anthropogenic GHG concentrations[15].

The scale of future climate changes will be strongly influenced by the volume of GHG emissions in the future and by climatic "feedback effects" which could amplify or reduce the warming effects of GHGs. These feedback effects include changes in the Earth's reflectivity due to melting sea ice and snow cover, potentially significant releases of methane as frozen ground warms[16], and changes in cloud cover.

2.2 Climate change is already being observed

A wide range of evidence suggests that many natural systems are already being affected by regional climate change, particularly by temperature increases[17]. The three principal datasets of global surface temperatures that combine land and sea surface temperature observations[18] all show similar warming trends[19]. Global surface temperature increased, on average, by approximately 0.74°C over the 100-year period 1906–2005[20]. Warming observed over both land and oceans suggests that the average temperature rise is not an accumulation of local warming arising from small-scale effects such as urban heat islands[21,22]. This surface temperature warming trend is closely corroborated by satellite data collected over the past 30 years measuring temperature change in the lower atmosphere (the 'troposphere')[23].

These temperature increases are unevenly distributed and are generally greater over land than the oceans[24]. The Arctic has warmed at almost twice the global average over the past 100 years[25]. This global warming pattern is accompanied by observed decreases in snow and ice cover, with measured reductions in mountain glaciers, the retreat of Arctic sea ice[26] and some melting of the Greenland and Antarctic ice sheets[27]. This melting of glaciers, ice caps and sheets, and thermal expansion of the oceans, has led to an estimated rise in average global sea level of 17cm over the last century[28]. Changes in

14 Woods, J., Williams, A., Hughes, J.K., Black, M. & Murphy, R. (2010), *Energy and the food system*. Philosophical Transactions of the Royal Society B, **365**: 2991-3006.

15 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p39.

16 O'Connor, F.M., Boucher, O., Gedney, N., Jones, C.D., Folberth, G.A., Coppell, R., Friedlingstein, P., Collins, W.J., Chappellaz, J., Ridley, J. & Johnson, C.E. (2010), Possible role of wetlands, permafrost, and methane hydrates in the methane cycle under future climate change: a review. Reviews of Geophysics, **48**: RG4005.

17 IPCC (2007), *Summary for Policymakers*. In: *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, 7-22.

18 The three datasets are administered by NASA's Goddard Institute for Space Studies, the US National Oceanic and Atmospheric Administration, and the UK Met Office/UEA Climate Research Unit.

19 Trenberth, K.E., Jones, P.D., Ambenje,, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. & Zhai, P. (2007), *Observations: Surface and Atmospheric Climate Change*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

20 *ibid.*

21 Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B. & Jones, P.D. (2006), *Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850*. Journal of Geophysical Research, **111:** D12106.

22 Parker, D.E. (2004), *Climate: Large-scale warming is not urban*. Nature, **432**: 290.

23 Karl, T.R., Hassol, S.J., Miller, C.D., Murray, W.L. (eds) (2006), *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC. Report available at: http://www.climatescience.gov/Library/sap/sap1-1/finalreport/default.htm (last accessed 21/06/11).

24 Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. & Zhai, P. (2007), *Observations: Surface and Atmospheric Climate Change*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

25 *ibid.*

26 *"Arctic sea ice falls to third-lowest extent; downward trend persists"*. Press release of 04/10/10 from the National Snow and Ice Data Centre (NSIDC), available at: http://nsidc.org/news/press/20101004_minimumpr.html (last accessed 21/06/11).

27 IPCC (2007), *Summary for Policymakers*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

28 Betts, R., McNeall, D., Buontempo, C. & de Gusamo, D. (2010), *The Science of Climate Change – A briefing*. Hadley Centre, Exeter, UK. Available from the Met Office on request.

frequency and/or intensity of some extreme weather events, such as heat waves[29] and heavy precipitation events[30], have also been observed, and recent studies into the attribution of climate change have sought to identify the extent of the contribution of human activity to given events. For example, a study of the 2003 European heatwave[31] showed that human influence had very likely at least doubled the probability of such an event.

The extent of climate change in the future will depend upon the achievement of lower stabilisation levels of GHGs[32] through global mitigation efforts over the next 20–30 years. Effective mitigation will require investment in and adoption of low-carbon energy generation, changes to lifestyle and behavioural patterns, and changes to industrial and agricultural practices[33]. The implementation of national and international policies to regulate and incentivise mitigation, and advances in technology, also have the potential to have a significant impact[34].

However, even if GHGs in the atmosphere are stabilised, inertia in the climate system would mean that the world is 'locked in' to a level of further warming for many decades as the climate system is slow to respond[35]. Sea levels will continue to rise for far longer[36]. The earlier a peak and subsequent fall in emissions occurs, the more likely it is that global warming can be limited to less than 2°C[37], leading to greater avoided dangerous and potentially irreversible impacts of climate change later in this century[38].

2.3 Predicting future climate change

Climate models are representations of the climate system based on fundamental physical laws and observations. The climate system is, however, highly complex and there are known uncertainties associated with climate predictions, for example on the future level of GHG emissions (see Section 2.3.2). To account for these uncertainties climate scientists present future projections as probabilistic assessments of climate change effects and impacts, covering a range of plausible different future scenarios to ensure that current policy decisions on climate change are flexible, robust and resilient to an uncertain future. The next two sections explore scenarios of future emissions, and the uncertainties inherent in future climate modelling that make accurate predictions difficult.

29 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

30 Zhang X. *et al*. (2007) *Detection of human influence on twentieth-century precipitation trends*. Nature, **448**:461–466.

31 Stott, P.A., Stone, D.A. & Allen, M.R. (2004) Human contribution to the European Heatwave of 2003. Nature **432**: 610-614.

32 IPCC (2007), *Summary for Policymakers*. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

33 *ibid.*

34 *ibid.*

35 R:3:(Annex B refers).

36 IPCC (2007), *Summary for Policymakers*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

37 Above pre-industrial temperatures. Fee, E. (ed) *et al*., *Scientific perspectives after Copenhagen*. Report for EU member states, commissioned by the EU's Climate Change Science Experts. Report available at: http://www.eutrio.be/files/bveu/media/documents/Scientific_Perspectives_After_Copenhagen.pdf (last accessed 21/06/11).

38 Met Office AVOID programme (2010), *Can we avoid dangerous impacts?* Available at: http://www.metoffice.gov.uk/media/pdf/a/o/avoid4.pdf (last accessed 21/06/11).

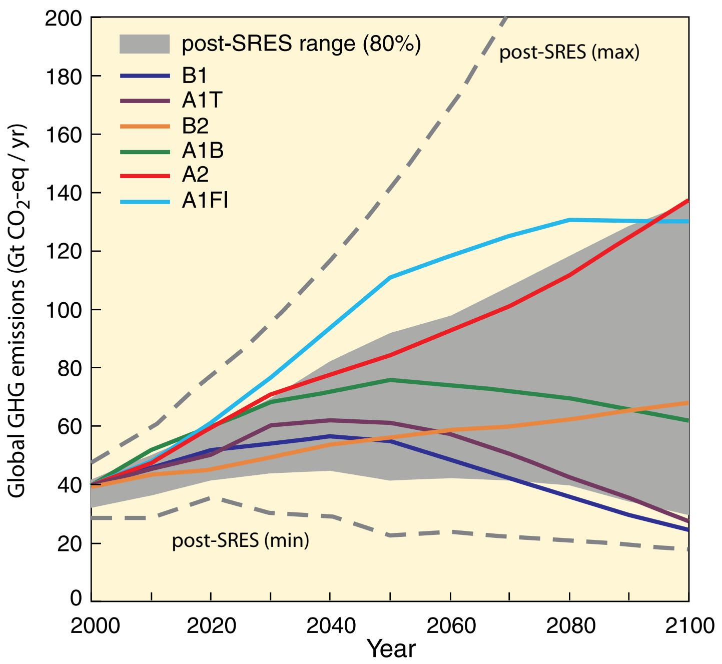
2.3.1 Emissions scenarios

The IPCC's 'SRES Scenarios'[39] comprise four scenario families (A1, A2, B1, B2) which cover a range of potential global GHG emissions trajectories in line with potential different future demographic, economic and technological trends (see Figure 2.1). These scenarios are used widely in assessments of future climate change, and their underlying assumptions act as inputs to many climate change vulnerability and impact assessments[40]. They represent 'non-intervention' scenarios, and explicitly exclude impacts from future climate change policies, i.e. deliberate reductions in emissions in response to awareness of climate change[41].

Where relevant, the analysis within this Report uses one or more of the following three scenarios, two of which are SRES scenarios and a third which was developed as part of the European ENSEMBLES project[44] to account for potential mitigation action in the future:

- **A1FI SRES scenario** (the A1 fossil-fuel intensive (FI) scenario, henceforth referred to as '**high emissions**'). This high emissions scenario represents a world where global population peaks in mid-century before declining; there is rapid economic growth and the introduction of new and more efficient technologies. It is an increasingly homogeneous world, where regional convergence, capacity building and increased social and cultural interactions are accompanied by a shrinking gap in per capita income between rich and poor. Technological advance is driven by fossil fuels[45].

Figure 2.1: Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published after SRES and before AR4 ("post-SRES", grey shaded area)[42]. Dashed lines show the full range of post-SRES scenarios. The GHG emissions include CO_2, CH_4, N_2O and fluorinated GHGs.[43]



39 IPCC (2000), *IPCC Special Report on Emissions Scenarios*. IPCC, Geneva, Switzerland.

40 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p66.

41 A new family of scenarios – the Representative Concentration Pathways (RCPs) – are being developed by the IPCC to consider mitigation within such future scenarios but are not yet available and have therefore not been considered in this Report. See: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios.pdf

42 Post-SRES scenarios were published between the release of the IPCC SRES report in 2000 and the publication of the IPCC Fourth Assessment Report in 2007. They are discussed in:
Fisher, B.S., Nakicenovic, N., Alfsen, K., Corfee Morlot, J., de la Chesnaye, F., Hourcade, J. -Ch., Jiang, K., Kainuma, M., La Rovere, E., Matysek, A., Rana, R., Riahi, K., Richels, R., Rose, S., van Vuuren, D. & Warren, R. (2007), Issues related to mitigation in the long term context, In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change.* Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. & Meyer, L.A. (Eds), Cambridge University Press, Cambridge, UK.

43 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p44.

44 ENSEMBLES was a European project which ran from 2004 to 2009 and produced Europe-wide probabilistic climate projections. It was coordinated by the Met Office Hadley Centre.

45 IPCC (2000), *Special Report on Emissions Scenarios. Summary for Policymakers*. IPCC, Geneva, Swizerland, p4.

- **A1B SRES scenario** (the A1 balanced (B) scenario, henceforth referred to as '**medium emissions**'). The medium emissions scenario has the same characteristics as described for the high emissions scenario, but technological advance is driven by a balance of fuel derived from all sources.
- **E1 ENSEMBLES scenario** ('**aggressive mitigation**'). The aggressive mitigation scenario was designed to match the EU target of stabilising atmospheric GHG emissions at 450ppm CO_2-equivalent[46], to keep global temperatures at 2°C above pre-industrial levels[47].

Modelling by the UK's Met Office Hadley Centre (and others, including several national meteorological organisations, and the UN World Meteorological Organization) has assessed how these emissions scenarios might affect global temperatures over time. Given that the Earth is locked in to a certain amount of climate change, largely because of the inertia in the climate system from past emissions[48], similar levels of warming up to the 2040s are predicted to occur under all three scenarios – approximately 1.3-1.7°C relative to the 1981-1999 global average[49]. Beyond 2040, pathways of temperature change diverge depending on the emissions scenario used[50]. As global temperatures continue to rise, climate change effects are predicted to become apparent through a variety of phenomena (see Section 2.4).

2.3.2 Uncertainties in climate modelling

Climate modelling can provide significant insights into the possible future evolution of the global climate system, but there are important uncertainties and gaps in current scientific knowledge which have a bearing on climate projections[51]. These are graphically represented in Figure 2.2 and can be broadly categorised into:

- **Internal (natural climate) variability**: the climate is a chaotic system. This means that it is highly sensitive to small changes, and naturally varies across all timescales. The characteristics of this variability for a given climate can be understood, but predicting what these specific variations will be for a given period is more complex and not possible over longer timescales. Thirty-year averages of climatic conditions are used to ensure that measurements are not biased by natural variability in any one year.
- **Future emissions**: the uncertainty about future levels of GHG emissions, which will depend on factors such as population growth, economic development and the use of low-carbon technologies, becomes increasingly important for climate projections covering the second half of this century. Evaluation of more than one scenario can be used (as done here) to consider the range of possible outcomes.
- **Models**: limitations in scientific understanding of (a) how to represent important processes of the climate system and (b) certain feedbacks and interactions between processes in climate models mean that there is uncertainty in the physics of the models. Each model differs in its configuration and input parameters, and therefore in its results.

The relative importance of these three kinds of uncertainty changes with the timescale of projections, as shown in Figure 2.2. Uncertainties associated with natural (internal) variability and climate modelling dominate in projections of the near term whereas those associated with uncertainty of future levels of emissions become increasingly important for projections beyond the 2040s.

46 ENSEMBLES (2009), Summary of research and results from the ENSEMBLES project. Available at: http://ensembles-eu.metoffice.com/ (last accessed 21/06/11).

47 den Elzen, M.G.J. & Meinshausen, M. (2005), *Meeting the EU 2°C climate target: global and regional emission implications*. Report 728001031/2005, Netherlands Environmental Assessment Agency, Bilthoven. Available at: http://unfccc.int/essential_background/library/items/3599.php?rec=j&priref=4965 (last accessed 21/06/11)

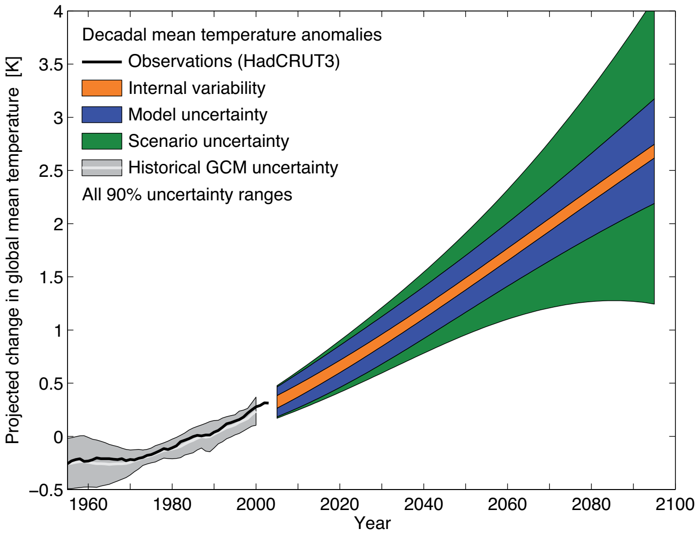
48 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p66

49 See Figure 2.3.

50 See section 2.4.1.

51 R:3 (Annex B refers).

Figure 2.2: Contributions to uncertainty in decadal mean surface air temperature change relative to the 1971-2000 average estimated from the CMIP3 ensembles[52], used as part of the UK Climate Projections[53]. Scenario uncertainty in the graph relates to emissions uncertainty described in the text. Image used for purpose of illustrating the uncertainties in climate modelling[54]



Climate ensembles are one approach that is used to address these dimensions of uncertainty. These are groups of model simulations run in parallel which differ slightly from one another in specific parameters. As all climate projections are inherently probabilistic, such ensembles provide a set of data from which stronger conclusions may be drawn than from single simulations[55]. However, some effects of climate change have considerable uncertainty, which may not be significantly reduced even by the use of ensembles, including regional scale impacts and the thresholds for large-scale, non-linear changes. These potential 'tipping points' include failure of ocean circulations or the Indian summer monsoon (see Box 2.1).

52 More information on CMIP3 is available at: http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php (last accessed 21/06/11).

53 More information on UKCIP is available at: http://ukclimateprojections.defra.gov.uk/content/view/1910/690/ (last accessed 21/06/11).

54 Hawkins, E. & Sutton, R. (2011), The potential to narrow uncertainty in projections of regional precipitation change. Climate Dynamics, in press, doi: 10.1007/s00382-010-0810-6.

55 Hewitt, C.D. & Griggs, D.J. (2004), Ensembles-based predictions of climate changes and their impacts (ENSEMBLES). ENSEMBLES Technical Report No. 1. ISSN 1752-2854. Available at: http://ensembles-eu.metoffice.com/tech_reports/ETR_1_vn2.pdf (last accessed 21/06/11).

Box 2.1 Tipping points

There is potential for climate change to push elements of the Earth system past a critical threshold or 'tipping point' beyond which they change state dramatically, leading to large-scale effects on human and ecological systems. By their very nature, **these events are highly uncertain** and predictions are difficult to make. Examples include:

- **Accelerated or irreversible melting of the Greenland Ice Sheet (GIS)** could occur should regional temperatures rise by more than around 3°C[56], as warming is not expected to be uniform across the globe. The IPCC consider the range in global average temperature rise for this tipping point (beyond which significant melting occurs) to be between 1.9°C and 4.6°C[57]. During the last inter-glacial period, when summer temperatures across Greenland were estimated to be around 3°C or higher than present, melting of the GIS is thought to have contributed between 1.9m and 3.0m to global sea level rise[58]. Potential impacts could include significant flooding risk to coastal areas. The large influx of fresh water into the North Atlantic may also have a negative effect on thermohaline circulation.
- The **Atlantic thermohaline circulation (THC)** is the 'conveyor belt' by which warm water from equatorial regions moves north, is cooled, and returns towards the equator. It is responsible for the milder winters experienced by the UK in comparison to other countries on the same latitude, such as Canada. If the THC were to collapse, this could have a significant cooling effect upon the UK climate[59]. The IPCC consider that while the strength of the THC may weaken, it is very unlikely that it would fail entirely before 2100[60]. Assessing the likelihood of any major change beyond this timescale is not possible.
- **Amazon forest dieback** could occur as a result of drying of the Amazonian climate[61,62]. However, human factors such as deforestation of the region may be considered at least as strong a risk factor for significant dieback as direct climate change[63,64]. It has been estimated that up to a quarter of total global biodiversity is contained within the Amazon region[65]. The Amazon rainforest is also a significant carbon sink. Dieback or loss through deforestation both release CO_2 emissions as well as reducing global carbon sequestration capacity, providing a further climate change feedback.

56 Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., Schellnhuber, J. (2008), *Tipping elements in the Earth's climate system.* PNAS, **105**: 1786-1793.

57 IPCC (2007), Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

58 Otto-Bliesner, B. L., Marshall, S. J., Overpeck, J.T., Miller, G. H., Hu, A. & CAPE Last Interglacial Project Members (2006), *Simulating Arctic Climate Warmth and Icefield Retreat in the Last Interglaciation.* Science **311**: 1751-1753.

59 Osborn, T. & Kleinen, T. (2008), *The Thermohaline Circulation*. Climatic Research Unit Information Sheet number 7, available at: http://www.cru.uea.ac.uk/cru/info/thc/thc.pdf (last accessed 21/06/11).

60 IPCC (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Eds: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Cambridge University Press, Cambridge, UK).

61 Cox, P.M., Betts, R.A., Collins, M., Harris, P.P., Huntingford, C. & Jones, C.D. (2004), *Amazonian forest dieback under climate-carbon cycle projections for the 21st century.* Theoretical and Applied Climatology, **78**: 137-156.

62 Betts, R.A., Cox, P.M., Collins, M., Harris, P.P., Huntingford, C. & Jones, C.D. (2004), *The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming.* Theoretical and Applied Climatology, **78**: 157-175.

63 Mahli, Y., Aragão, L.E.O.C., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., Sitch, S., McSweeny, C. & Meir, P. (2009), *Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest.* Proceedings of the National Academy of Science, **106**: 20610-20615.

64 Nepstad, D.C., Stickler, C.M., Soares-Filho, B. & Merry F. (2008), *Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point.* Philosophical Transactions of the Royal Society B, **363**: 1737-1746

65 Mahli, Y., Roberts, J.T., Betts, R.A., Kileen, T.J., Li, W. & Nobre, C.A. (2007), *Climate change, deforestation, and the fate of the Amazon.* Science, **319**: 169-172.

The long-term consequences of decisions that are made to mitigate future emissions of GHGs, alongside any adaptation to climate change, cannot be accurately predicted by modelling. A range of future emissions scenarios are therefore used, without a likelihood being assigned to any one scenario. These provide the current 'best estimate' of the range of possible futures, allowing policy to be informed by the best currently available evidence. However, expanding scientific knowledge of the range of possibilities in the system (moving from 'unknown unknowns' to 'known unknowns') is driving the development of more complex and complete climate models, and will allow scientists to make projections with greater confidence when a range of emissions scenarios are used.

2.4 Potential effects on the future global climate

Up to the 2040s the uncertainties in changes to the climate due to different emissions scenarios are small and largely irrelevant[66]. Beyond this period, emissions scenarios become much more important and climate projections for the medium emissions and aggressive mitigation scenarios demonstrate significant differences[67].

The impacts of climate change will arise not only through large-scale changes and immediately damaging effects, such as severe weather events, but also long periods of moderate variation which may have equally significant impacts, and present greater challenges for adaptation. For example, several years of moderate drought or above average rainfall may have impacts as significant as a single, severe drought or flood. This convergence of small events needs to be considered alongside more severe (but less common) weather events.

This section presents future projections to both the 2040s and to 2100 for global temperature, sea level rise, changes in precipitation and glacial melt, and extreme weather based on modelling work carried out for this Report by the Met Office Hadley Centre[68]. A summary of these projections is shown in Box 2.2.

An ensemble (a group of 17 closely related parallel model simulations, validated against past climate observations) of the coupled atmosphere-ocean general circulation model HadCM3 was used to generate projections of future climate up to the 2040s in the context of the medium emissions scenario (described in Section 2.3.1). Only one emissions scenario was used over this timescale, as the inertia in the climate system means projections under different emissions scenarios are very similar. For projections to 2100, a more recent model (HadGEM2) with a higher resolution was used[69]. Over a longer timescale emissions scenarios become more important, hence projections under the medium emissions and aggressive mitigation scenarios (described in Section 2.3.1) were compared.

66 R:3 (Annex B refers).

67 *ibid.*

68 *ibid.*

69 For the purposes of this Report, the use of a different model makes little difference as similar results can be produced using the HadCM3 model. However, the HadGEM2 model has a higher grid resolution and is more suitable for studying climate extremes.

Box 2.2 Summary of climate change effects

This table summarises the key climate change effects discussed in this section. Details of the relevant evidence, the scenarios, and the caveats which apply to any climate change projections are discussed in Section 2.4.

Temperature	• Up to about 2040, mean global temperatures are projected to increase by approximately 1.3-1.7°C across the world (relative to the 1981-1999 global average) under the three scenarios used in this Report. • All regions are expected to experience an increase in extreme high temperature events. • By 2080, mean global temperatures are projected to be around 3.5°C higher than the 1981-1999 global average for the medium emissions scenario, and around 1.5°C for the aggressive mitigation scenario.
Sea level rise	• Significant increases in sea level are expected in many coastal areas by the 2040s. • By 2100, average sea level may rise by 0.23–0.43m under the medium emissions scenario. • There will be regional variation in sea level rise.
Precipitation	• Less precipitation in parts of the Amazon region, southern Africa and Southeast Asia, and more in the high latitudes of Northern America, Europe and Central and North Asia is projected by the 2040s. • By the 2040s, in some regions annual mean precipitation could be 500mm more or less than today.
Extreme weather events (floods, droughts, storms)	• By the 2040s, many areas of the world (particularly in tropical and high latitude areas) may have increased intensities of heavy rainfall. • Drought conditions may become further prolonged by the 2040s, with increased risk in already drought-prone regions such as Australia, Brazil and parts of Africa. Europe and China may also experience significant increases in duration of drought. • By 2100, under the medium emissions scenario, the Amazon region and equatorial West Africa may be almost constantly under moderate drought conditions, and frequent droughts may occur in the western Mediterranean. • Severe tropical cyclones may become more intense in the future with stronger winds and heavier rainfall.

2.4.1 Temperature

Mean global temperatures are projected to increase across the world for at least the next three decades in all scenarios used in this Report (high and medium emissions, and aggressive mitigation, Section 2.3.1). By the 2040s, the largest increases are likely to be in the high latitude regions of the northern hemisphere, with much of Canada, Russia and the Arctic region experiencing significant warming[70]. To a lesser extent, the Amazon region and parts of China are also likely to see temperature increases above those experienced elsewhere over the same timescale, with South Asia and Southeast Asia experiencing

70 R:3 (Annex B refers).

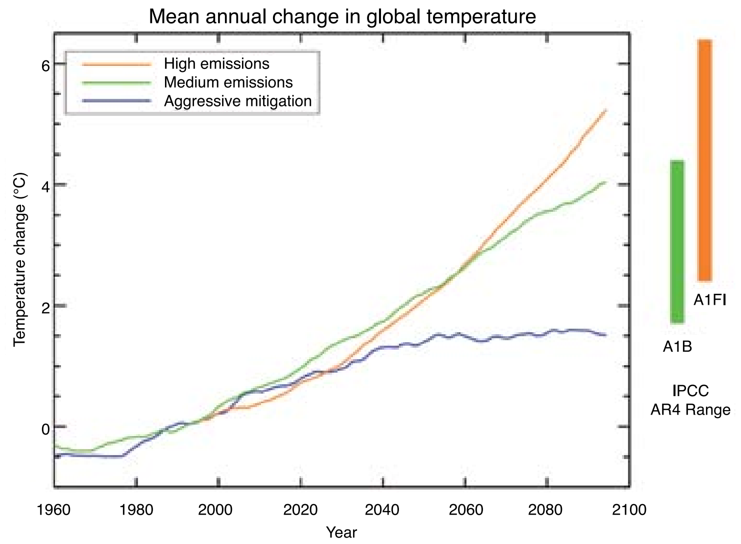
the lowest projected increases in mean temperature[71]. All regions are expected to experience an increase in extreme high temperature events[72], with Canada, Russia and central Africa projected to experience the largest increases in maximum temperatures[73].

Up to the 2040s there is little difference between the temperature projections of the three emissions scenarios considered by this Report. Beyond this date temperature projections begin to diverge (Figure 2.3). This divergence depends upon the level of global emissions, with the medium emissions scenario leading to average global temperatures that are around 3.5°C higher than the 1981-1999 global average, by 2080. Temperature projections for the aggressive mitigation scenario level off at about 1.5°C increase over the same timescale[74].

2.4.2 Sea level rise

Observations indicate that global average sea level rose by 1.7 ± 0.5 mm per year over the last century[76], with some evidence that the rate of sea level rise accelerated up to the end of the century[77]. However, sea levels are not rising uniformly across the globe, and there is also considerable decadal variability in the measured rate of rise[78].

Figure 2.3: Projected global mean temperature increases under different scenarios used by this Report, relative to the 1981-1999 global average. Including the IPCC AR4 'likely ranges' for A1B and A1FI for context. Aggressive mitigation projection generated using a different version of the Hadley Centre climate model to that used for the high- and medium-emissions projections, which has been accounted for when generating this comparison[75].



71 It should be noted that these projections differ from those of the IPCC AR4 WG1 report, which predicts that South and East Asia will experience warming above the global mean, and South-East Asia will experience warming at or near to the global mean. See section 11.4 of: Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: *Regional Climate Projections*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

72 Defined as the likelihood of a 1-in-20-year heatwave event, relative to 2000.

73 R:3 (Annex B refers).

74 There is general agreement between climate models for temperature, which provides some confidence in the projections of future temperatures. However, confidence at the regional scale is lower, for example regional climates are affected by albedo changes from cloud cover and atmospheric aerosols, and models are only now being developed with sufficient sensitivity to represent these factors.

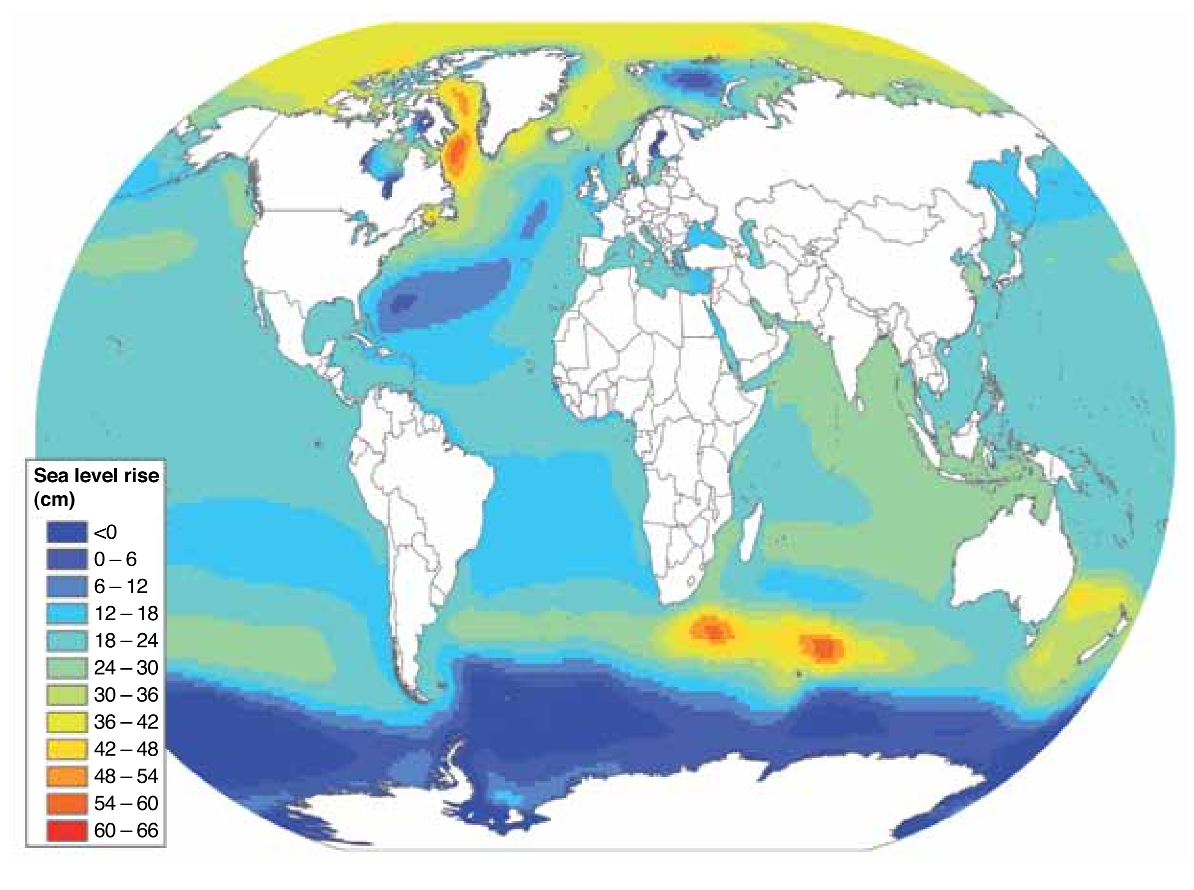
75 No comparable estimation of 'likely range' for E1 included since only one simulation is available. Projection modelling carried out by the Met Office Hadley Centre. Betts, R., Hartley, A. & McColl, L. (2010), *Is UKCP09 valid for an aggressive mitigation scenario?* Briefing submitted to DEFRA for the Climate Change Risk Assessment.

76 Bindoff, N.L. *et al.* (2007), Observations: Oceanic Climate Change and Sea Level. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor & H.L. Miller (eds.). *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

77 Church, J.A. & White, N.J. (2006), *A 20th century acceleration in global sea-level rise*. Geophysical Research Letters, **33**: 01602, doi: 10.1029/2005GL024826.

78 Bindoff, N.L. *et al.* (2007), Observations: Oceanic Climate Change and Sea Level. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor & H.L. Miller (eds.). *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Figure 2.4: Projected time-mean relative sea level rise for 2040, relative to the 1980-1999 average level. Modelling carried out by Met Office Hadley Centre for this Report[79]



Significant increases in sea level are expected for many coastal areas by 2040 (Figure 2.4). By 2100, under the medium emissions scenario, projections suggest that the average sea level rise will be between 0.23m and 0.43m, with extremes of over 0.6m projected by two models[80]. However, projections from the aggressive mitigation scenario indicate that about one-fifth of the mean rise could be avoided[81]. Regional variation in sea level rise is due in part to the fact that the surface of the oceans is not 'flat' as it is affected by concentrations of mass in the Earth's interior, as well as local topography[82]. Regional sea levels may also be affected by large-scale currents and regional sea temperatures[83].

Sea level rise has the potential to lead to the inundation of low-lying coastal areas. About 1.2 billion people live within 100km of the coast and 100m of sea level[84], but it is far from clear what proportion of these communities would be at risk from long-term sea level rise.

2.4.3 Precipitation and glacial melt

Projections of global-scale patterns of circulation and precipitation have higher levels of confidence than regional-scale projections for several reasons: first, rainfall records in many parts of the world (e.g. Africa and the Middle East) are sparse, particularly for intense events, and identifying current trends is challenging. Secondly, most climate models do not resolve monsoon events and their associated rainfall

79 R:3 (Annex B refers).

80 2080-2099 relative to the 1980-1999 average, using the HadCM3C and HadGEM2-AO models.

81 R:3 (Annex B refers).

82 The European Space Agency's Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission is currently mapping the Earth's gravitational field, and will provide the most accurate measurements to date as to the shape of this global "flat" surface, or geoid. For more information, see http://www.esa.int/SPECIALS/GOCE/index.html (last accessed 21/06/11).

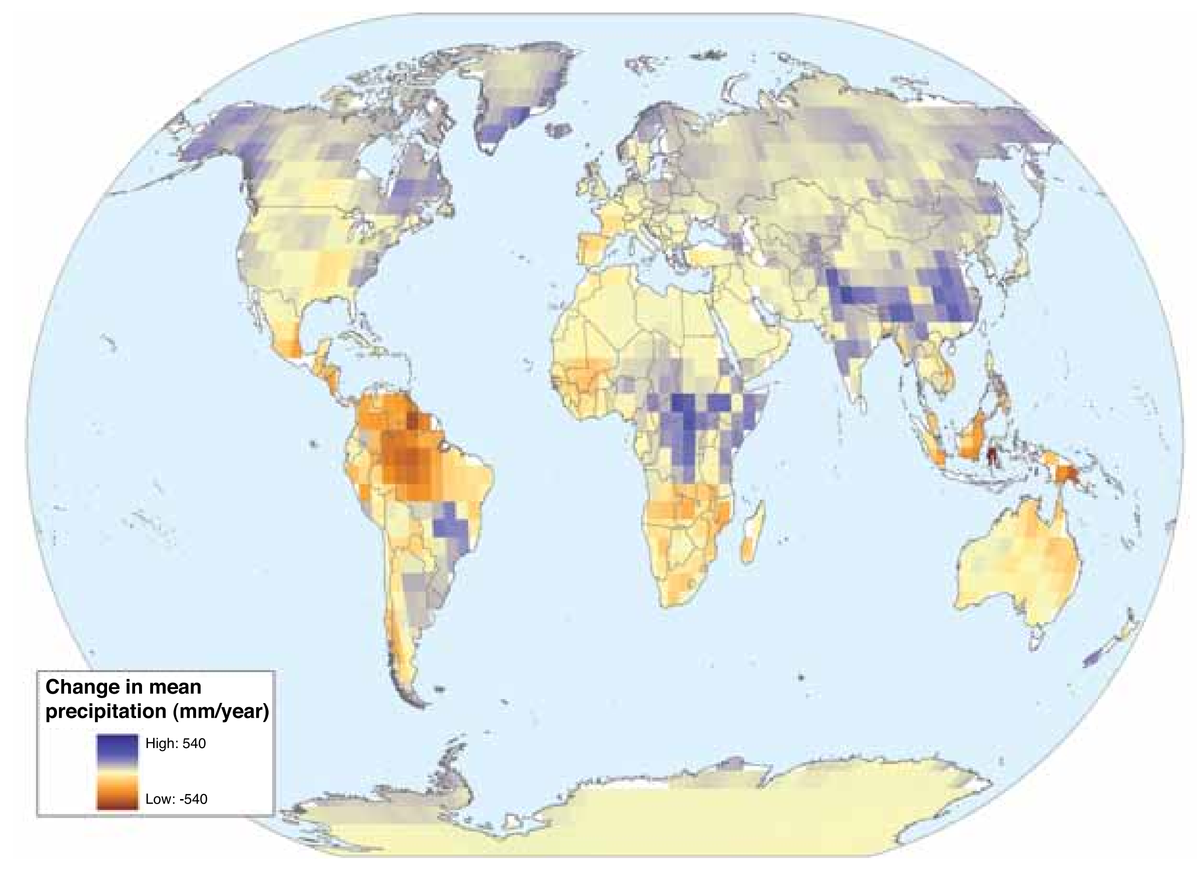
83 For more information, see the website of the Permanent Service for Mean Sea Level, a body funded by the UK Natural Environment Research Council, available at: http://www.psmsl.org/train_and_info/faqs/ (last accessed 21/06/11).

84 Small, C. & Nicholls, R.J. (2003), *A global analysis of human settlement in coastal zones*. Journal of Coastal Research, **19**: 584-599

well[85]. Finally, satellite measurement of rainfall over the oceans is still being developed. The use of an ensemble of climate models (see section 2.3.2) allows these uncertainties to be minimised, enabling regional predictions to be made, albeit with lower confidence than predictions at a global scale [86].

Ensemble modelling carried out for this project[87] signals a decrease in precipitation in parts of the Amazon region, southern Africa and Southeast Asia by the 2040s (Figure 2.5). Decreased precipitation to a lesser extent is also predicted over this timescale for the Mediterranean and eastern Australia, although agreement across the ensemble is lower in these areas. The high latitudes of North America, Europe and Central and North Asia are more likely to experience increased precipitation by the 2040s, but the projections for increases in central Africa and Asia have a lower confidence due to a lower level of agreement across different simulations within the ensemble[88]. By 2100 a smaller decrease in precipitation over the Amazon, Africa, and Southern Europe is projected in the aggressive mitigation scenario than under the medium emissions scenario[89].

Figure 2.5: Projected change in annual mean precipitation (mm per year) for 2040[90], relative to 1970-1999. The projection is the member of the ensemble with the median change in annual mean precipitation averaged over the land surface selected from an ensemble of 17 scenarios with variants of the HadCM3 climate model.



85 Randall, D.A., Wood, R.A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Kattsov, V., Pitman, A., Shulka, J., Srinivasan, J., Stouffer, R.J., Sumi, A. & Taylor, K.E. (2007). Climate models and their evaluation. In: Solomon, S., D. Qin, M. Manning, Z. Chen, .Marquis, K.B. Averyt, M. Tignor and H.L. Miller (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, United Kingdom and New York, NY, USA.

86 R:3 (Annex B refers).

87 *ibid.*

88 *ibid.*

89 *ibid.*

90 Based on a 30-year mean, 2025-2055.

Rainfall-driven runoff is an important contributor to global freshwater supplies, and by the 2040s water availability is therefore projected to decline in the Amazon region, southern Africa and Southeast Asia, although North America, South and East Asia may experience increases in runoff [91]. Runoff projections also take evaporation into account, which is predicted to generally increase in a warming world. Evaporation may be counteracted to an extent by rising levels of atmospheric CO_2 causing a decrease in water loss from plants to the atmosphere, although there is considerable uncertainty about the extent of this effect.

Another important source of fresh water is glacial melt. There have been considerable decadal variations in glacier trends. While in some areas glaciers have been stable or advancing, observations indicate that since the 1980s there has been a general trend for global glacier retreat[92]. It is not possible to attribute recent warming to this retreat, but the IPCC consider it likely[93,94]. Any increase in glacial melt will, in the short term, initially increase river flow[95], which may bring greater risk of flooding. In the longer term it is likely that there will be an eventual decline in runoff, which may lead to water scarcity in those regions dependent upon glacier-fed rivers, although the potential timescale for this decline is uncertain[96]. For example, Himalayan glaciers feed rivers such as the Indus, Ganges and Brahmaputra, which currently support domestic and agricultural water resources and important fisheries for nearly 500 million people[97]. Where observations exist, they indicate a general trend towards glacier retreat in the Himalayas and neighbouring ranges[98]. However, there is no uniform response across the region and characteristics of individual glaciers (such as debris cover and local topography) have been shown to be an important factor in glacier behaviour[99].

2.4.4 Extreme weather events

Extreme weather events are events that deviate significantly from multi-decadal measurements. For example, the World Meteorological Organization (WMO) uses climate data gathered between 1961 and 1990 to define normal values, and, on this basis, an extreme high temperature may be defined as one occurring only once in every 30 years[100]. Such extreme events can occur for a range of climatic indicators, including heavy rainfall or long droughts, high or low daily temperatures, and extreme storms or winds.

By the 2040s, many areas of the world (particularly in tropical and high latitude areas that experience increases in mean precipitation) may be experiencing increased intensities of heavy rainfall[101], which will probably lead to more frequent flooding events[102]. Even for those areas that experience a decrease in mean precipitation, the intensity of rainfall events is expected to increase, but there would be longer periods between rainfall events[103]. A projected increase in the likelihood of wet winters in Central and Northern Europe could lead to a greater chance of winter flooding due to increased precipitation

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91 R:3 (Annex B refers).

92 Zemp, M., Roer, I., Kaab, A., Hoelzle, M., Paul, F. & Haeberli, W. (2008), *Global glacier changes: facts and figures*. Zurich, Switzerland: UNEP, World Glacier Monitoring Service.

93 Lamke, P., J. Ren, R. B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fuji, G. Kaser, P. Mote, R. H. Thomas and T. Zhang 2007: Observations: Changes in Snow, Ice and Frozen Ground. In: *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, United Kingdom and New York, NY, USA: Cambridge University Press.

94 Bates, B.C., Kundzewicz, Z.W., Wu, S. & Palutikof, J.P. (2008), *Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change*. IPCC Secretariat, Geneva.

95 Juen, I., Kaser, G. & Georges, C. (2007), *Modelling observed and future runoff from a glacierized tropical catchment (Cordillera Blanca, Peru)*. Global and Planetary Change, 59: 37-48.

96 R:3 (Annex B refers).

97 Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K. & Wiltshire, A. (2010), *Implications of climate change for agricultural productivity in the early twenty-first century*. Philosophical Transactions of the Royal Society B, **365**: 2973-2989

98 Zemp, M., Roer, I., Kaab, A., Hoelzle, M., Paul, F. & Haeberli, W. (2008), *Global glacier changes: facts and figures*. Zurich, Switzerland: UNEP, World Glacier Monitoring Service.

99 Scherler, D., Bookhagen, B. & Strecker, M.R. (2011) *Spatially variable response of Himalayan glaciers to climate change affected by debris cover*, Nature Geoscience, doi:10.1038/ngeo1068.

100 More information on climate variability and extreme events may be found on the website of the World Meteorological Organization, at: http://www.wmo.int/pages/themes/climate/climate_variability_extremes.php (last accessed 21/06/11).

101 R:3 (Annex B refers).

102 Watterson, I.G. (2005), Simulated changes due to global warming in the variability of precipitation, and their interpretation using a gamma-distributed stochastic model. Advances in Water Resources, **28**: 1368-1381.

103 IPCC (2007), *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, UK and New York, NY, USA: Cambridge University Press, p750.

runoff[104]. Similarly, there is a greater probability of wetter summers in the Asian monsoon region, which suggests an increased risk of flooding[105].

By 2100, there are some noticeable differences in projections of heavy rainfall between the medium emissions and aggressive mitigation scenarios across the world, demonstrating that future emissions levels are likely to have a significant impact on regional incidences of rainfall and flooding. The level of global change for five-day average precipitation maximums (relevant to creating conditions for flooding) for both the medium emissions and aggressive mitigation scenarios is similar, increasing by approximately 2mm[106]. In some regions, the choice of emissions scenario affects only the extent to which a change is observed. For example, in the Amazon, a more severe decrease in five-day average rainfall is seen in the medium emissions scenario than in the aggressive mitigation scenario. In other regions, the choice of scenario affects the direction of change. For example, India is projected to experience an increase in five-day average rainfall under medium emissions but a decrease under aggressive mitigation.

Duration of drought conditions beyond multi-decadal averages may become further prolonged by the 2040s, with increased risk in already drought-prone regions such as Australia, Brazil and parts of Africa. Regions such as Europe and China may also experience significant increases in duration of drought[107]. By 2100 there are noticeable differences between the medium emissions and aggressive mitigation scenarios in the length of time regions are defined as being under drought. Under the medium emissions scenario, the Amazon region and equatorial West Africa may be almost constantly under moderate drought conditions, and frequent droughts are projected to occur in the western Mediterranean. Much of Africa, Europe, the Middle East, Southeast Asia, Australia and North America are affected by drought to a greater extent than the present day[108]. Under the aggressive mitigation scenario, these regions are projected to be much less affected by drought, which occurs at a frequency much closer to that of the present day[109].

Although there is limited consensus amongst climate models on the regional variations in frequencies of tropical cyclones, studies and modelling do indicate that they may become more intense in the future with stronger winds and heavier rainfall[110,111,112,113]. This increase in intensity could cause devastating harm to crops, as well as disruption and physical damage to critical infrastructure.

The extent and nature of the effects experienced by different regions are likely to vary with the magnitude, timing and location of climate changes which take place. Up to the 2040s, temperature and sea-level projections are very similar under all scenarios. Beyond this period, levels of global GHG emissions have an increasing influence on how climate change will impact regions of the world. Taking into account all of the evidence, the IPCC conclude that the regions most likely to be significantly affected by climate change effects are the Arctic, Africa, small low-lying islands (due to high exposure to risk of sea-level rise and increasing storm surges), and Asian mega-deltas (because of concentrated populations at high exposure to sea-level rise, storm surges and river flooding)[114].

104 Meehl, G.A., T. F. Stocker, W. D. Collins, P. Firedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. M. Murphy, A. Noda, S. C. B. Raper, I. G. Watterson, A. J. Weaver and Z-C. Zhao (2007), Global Climate Projections. In: *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, United Kingdom and New York, NY, USA: Cambridge University Press.

105 Palmer, T.N. & Räisänen, J. (2002), *Quantifying the risk of extreme seasonal precipitation events in a changing climate*. Nature, **415**: 514-517.

106 R:3 (Annex B refers).

107 *ibid.*

108 *ibid.*

109 *ibid.*

110 Meehl, G.A. *et al.* (2007), Global Climate Projections. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor & H.L. Miller (eds.). *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

111 Bengtsson, L. *et al.* (2007), *How may tropical cyclones change in a warmer climate?* Tellus, **59**: 539-561.

112 Gualdi, S., Scoccimarro, E. & Navarra, A. (2008), Changes in tropical cyclone activity due to global warming: results from a high-resolution coupled general circulation model. Journal of Climate, **21**: 5204-5228.

113 McDonald, R.E., Bleaken, D.G., Cresswell, D.R., Pope, V.D. & Senior, C.A. (2005), *Tropical storms: representation and diagnosis in climate models and the impacts of climate change*. Climate Dynamics, **25**: 19-36.

114 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

3 UK threats and challenges part A

This chapter introduces the potential threats to, and challenges for, the UK from climate change impacts overseas.

Impacts on the UK's foreign policy, security and its role on the international stage are all explored. The UK's interdependencies through the global systems of finance and trade are also considered.

3 UK threats and challenges part A

Over the next few decades it is likely that the world will continue to experience rapid population growth, significant demographic shifts, increased globalisation, greater global inequality, resource scarcity (including water insecurity) and shifts in economic power[1,2,3,4]. All of these trends pose significant challenges which the international community will have to confront. Climate change is a discrete challenge, the effects of which may act as a 'risk multiplier', interacting with other trends, exacerbating existing tensions and insecurity, and making it even more difficult to address poverty, disease, and food and water insecurity. Climate change may also materially affect global economic growth through its direct effects on non-sustainable natural resources. The impacts of climate change mitigation policies on the consumption of those resources may also be influential[5].

The substantial uncertainty and complexity that arises in assessing the physical effects of future climate change also applies to any consideration of the political, security, economic and social impacts, and the interactions of the latter with wider global drivers of change. Impacts are likely to differ significantly across sectors, regions, countries and populations. In areas with high vulnerability to climate change and low adaptive capacity, net impacts may be significantly larger than implied by global aggregate estimates[6].

With all its uncertainties, climate change impacts overseas are expected to affect the UK in diverse ways, with implications for global governance and security, finance and trade, international infrastructure, resources and commodities, as well as human health and behaviour. The UK also has the opportunity to build upon its existing strengths and rise to the challenges posed by global climate change by showing international leadership, and developing its capabilities to assist other countries. These impacts and their implications for the UK are the subject of Chapters 3, 4 and 5 – with the most important risks highlighted in boxes.

This chapter identifies how the effects of climate change in other countries may affect the UK's role on the international stage – through pressures on the global governance structures of which the UK is a member, through increased demands for interventions to achieve international security, and humanitarian action, through calls to meet its international roles and responsibilities, and through its relationship with the UK Overseas Territories. The UK's interdependencies through the global systems of finance and trade are also discussed.

3.1 Foreign policy and security

The UK's prosperity and national security depend heavily on global stability, which in turn depends upon effective structures for global governance[7], legal instruments, and the maintenance of international networks of trade and diplomacy[8]. As such, it is important for the UK to understand how these networks will be affected as the world experiences changes in temperature, extreme weather, sea level rise and precipitation from climate change in the decades ahead. In this section, the potential risks arising from the impacts of these changes on global networks and regions are identified in the areas of:

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1 IPCC (2007), *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, 7-22.

2 Cabinet Office (2007), *The Economics of Climate Change: The Stern Review*. UK: Cambridge University Press.

3 National Intelligence Council (2008), *'Global Trends 2025: A Transformed World', Fourth unclassified report of the National Intelligence Council,* available at: http://www.dni.gov/nic/NIC_2025_project.html (last accessed 21/06/11).

4 Ministry of Defence/DCDC (2010), *Strategic Trends Programme: Global Strategic Trends – Out to 2040*, 4th Edition. Available at: http://www.mod.uk/DefenceInternet/MicroSite/DCDC/OurPublications/StrategicTrends+Programme/TheDcdcGlobalStrategicTrendsProgramme.htm (last accessed 21/06/11).

5 Helm, D. (2008), *Climate-change policy: why has so little been achieved?* Oxford Review of Economic Policy, **24**: 211-238.

6 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

7 Defined as the international institutions and regimes which provide structured management of global processes in the absence of global government.

8 Cabinet Office (2009), *UK National Security Strategy: Security in an Interdependent World*. Available at: http://interactive.cabinetoffice.gov.uk/documents/security/national_security_strategy.pdf (last accessed 21/06/11).

- The UK's role in global governance structures. This Section explores how these structures can maintain capacity and legitimacy while responding to the pressures posed by a changing climate.
- The UK's national security and its role in future international interventions. A variety of risks, including domestic protests driven by climate change overseas, and increased UK interventions and tensions within the Arctic region are explored.
- The UK Overseas Territories. These represent a unique area of risk to the UK due to the geography, location and its constitutional relationships with these territories.

3.1.1 Global governance

Membership of bodies including the UN, NATO, the Commonwealth, the European Parliament and the Council of the EU help give the UK the influence and legitimacy to address transnational issues unilaterally and through the institutions themselves in a way that protects the UK's national security and international interests. This supports and defines the UK's international influence, strengthening its ability to achieve national aims while protecting its citizens. However, there is a risk that current structures for global governance will be unable to adapt to the additional challenges posed by climate change up to the middle of this century, with potentially serious impacts on UK foreign and security policy[9].

Maintaining capacity and legitimacy

International security is increasingly dependent on global governance structures and their capacity to facilitate global responses to a wide range of international issues. These include the impacts of changing power dynamics, shifting territorial boundaries, access to resources, the proliferation of non-state actors, failing states, and transnational threats[10]. For the last 60 years, the international system has been characterised by multilateralism, as exemplified by such structures as the United Nations and the World Trade Organisation[11]. Whether this cooperation can be sustained in the future is uncertain. Thus, developing and maintaining a resilient system of global governance to ensure continued stability will be a 'central theme' over the next 50 years[12].

Global governance structures have not adapted well to the growing power and influence of advanced developing nations or BRICs (Brazil, Russia, India and China)[13,14]. In particular, the global response to climate change exemplified by the 2009 international negotiations at the United Nations Framework Convention on Climate Change (UNFCC) in Copenhagen has highlighted the way in which some developing states and communities feel excluded from decisions that directly affect their security[15]. Coupled with the fact that some global governance structures are often viewed sceptically by some countries because Western interests remain embedded in the articles and statutes of international institutions such as the UN, IMF and the World Bank[16,17], there is a risk that their real or perceived legitimacy will be further reduced, sapping them of the political will needed to maximise their

9 UK Foreign and Commonwealth Office (2010), *Preparing for Global Climate Change: An Adaptation Plan for the FCO.* Available at: http://www.fco.gov.uk/resources/en/pdf/about-us/our-publications/climate-adaptation-plans (last accessed 21/06/11).

10 Kavalski, E. (2008), *The complexity of global security governance: An analytical overview*, Global Security. **22**: 423-443.

11 Originally named the 'General Agreement on Tariffs and Trade' until the establishment of the World Trade Organization in 1995.

12 Ministry of Defence/DCDC (2010), *Strategic Trends Programme: Global Strategic Trends – Out to 2040*, 4th Edition. Available at: http://www.mod.uk/DefenceInternet/MicroSite/DCDC/OurPublications/StrategicTrends+Programme/TheDcdcGlobalStrategicTrendsProgramme.htm (last accessed 21/06/11).

13 Campbell, K. & Weitz, R. (2008), *The Clear Implications of Global Climate Change*. In Campbell, K.M. (ed.), *Climatic Cataclysm: The Foreign Policy and National Security Implications of Climate Change.* Washington: Brookings Institution.

14 Rybinski, K. (2009), *A new world order.* Open Democracy, available at: http://www.opendemocracy.net/article/a-new-world-order (last accessed 21/06/11).

15 Steadman, S.J., Jones, B. & Pascual, C. (2010), *A plan for action: A new era of international cooperation for changed world: 2009, 2010 and beyond.* Part of the Managing Global Insecurity project, Center for International Security and Cooperation, Stanford University. Available at: http://cisac.stanford.edu/publications/managing_global_insecurity_a_plan_for_action/ (last accessed 21/06/11).

16 Held, D. (2010), *The changing face of global governance: Between past strategic failure and future economic constraints*. Social Europe Journal, available at: http://www.social-europe.eu/2010/01/the-changing-face-of-global-governance-between-past-strategic-failure-and-future-economic-constraints/ (last accessed 21/06/11).

17 Saxer, M. (2010), *The Comeback of Global Governance. Ways Out of the Crisis of Multilateral Structures*. Dialogue on Globalisation Briefing Papers, 2009, available at: http://www.fes-globalization.org/dog_publications/global_governance.htm (last accessed 21/06/11).

effectiveness. Because of the uneven distribution of climate change impacts between low- and high-income countries, these divisions are likely to be exacerbated[18].

While the limitations and weaknesses of current global governance structures are well understood[19], there are questions over whether they can survive the additional pressures which are likely to arise as the impacts of climate change are felt around the world. Climate change is becoming a key geopolitical issue with seemingly localised environmental impacts having implications for global transportation, international law, border security, the global food supply, stability of infrastructure, access to resources and the ability of states and other organisations to project power and maintain economic stability. It is contributing to a changing geopolitical environment and its potential to trigger widespread political and social upheaval is introducing new factors into the geopolitical calculations of states[20].

Responding to pressures from climate change

Current global governance structures largely reflect an international system built to regulate the behaviour of 'rational' states to prevent outbreaks of interstate war. They were not designed to support governments whose resources to govern have become overstretched leading to a loss of confidence in the state and potential political, social and economic breakdown at the local level. As long as global governance structures continue to operate within the traditional boundaries of security policy, they will lack the functional capacity to enable international co-operation to agree the mitigation and adaptive strategies required to prevent the further deterioration of state and non-state relations in the international system. International institutions may struggle to adapt their operations to address the impacts of climate change which cannot be managed or contained within national borders[21]. Threats to security are more likely to stem from the overstretching or collapse of the governance capacity of states rather than from states aggressively pursuing territory and resources. Global responses to regional conflicts, international intervention and strategies of conflict prevention are likely to be essential to prevent the breakdown of trade, finance and diplomatic relations on which so many states depend.

In the absence of effective action through global governance structures, states with the diplomatic and financial capability may opt for unilateral action, or regional or ad hoc coalitions, to protect their interests[22,23]. These interests could take the form of securing important resources and commodities, including land and water[24]. The legitimacy of such action may prove highly questionable as it would lack the mandate that a multilateral institution such as the UN has for extraterritorial intervention to maintain international security. Whether intervention takes the form of unilateral or regional action, or is supported globally, will have important implications for its legitimacy, likely success, and potential for containing conflict. Clearly the collapse of global governance could exacerbate tensions between and within countries, undermine co-operation and generate further insecurity as countries and communities focus on protecting themselves, potentially at the expense of others[25].

18 Muldoon, J. (2004), The *Architecture of Global Governance: An Introduction to the Study of International Organisations*. Oxford: Westview Press.

19 R:2 (Annex B refers).

20 IPPR (2009), *Shared Destinies: Security in a Globalised World. The interim report of the IPPR Commission on National Security in the 21st Century*. Available at: http://www.ippr.org (last accessed 21/06/11).

21 Muldoon, J. (2004), *The Architecture of Global Governance: An Introduction to the Study of International Organisations.* Oxford: Westview Press.

22 Gowan, R. and Jones, B. (2010), *Back to Basics: The UN and Crisis Diplomacy in an Age of Strategic Uncertainty. Centre on International Cooperation* (New York University).

23 Haldén (2007), *The Geopolitics of Climate Change* report by the Swedish Defence Research Agency (FOI), 2007. Available at: http://www.foi.se/upload/projects/Africa/FOI-R--2377--SE.pdf (last accessed 21/06/11).

24 UN FAO, IIED & IFAD (2009*), Land grab or development opportunity? Agricultural investment and international land deals in Africa*. Report available at: http://www.fao.org/docrep/011/ak241e/ak241e00.htm (last accessed 21/06/11).

25 Mabey, N. & Silverthorne, K. (2009), *What the Security Community Needs from Copenhagen: Washington Roundtable*, *E3G*. Available at: http://www.e3g.org/programmes/climate-articles/what-the-security-community-needs-from-copenhagen-washington-roundtable/ (last accessed 21/06/11).

Implications for the UK

The UK has a significant stake in ensuring that global governance structures have both the legitimacy and the capacity to support those states and regions which are most vulnerable to climate change. To ensure continued security and prosperity, the UK will need international institutions that have both the legitimacy and the capacity to address transnational security issues. However, there is a real danger that climate change will weaken these institutions. In a worst-case scenario, if the international system of global governance fragments, the UK risks finding itself without any clear platform for global engagement at a time of significant geopolitical transformation.

The UK's international influence is reduced due to the weakening and loss of legitimacy of global governance structures as they are unable to respond to new global security issues driven by climate change.

3.1.2 National security and international interventions

The threat to UK national security from climate change was highlighted in the 2010 National Security Strategy, which states that "*our security is vulnerable to the effects of climate change and its impacts on food and water*"[26], concluding that "*the physical effects of climate change are likely to become increasingly significant as a 'risk multiplier', exacerbating existing tensions around the world*"[27]. Implicit in this description is the assertion that climate change cannot be considered the sole driver for many of the risks posed to national security. Indeed, climate change has been proposed as one of several drivers of the recent "Arab Spring" protests and uprisings in North Africa, as failed harvests in Russia, Canada and Ukraine led to a spike in food prices[28]. As countries in the Middle East and North Africa are highly reliant on imported food, these regions are considered to have a high level of food insecurity[29]. However, many other factors, such as political freedom, justice and corruption, were also cited as drivers of unrest. As such, the risks listed below may be driven by a number of factors other than climate change and, where possible, these are identified:

- an increase in **failed states and ungovernable spaces** acting as a source of growing insurgent and terrorist activity;
- an increase in calls for **international interventions** in regions where tensions have been exacerbated;
- more calls for international **humanitarian assistance and contingency arrangements** are made;
- as a result of more severe and widespread impacts from climate change impacts overseas, **UK domestic protests** increase, for example due to unrest spread through diaspora communities;
- the expansion of civil nuclear power as nations attempt to decarbonise their energy generation leads to greater risk of **nuclear proliferation**;
- **future defence planning** fails to incorporate the full impacts of climate change;
- tensions in the **Arctic region** present potential trade and conflict risks to the UK.

Failed states and ungovernable spaces

Recent analysis has found no evidence to support a simple correlation or direct causal link between climate variability and short-term variation in civil war risk in Africa[30]. However, analysis of past events may be of limited value in the context of the predicted acceleration of climate change and increases in severity of extreme events which are projected to occur in the decades ahead. Deprivation, including food insecurity, has been suggested as a potential driver of civil war[31,32]. Projected negative impacts on food and

26 HM Government (2010), *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. UK: The Stationery Office.
27 *ibid.*
28 Johnstone, S. & Mazo, J. (2011), *Global warming and the Arab Spring*. Survival, **53**: 11-17.
29 Breisinger, C., van Rheenen, T., Ringler, C., Nin Pratt, A., Minot, N., Aragon, C., Yu, B., Ecker, O. & Zhu, T. (2010), *Food security and economic development in the Middle East and North Africa*. International Food Policy Research Institute discussion paper 00985, available at: http://www.ifpri.org/sites/default/files/publications/ifpridp00985.pdf (08/04/11).
30 Buhaug, H. (2010), *Climate not to blame for African civil wars*. Proceedings of the National Academy of Sciences, doi:10.1073/pnas.1005739107.
31 Collier, P. (1999), *On the economic consequences of civil wars*. Oxford Economic Papers, **51**: 168-183.
32 Goldstone, J.A. *et al.* (2003), *State Failure Task Force Report: Phase III findings*. Maclean, VA: Science Applications International.

water availability beyond the middle of the 21st century (see Section 4.2) may therefore increase the risk of failed states and future regional conflict. This is likely to be the case where governance capacity at the state level is already overstretched and is unable to manage the physical impacts of precipitation change, droughts and temperature change. Twenty-eight of the 38 states identified as being at the highest risk ("alert" status) by the Failed States Index 2010[33] are also defined as Low-Income Food-Deficit Countries (LIFDCs)[34] by the UN FAO[35]. Under such circumstances, civil unrest, inter-communal violence, mass displacement, breakdown of trade, and state failure become increasingly possible. In turn this may have security implications for the UK as non-state actors exploit ungoverned or ill-governed spaces[36] (see Box 3.1), and facilitate global organised crime (such as drug and human trafficking).

Furthermore, an increase in ungoverned spaces may have implications for trade routes and supply chains upon which the UK relies. Piracy off the coast of Somalia accounted for 92% of all ship seizures in 2010[37] and 44% of all global piracy incidents in the first nine months of 2010[38], affecting ships carrying oil from the Middle East and goods from Asia to Europe. As well as the risk of goods not reaching their destination, costs relating to insurance and re-routing may increase the cost of transporting goods[39]. Maritime piracy is estimated to have had a total global cost of between $7 billion and $12 billion in 2010 with $2.4 to $3 billion being spent on re-routing ships, and between $460 million and $3.2 billion on excess insurance premiums from transiting around the Horn of Africa[40].

Box 3.1 Ungovernable regions in Guatemala

The potential for climate change to facilitate or accelerate the establishment of ungovernable regions under certain climatic and security circumstances is exemplified in Guatemala. Recent success for the Mexican and Colombian governments in disrupting criminal operations has led to criminal organisations moving into the northern Guatemalan state of Petén, where they are able to operate with greater freedom and retain control of much of the region[41]. In 2008, extensive flooding in Petén made the region almost unreachable by government security forces, already stretched to capacity. As a consequence, the government is finding it increasingly difficult to govern this region[42]. Displaced people from drought-prone regions in Guatemala are migrating to Petén, invading protected wildlife habitats, clashing with police and forging alliances with local drug lords to obtain territorial control[43]. If extreme weather events occur more frequently or more severely as a result of future climate change there will be an increased threat to the governance and social stability of the country.

Flooding may also contribute to the weakening of state institutions. For example, it has been proposed that decreasing glaciation along with projected changes in frequency and intensity of extreme precipitation in the Himalaya and the Hindu Kush (the so-called "third pole") may intensify insecurity in an already unstable region[44]. The flooding in Pakistan in 2010 displaced an estimated 20 million people[45] and created a temporary ungovernable space. The activities of militant groups in affected areas providing

33 Failed States Index 2010, produced by the Fund for Peace. Available at: http://www.fundforpeace.org/web/index.php?option=com_content&task=view&id=99&Itemid=140 (last accessed 21/06/11).

34 Definition and list of current LIFDCs may be found at: http://www.fao.org/countryprofiles/lifdc.asp (last accessed 21/06/11).

35 List of LIFDCs defined by the UN Food and Agriculture Organization is available at: http://www.fao.org/countryprofiles/lifdc.asp (last accessed 21/06/11).

36 HM Government (2010), *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. UK: The Stationery Office.

37 International Chamber of Commerce Commercial Crime Services, *Hostage-taking at sea rises to record levels, says IMB*, 17/01/11. Available at: http://www.icc-ccs.org/ (last accessed 21/06/11).

38 International Chamber of Commerce Commercial Crime Services, *Pirates intensify attacks in new areas, with first Somali hijacking reported in Red Sea*, 18/10/10. Available at: http://www.icc-ccs.org/ (last accessed 21/06/11).

39 Middleton, R. (2008), *Piracy in Somalia – Threatening Global Trade, Feeding Local Wars*. Chatham House.

40 One Earth Future (2010), *The Economic Cost of Maritime Piracy.* One Earth Future working paper, December 2010. Available at: http://oneearthfuture.org/images/imagefiles/The%20Economic%20Cost%20of%20Piracy%20Full%20Report.pdf (last accessed 21/06/11).

41 Feakin, T. & Depledge, D. (2010), *Climate-Related Impacts on National Security in Mexico and Central America.* Report by the Royal United Services Institute.

42 *ibid.*

43 *ibid.*

44 *The Waters of the Third Pole: Sources of Threat, Sources of Survival* (2010). A report by Aon Benfield UCL Hazard Research Centre (University College London), China Dialogue & the Humanitarian Futures Programme (King's College London). Available at: http://www.chinadialogue.net/UserFiles/File/third_pole_full_report.pdf (last accessed 21/06/11).

45 Prime Minister Gillani, quoted in Washington Post article of August 15th 2010, titled *'Pakistan floods affecting 20 million; cholera outbreak feared'*. Available at: http://www.washingtonpost.com/wp-dyn/content/article/2010/08/14/AR2010081400427.html (last accessed 21/06/11).

aid and assistance in the absence of state forces might increase their levels of support for these groups and undermine state legitimacy[46]. The presence of such groups was widely reported in the Western media[47,48,49].

It has been estimated that by 2050, 8.7 million people and 28,000 km^2 of land in river delta regions around the world will be at risk of inundation if current rates of sea level rise are maintained[50]. For example, estimates suggest that 1 metre of sea level rise in the Nile Delta would have an adverse impact on around 9% of the population[51] of Egypt, and more than 6% of national GDP would be affected through inundation[52], although it is very uncertain when such sea level rises will be realised[53]. As sea levels rise and make coastal flooding more likely, and glaciers recede and water pressures increase in the Himalayas (vital to the water supply to more than a fifth of the global population[54]), a corresponding rise in ungovernable spaces due to a breakdown of civil infrastructure can be expected.

The risk of increasing severity or frequency of flooding and drought events under a changing climate – combined with other drivers of change – have the potential to overwhelm more vulnerable countries, leading to an increase in failed states and ungovernable regions. These effects have security implications for the UK, through increased international terrorism and insurgent activity, and the facilitation of global organised crime.

International interventions

Rising regional tensions are likely to lead to more calls for UN or NATO based interventions, including pressures on the UK to become physically engaged in regions through military intervention and stabilisation operations. The 2010 UK Strategic Defence and Security Review[55] states that "*our obligations to our NATO Allies will continue to be among our highest priorities and we will continue to contribute to NATO's operations and its Command and Force Structures, to ensure that the Alliance is able to deliver a robust and credible response to existing and new security challenges*". This commitment, along with the UK's position as a permanent member of the UN Security Council, suggests that it is likely that future calls for intervention by these institutions will require a response by the UK.

Whether climate change will act as a driver of interstate conflict is highly uncertain. A study commissioned for the Foresight Global Food and Farming Futures project concluded that while shortages of food and water act as drivers in small-scale regional and inter-group conflict, there is little evidence to suggest, when taken in isolation, they could cause inter-state conflict[56]. However, there is some evidence that food and water scarcity driven by climate change has the potential to exacerbate existing drivers of tension and regional conflict between groups and within nations[57]. In the region of the

46 The Pew Project on National Security, Energy and Climate (2010), *The Impact of Monsoon Floods on America's National Security*. Available at: http://www.pewclimatesecurity.org/resources/ (last accessed 21/06/11).

47 *Pakistan floods provide political boon to Islamic militants*, 11/08/10, World Politics Review. Report available at: http://www.worldpoliticsreview.com/articles/6244/pakistan-floods-provide-political-boon-to-islamic-militants (last accessed 21/06/11).

48 *Pakistan floods 'hit 14m people'*, 06/08/10. BBC. Report available at: http://www.bbc.co.uk/news/world-south-asia-10896849 (last accessed 21/06/11).

49 *U.S. to give more flood aid to Pakistan*, 25/08/10. Reuters. Report available at: http://www.reuters.com/article/2010/08/25/us-pakistan-floods-idUSTRE66T3RS20100825 (last accessed 21/06/11).

50 Estimate based on 2006 rate of effective sea level rise (0.5-12.5 mm per year) and a representative sample of 40 deltas worldwide, representing 42% of global terrestrial runoff. Ericson, J.P., Vörösmarty, C.J., Dingman, S.L., Ward, L.G. & Meybeck, M. (2006), *Effective sea-level rise and deltas: Causes of change and human dimension implications*. Global and Planetary Change, **50**: 63-82.

51 Based on population density within inundation region.

52 Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. & Yan, J. (2007), *The impact of sea level rise on developing countries: a comparative analysis*. World Bank Policy Research Working Paper 4136. Available at: http://www.worldbank.org/ (last accessed 21/06/11).

53 Marcos, M. & Tsimplis, M.N. (2008), *Comparison of results of AOCGMs in the Mediterranean Sea during the 21st century*. Journal of Geophysical Research, **113**: C12028.

54 *The Waters of the Third Pole: Sources of Threat, Sources of Survival* (2010). A report by Aon Benfield UCL Hazard Research Centre (University College London), China Dialogue & the Humanitarian Futures Programme (King's College London). Available at: http://www.chinadialogue.net/UserFiles/File/third_pole_full_report.pdf (last accessed 21/06/11).

55 HM Government (2010), *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review*. UK: The Stationery Office. Available at: http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_191634.pdf (last accessed 21/06/11).

56 Allouche, J. (2010), *The sustainability and resilience of global water and food systems: A political analysis of the interplay between security, resource scarcity, political systems and global trade*. Driver review SR24 commissioned for the UK Government's Foresight Global Food and Farming Futures project, available at http://www.bis.gov.uk/foresight/our-work/projects/published-projects/global-food-and-farming-futures (last accessed 21/06/11).

57 *ibid.*

Nile basin, concern over conflict as a result of water use is high enough to have triggered the creation of the Nile Basin Initiative, which has a membership of nine states in the region with the stated aim of achieving "*sustainable socio-economic development through the equitable utilisation of, and benefit from, the common Nile Basin water resources*" and "*promote regional peace and security*"[58].

The UK is the third largest contributor to the UN peacekeeping budget, providing 8.16% of the $7.3 billion budget in 2010[59], and is a permanent member of the Security Council. As such, increasing tension and civil unrest driven by food and water scarcity[60] may increase requests for intervention from the UK and other UN or NATO members. For example, environmental degradation and regional climate variability and change have been proposed as major causes for the conflict in Darfur, and as a potential driver for further conflict throughout Sudan and other countries in the Sahel belt[61]. Tensions prior to the regional conflict in the Darfur region appear to have been exacerbated by drought – rainfall decreased between 16-30% over 40 years, causing a 60 mile shift in desert boundaries[62]. The Sudanese government lacked the infrastructure to deal with the growing crisis, and in the ensuing conflict, 500,000 people were killed and a further two million became refugees. As a result, the UN and the African Union currently have over 23,000 personnel in the region, at a cost of $1.8 billion per year[63].

The UK, as an active member of global governance structures, faces more calls to help formulate and contribute to international interventions in regions where tensions arise or are exacerbated by climate change impacts.

Humanitarian assistance and contingency arrangements

As well as the possibility of greater demand for intervention, there is the potential for a corresponding rise in requests for development funding and international humanitarian assistance. The UK government, led by the Department for International Development, responds to calls for assistance from countries following major international disasters and humanitarian crises, providing finance, expertise and assets as appropriate. The UK government also has a duty to help UK citizens and their interests who are in need where disasters occur in other countries (for example the evacuation of entitled personnel from Japan following the 2011 earthquake[64]), as well as responding to UN calls for assistance, contributing personnel, military, civil defence and assets for civil protection. Operation PANLAKE, the UK military's contribution to the humanitarian relief effort following the Haiti earthquake of 2010, was an example of the involvement of the UK in international assistance operations.

Climate change is likely to have a significant impact on global health and wellbeing through changing patterns of disease and mortality, increased frequency or intensity of extreme events, and through impacts on food, water, shelter and population[65] (see Section 4.3). These potential impacts may increase pressure on UK humanitarian assistance budgets for proactively building resilience, and reactive responses to disasters. In 2009/10, the UK spent £435 million[66] on humanitarian assistance, while the Disasters

58 More information on the Nile Basin Initiative may be found at: http://www.nilebasin.org/newsite/ (last accessed 21/06/11).

59 United Nations (2011), UN Peacekeeping Background Note. Available at: http://www.un.org/en/peacekeeping/documents/backgroundnote.pdf (last accessed 21/06/11).

60 Allouche, J. (2010), The sustainability and resilience of global water and food systems: A political analysis of the interplay between security, resource scarcity, political systems and global trade. Driver review SR24 commissioned for the UK Government's Foresight Global Food and Farming Futures project, available at http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures (last accessed 21/06/11).

61 UNEP (2007), *Sudan Post Conflict Environmental Assessment*. Report available at: http://www.unep.org/sudan/ (last accessed 21/06/11).

62 UNEP (2007), *Environmental Degradation Triggering Tensions and Conflict in Sudan*. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?ArticleID=5621&DocumentID=512&l=en (last accessed 21/06/11).

63 Personnel numbers correct as of 30/08/10, financial data for July 2010 to June 2011. UNAMID Facts and Figures, available at: http://www.un.org/en/peacekeeping/missions/unamid/facts.shtml (last accessed 21/06/11).

64 *Japan earthquake: Foreign evacuations increase*. BBC News, 18 March 2011. Available at: http://www.bbc.co.uk/news/world-asia-pacific-12775329 (last accessed 21/06/11).

65 Lancet/UCL (2009), *The Lancet Commissions: Managing the health effects of climate change*. The Lancet, **373**: 1693-1733.

66 DfID Statistics on International Development (2010). Top Ten Recipients DFID Bilateral Humanitarian Assistance 2006/07 – 2008/09. Available at: http://www.dfid.gov.uk/About-DFID/Finance-and-performance/Aid-Statistics/Statistic-on-International-Development-2010/SID-2010---Tables-index/ (last accessed 21/06/11).

Emergency Committee raised over £73 million from UK public donations for disaster relief [67,68]. The UK also spent £683 million on health and almost £106 million on water supply and sanitation over the same timescale as part of its international development budget[69,70]. If extreme weather events increase in frequency or intensity as projections for climate change suggest (see Section 2.4), it is likely that pressures on these resources will grow. A recent review of how the UK government should respond to humanitarian disasters has recommended that building resilience to the threat of climate change in countries at risk is integrated into the core DfID programme[71].

Increased frequency or intensity of extreme weather events increases pressure on existing humanitarian assistance and contingency arrangements (e.g. evacuations) provided by the UK government and charities.

Domestic protests

UK foreign policy (especially military action) can have significant impacts on the political mobilisation of various communities within the UK. New communication technologies allowing easy access to news, images and information from overseas, and significant numbers of diaspora communities within the UK, means that military or humanitarian action (or inaction) overseas may lead to the mobilisation of people to seek particular political responses, especially where the UK is directly involved in overseas conflict, either diplomatically or militarily[72]. In some cases the UK's foreign policy responses may have direct impacts on the political mobilisation of ethno-national communities with links to regions experiencing conflict[73].

Although not related to climate change, the large-scale protects in 2009 of the Tamil diaspora in the UK, driven by the conflict between Tamil militant groups and the Sri Lankan state[74], cost almost £8 million to police[75]. This is an example of how troubles and unrest in other countries can be transmitted to the UK, via media, networks and social connections such as diaspora communities.

The potential for climate change to increase the risk of overseas tensions and calls for UK interventions, combined with the links of diaspora communities in the UK to countries at risk from climate disruption, could lead to increased protests and activism within the UK. In some cases an increase in the scale, regularity and disruptive impact of protests may heighten the risk of disruption to government, business and wider society, and place pressure on UK policing and the judicial system.

Transmission of climate change-driven unrest overseas to the UK leads to an increase in the scale, frequency and disruptive impact of protests, placing pressure on policing and the judicial system.

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67 Total Official Development Assistance spending in 2009 was more than £7.3 billion, 0.52% of gross national income. The UK has agreed to the UN target of spending 0.7% of gross national income on international aid by 2013. Source: DfID Statistics on International Development 2010, available from: http://www.dfid.gov.uk/About-DFID/Finance-and-performance/Aid-Statistics/Statistic-on-International-Development-2010/ (last accessed 21/06/11).

68 DEC (2009), *Annual Trustees' Report & Accounts 2008/09*. Available from: www.dec.org.uk (last accessed 21/06/11).

69 DfID Statistics on International Development (2010), Additional table A3: DfID bilateral expenditure by input sector code 2000/01 to 2009/10. Available at: http://www.dfid.gov.uk/About-DFID/Finance-and-performance/Aid-Statistics/Statistic-on-International-Development-2010/SID-2010-Additional-tables/ (last accessed 21/06/11).

70 DfID (2011), *Humanitarian Emergency Response Review*. Available from: http://www.dfid.gov.uk/Documents/publications1/HERR.pdf?epslanguage=en (last accessed 21/06/11).

71 *ibid.*

72 Joseph Rowntree Foundation (2011), *The Impact of Overseas Conflict on UK Communities*.

73 *ibid.*

74 International Crisis Group (2010), *The Sri Lankan Tamil Diaspora After The LTTE*. Asia Report number 186, available at: http://www.crisisgroup.org/en/publication-type/media-releases/2010/asia/the-sri-lankan-tamil-diaspora-after-the-ltte.aspx (last accessed 21/06/11).

75 Home Affairs Committee (2009), *Policing of the G20 Protests*. Available from: http://www.publications.parliament.uk/pa/cm200809/cmselect/cmhaff/418/41804.htm (last accessed 21/06/11).

Nuclear proliferation

To meet targets for reduced GHG emissions and low-carbon energy goals, the International Atomic Energy Agency (IAEA) and other organisations are projecting a significant expansion of nuclear energy worldwide. In one IEA scenario, nuclear energy would provide a quarter of global energy by 2050[76], although the wider impact of recent damage to the Fukushima Daiichi nuclear plant[77] on the future of civil nuclear programmes is as yet unclear. The UK supports the peaceful use of nuclear energy worldwide, as a right for all countries under the Nuclear Non-Proliferation Treaty (NPT)[78]. As a nuclear-weapons state, the UK has a particular role in supporting the non-proliferation agenda, and uses its nuclear expertise and capabilities to contribute more generally to guiding international nuclear developments. For example, the UK supports multinational approaches to the nuclear fuel cycle[79], which aim to allow development of civil nuclear power and give countries the choice of not pursuing the economically costly full fuel cycle. This reduces the risks of proliferation by removing the need for countries to develop indigenous proliferation-sensitive enrichment or reprocessing capabilities. Examples include the creation of uranium fuel banks under IAEA control or the UK-led initiative that would provide assurance that supplies of enriched nuclear fuel would not be interrupted or stopped for non-commercial reasons.

However, expansion of civil nuclear power does raise security issues[80], as it may provide state or non-state actors opposed to the UK with greater access to fissile material and knowledge, and could lead to further risks of proliferation. However, these risks can be mitigated to a large extent through the application of IAEA safeguards, which are aimed at detecting diversion of nuclear material and providing credible assurance of the absence of undeclared nuclear material and activities[81]. A key mitigating step over the medium term will be the continued development of technologies through initiatives such as the Generation IV International Forum[82], which are increasingly proliferation resistant, and which offer further advances in passive safety and efficiency and waste reduction. Should decarbonisation of global energy generation continue to grow as a priority, sustained international cooperation will be required to ensure that non-proliferation and security measures are fully integrated into civil nuclear programmes. Climate change is only one driver of the expansion of civil nuclear power (and any potential threat to the UK through proliferation), with energy security, improved cost-effectiveness of nuclear generation, and benefits for baseload electricity all potentially increasing demand for the technology.

Expansion of civil nuclear power through countries moving to a low-carbon energy infrastructure could increase the risk of nuclear proliferation, but this can be mitigated to a large extent through IAEA safeguards.

Future defence capability

The UK's 2010 National Security Strategy considers that although no state currently has the capability and intent to pose a conventional military threat to the UK, an international military crisis or a conventional attack by a state on another NATO or EU country, or on a UK Overseas Territory, are risks the UK could face in the future[83]. Traditional war-fighting capabilities will therefore continue to be needed, but with the prospect of being deployed under more challenging operational conditions which would

76 ETP BLUE Map scenario. International Energy Agency (2010), *Energy Technology Perspectives 2010: Scenarios and Strategies to 2050, Executive Summary*. IEA: Paris. Report available at: http://www.iea.org/techno/etp/etp10/English.pdf (last accessed 21/06/11).

77 On 20 March 2011, the Fukushima Daiichi nuclear plant was badly damaged by the Category 9 earthquake and subsequent tsunami to the East of Honshu, Japan. More information is available on the International Atomic Energy Agency website at: http://www.iaea.org/newscenter/news/tsunamiupdate01.html (last accessed 21/06/11).

78 UK Foreign & Commonwealth Office, 'Peaceful uses of nuclear energy'. Available at: http://www.fco.gov.uk/en/global-issues/counter-proliferation/nuclear-2010/peaceful-uses/ (last accessed 21/06/11).

79 For more information see the IAEA website, '*Multilateral approaches to the fuel cycle*'. Available at: http://www.iaea.org/newscenter/focus/fuelcycle/ (last accessed 21/06/11).

80 International Energy Agency/Nuclear Energy Agency (2010), *Technology Roadmap: Nuclear Energy*. Report available at: http://www.iea.org/papers/2010/nuclear_roadmap.pdf (last accessed 21/06/11).

81 For the IAEA to gain credible assurance of the absence of undeclared nuclear material and activities, the country would need to have both a Comprehensive Safeguards Agreement and an Additional Protocol in force, see http://www.iaea.org/OurWork/SV/Safeguards/safeg_system.pdf

82 Further information on the Generation IV International Forum programme is available at: http://www.gen-4.org/index.html (last accessed 21/06/11).

83 HM Government (2010), *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. UK: The Stationery Office.

include higher temperatures and water scarcity, and a decreasing reliance on fossil fuels. Although the UK military already plan for operations in extreme weather (for example, in temperatures above 40°C in Afghanistan as well as in Arctic conditions), the frequency of operations in a climate-stressed future is likely to rise, with the emphasis on non-operational defence engagement overseas directed at conflict prevention, security sector reform and capability building[84]. Assessments of military capability considering the scale of operations in extreme weather, and how frequently and concurrently they might be undertaken in the future, will therefore be required.

Assessments of defence capability will need to incorporate climate change alongside other existing trends in its planning to ensure that the military remain equipped and plan for a range of types of future operations over the next 50 years. Given the protracted lead-times for procuring defence hardware, and long service lives, it will be particularly important that climate change risk is considered in the relevant procurement, acquisition and support processes[85]. To address this risk, the Ministry of Defence committed in 2010 to developing "…*a process to take climate change into account during the capability planning and procurement process*"[86].

UK defence capability requirements fail to take into account the implications of climate change on the nature of future operations and operational environments.

The Arctic region

The Arctic has experienced more significant warming over the past 100 years than the rest of the world[87]. Snow-covered areas are predicted to contract and widespread thawing of permafrost is predicted to occur by the end of this century. Sea ice is projected to shrink in the Arctic under all SRES scenarios[88]. The region has significant economic importance: its gross product in 2001 was worth $230 billion, derived primarily from the exploitation of fisheries, metallic minerals and fossil fuels in Russia[89]. The US Geological Survey estimates that the Arctic contains 30% of global undiscovered natural gas and 13% of undiscovered oil, again largely concentrated in Russia[90]. While scenarios developed by the International Energy Agency differ on whether total global oil production will decline before 2035, they do predict an increase in global demand for oil, driven largely by China and India[91]. Oil and gas production in the Arctic region is therefore expected to increase. Hence, countries with territory within the Arctic Circle are likely to exploit their natural resources as they become more accessible through receding Arctic ice.

Growing competition for these natural resources as ice recedes could lead to security challenges in the area[92]. Parts of the Arctic region are subject to dispute over borders and territory between nations, such as Hans Island, which has been claimed by both Canada and Denmark[93], and the Lomonosov Ridge,

84 HM Government (2010), *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review*. UK: The Stationery Office.

85 MOD (2010), *MOD Climate Change Strategy 2010*. Available at: http://www.mod.uk/NR/rdonlyres/58799038-34D2-4A93-94C8-6BBF770B9EA0/0/MODClimateChangeStrategyFINAL.pdf (last accessed 21/06/11).

86 Serial 27 of Target D ("Capability Planning and Procurement process ensures climate change impacts are assessed and managed") of the MOD Climate Change Delivery Plan (2010). Available at: http://www.mod.uk/DefenceInternet/AboutDefence/WhatWeDo/HealthandSafety/SSDCD/ClimateChangeAndEnergy.htm (last accessed 21/06/11).

87 Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. & Zhai, P. (2007), *Observations: Surface and Atmospheric Climate Change*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

88 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p46. No corresponding information is available for the E1 aggressive mitigation scenario.

89 Value in 2002 $. Dulhaime, G. *et al.* (2004), *Chapter 4: Economic Systems*. In: the *Arctic Human Development Report* of the Arctic Council's Sustainable Development Working Group, pp. 69-84. Available at: http://www.svs.is/AHDR/AHDR%20chapters/English%20version/AHDR_chp%204.pdf (last accessed 21/06/11).

90 Gautier, D.L. *et al.* (2009), *Assessment of undiscovered oil and gas in the Arctic*. Science, **324**: 1175-1179.

91 IEA (2010), *World Energy Outlook: Executive Summary*. Available at: http://www.worldenergyoutlook.org/docs/weo2010/WEO2010_ES_English.pdf (last accessed 21/06/11).

92 Berkman, P.A. (2010), *Environmental security in the Arctic Ocean: Promoting co-operation and preventing conflict*. RUSI Whitehall Paper number 75.

93 BBC, *Canada island visit angers Danes*. Published 25/07/05, available at: http://news.bbc.co.uk/1/hi/world/europe/4715245.stm (last accessed 21/06/11).

disputed by Canada and Russia[94]. Unlike the Antarctic[95], the Arctic is not covered by an overarching treaty or single international agreement. However, a strong legal framework already exists, most notably via UNCLOS (the United Nations Convention on the Law of the Sea[96]), and there are a large number of other agreements and international bodies[97] whose general aims are to encourage co-operation between Arctic countries. It is therefore unlikely that regional tension will lead directly to conflict[98]. Indeed previous jurisdictional disagreements have been solved amicably. For example, the USA and Canada have a bilateral agreement allowing US icebreakers to pass through Canadian waters, on the understanding that they will always seek permission from Canada, which will always be given[99]. However, there are still uncertainties on how the Arctic coastal states will protect their "*sovereignty, sovereign rights and jurisdiction in large areas of the Arctic Ocean*"[100] for the potential exploration of natural resources, and on the impact of increased militarisation of the Arctic[101].

As the Arctic becomes more accessible, the potential for disputes over access and continental shelf claims increases tensions and damages UK economic and trade interests.

3.1.3 UK Overseas Territories

The UK has responsibility for 14 Overseas Territories[102], which differ in size, population, and economic development (see Figure 3.1). However (with the exception of the British Antarctic Territory, Gibraltar, and the Sovereign Base Areas – Akrotiri and Dhekelia – on Cyprus), all are small islands and are among those that the IPCC has identified as "*most vulnerable*" and "*virtually certain to experience the most severe ecological impacts*" of climate change[103].

94 Proelss, A. (2009), *Governing the Arctic Ocean*. Nature Geoscience, **2**: 310-313.

95 This is covered by the 1959 Antarctic Treaty, which aims to ensure that the region remains peaceful and demilitarised.

96 Stokke, O.S. (2007), *A legal regime for the Arctic? Interplay with the Law of the Sea Convention*. Marine Policy, **31**: 402-408.

97 These include the Arctic Council, the Arctic Military Environmental Co-operation programme, the Nordic Council and the Spitsbergen Treaty.

98 Berkman, P.A. (2010), Environmental security in the Arctic Ocean: Promoting co-operation and preventing conflict. RUSI Whitehall Paper number 75.

99 *ibid.*

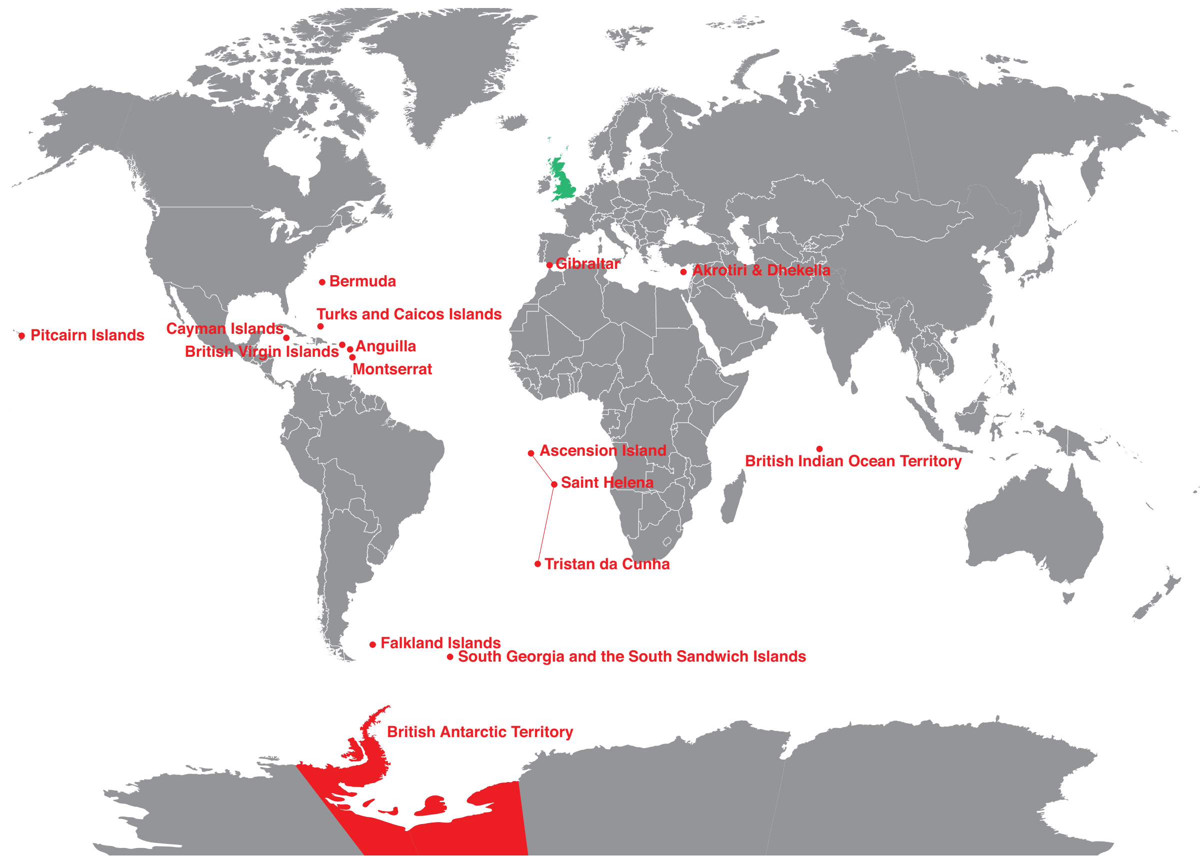
100 The Ilulissat Declaration of the 2008 Arctic Ocean Conference. Available at: http://www.oceanlaw.org/downloads/arctic/Ilulissat_Declaration.pdf (last accessed 21/06/11).

101 Berkman, P.A. (2010), Environmental security in the Arctic Ocean: Promoting co-operation and preventing conflict. RUSI Whitehall Paper number 75.

102 The UK Overseas Territories are: Anguilla, Bermuda, British Antarctic Territory, British Indian Ocean Territory, British Virgin Islands, Cayman Islands, Falkland Islands, Gibraltar, Montserrat, the Pitcairn Islands (including, Pitcairn, Henderson, and Ducie and Oeno), St Helena and St Helena Dependencies (Ascension and Tristan da Cunha), South Georgia and South Sandwich Islands, Sovereign Base Areas of Akrotiri and Dhekelia (on the island of Cyprus), The Turks & Caicos Islands.

103 Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) (2007), *Climate Change 2007 (AR4): Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press: Cambridge, UK, pp.976.

Figure 3.1: The UK's Overseas Territories (highlighted in red).



Impacts on UK Overseas Territories

Small islands present one of the hotspots of societal and natural system vulnerability to climate change, and could lose significant parts of their land area with a sea-level rise of 0.5-1m[104]. Large parts of the Indian Ocean are projected to experience over 0.3m sea level rise by 2040 under the medium emissions scenario, and rises of over 0.5m are predicted in other areas of the globe[105]. Even in islands of higher elevation, infrastructure is generally concentrated around the periphery, and hence is vulnerable to sea-level rise. Biodiversity, much of it endemic, is also likely to be significantly affected because, as habitats are reduced in size, they are less likely to be able to support viable populations of plants and animals.

Many small islands worldwide are already at risk from diverse environmental hazards. Sea-level rise and possible changes in the frequency and/or intensity of extreme weather events, i.e. heatwaves, extreme temperature and heavy precipitation, tropical cyclones, storm surges, and coastal, river and rain-induced flooding, constitute the components of climate change that are the impacts of most concern[106]. Owing to their remoteness and vulnerability, potential impacts of sea-level rise and more intense storms, including damage to infrastructure such as ports, harbours, airport structures and facilities, could result in some islands being completely cut off from communication with the outside world. There are also likely to be significant health impacts arising from both sea-level rise and extreme weather events[107].

104 Mimura, N., Nurse, L., McLean, R.F., Agard, J., Briguglio, L., Lefale, P., Payet, R. and Sem, G. (2007), *Small islands.* In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.), *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp. 687-716.

105 R:3 (Annex B refers).

106 R:6.1 (Annex B refers).

107 Sear, C. *et al.* (2001), *The Impacts of Global Climate Change on the UK Overseas Territories.* Technical Report and Stakeholders Survey. Natural Resources Institute and Tyndall Centre for Climate Change Research, Kent and Norwich, UK. Available at: http://www.tyndall.ac.uk/content/impacts-global-climate-change-british-overseas-territories (last accessed 21/06/11).

An assessment of the potential implications of climate change for biodiversity within the Territories has been published[108]. Coral reefs represent the most ecologically important components of coastal systems that are significantly threatened, and their loss could bring severe adverse consequences for coastal populations and infrastructure given the protection and buffering these coral reefs provide from strong waves and storms[109,110]. The potential loss of protection to mangroves, sea grasses and other coastal ecosystems would lead to further loss of habitats, including nursery grounds for fisheries, and coastal erosion[111]. Additional stresses include temperature rise in the sea surface and acidification of the oceans. All of these possible outcomes present a major threat to the wellbeing of the populations and natural environments of most of these small islands.

In addition, many of the Overseas Territories rely on their coastal ecosystems to sustain their economies. Fisheries provide not only a source of food but also a major source of income for some Overseas Territories (accounting for up to 85% of GDP in South Georgia and the South Sandwich Islands) and also facilitate tourism, for example dive tourism in the Caribbean[112].

Implications for UK government

The Foreign and Commonwealth Office has the overall lead on policy for the Overseas Territories. Other government departments such as the Department for International Development, Department for Environment, Food and Rural Affairs, Department of Health and the Ministry of Defence have specific responsibilities (such as the quota system run by the Department of Health for some Overseas Territories to have free access to National Health Service facilities); other departments provide advice and support in other specialist areas, ranging from transport safety to internal security. Since 2002, the vast majority of citizens of the Overseas Territories have been entitled to hold British citizenship, and entitlement to reside in the UK[113]. There are also a number of strategic military bases (such as the Sovereign Base Areas in Cyprus) situated in the Overseas Territories, which provide capability for the UK and, through lease of a base on Diego Garcia, the USA.

Further UK responsibility arises from the fact that, due to their constitutional relationship with the UK, the Overseas Territories are unable to apply for many international funds available for small nations to support mitigation of, and adaptation to, climate change effects. For example, whilst programmes under the Global Environmental Facility have been implemented in the independent Caribbean Community (CARICOM) to help planning for adaptation to climate change, the Overseas Territories have not been eligible for funding given their unique relationship with the UK[114].

Although the UK recognises its responsibilities to the inhabitants and ecosystems of the Overseas Territories, and would be ready to respond to any extreme event, there is scope for central government departments to consider their role in the achievement of proactive adaptation by these communities. While the Overseas Territories are responsible for their own actions, and environmental policy is a devolved responsibility, it is accepted by the UK government that they lack the expertise, resources and capacity to cope without UK assistance. The UK has not only moral, political and legal obligations to give support if local governance arrangements are unable to cope[115], but also has contingent liability for disasters caused by extreme weather events, health impacts from extreme events or rising sea levels, and economic collapse due to failed ecosystems. Hence it is clearly in the interests of the Overseas

108 McWilliams, J.P. (2009), *Implication of climate change for biodiversity in the UK Overseas Territories*. JNCC Report, No. 427, p.93.

109 Wilkinson, C. (ed.) (2000), *Status of Coral Reefs of the World: 2000.* Australian Institute of Marine Science, Cape Ferguson, Australia. Available at: http://www.reefbase.org/download/gcrmn_download.aspx?type=10&docid=6022 (last accessed 21/06/11).

110 Sear, C. *et al.* (2001), *The Impacts of Global Climate Change on the UK Overseas Territories*. Technical Report and Stakeholders Survey. Natural Resources Institute and Tyndall Centre for Climate Change Research, Kent and Norwich, UK. Downloadable from: *http://www.seaturtle.org/PDF/Sear_2001_TechReportClim.pdf*

111 McWilliams, J.P. (2009), *Implications of climate change for biodiversity in the UK Overseas Territories*. JNCC Report, No. 427.

112 Brown, N. (2008), *Climate change in the UK Overseas Territories: An Overview of the Science, Policy and You*. Peterborough, UK: Joint Nature Conservation Committee.

113 For more information, see the British Overseas Territories Act (2002), available at: http://www.legislation.gov.uk/ukpga/2002/8/contents (last accessed 21/06/11).

114 DfID (2007), *Project: Enhancing Capacity for Adaptation to Climate Change in the Caribbean UK Overseas Territories*. Available from: http://www.dfid.gov.uk/r4d/SearchResearchDatabase.asp?ProjectID=60563 (last accessed 21/06/11).

115 NAO FCO (2007), *Managing Risk in the Overseas Territories 2007*. The Stationery Office. Available at: http://www.nao.org.uk/publications/0708/managing_risk_in_the_overseas.aspx (last accessed 21/06/11).

Territories and UK Government that the Overseas Territories' vulnerability to climate change is minimised.

UK government departments do not act proactively to address adaptation in UK Overseas Territories, leaving them vulnerable to the impacts of climate change, with repercussions on the UK.

3.2 Finance and business

This section explores risks to the UK's finance and business networks. The UK's position as a financial centre for global trade, and its reliance on global networks mean that it is likely to experience indirect and systemic effects from any substantial climate change events or trends.

3.2.1 UK financial sector

In 2010, UK financial services contributed at least 10% of UK GDP[116]. The UK financial sector supports more than one million jobs[117] and contributes a major proportion of UK tax revenue, comprising more than 11.2% of total government tax receipts in 2010[118]. UK financial services, and those in London in particular, have leading market positions in a range of diverse activities and in the global financial market[119]. The UK banking sector (representing half of UK-based financial services' GDP and employment) originates more cross-border bank lending than any other country (18% of the world total in September 2009), with approximately 50% of European investment banking activity conducted in London[120]. Nearly one third of the £3,700 billion assets managed in the UK are managed on behalf of overseas clients[121]. Ratings also repeatedly place London as the most globally connected amongst all international financial centres[122,123,124,125,126], and this wide-ranging international influence is consistent across all functions of UK financial services.

Impacts on the financial sector

The UK's economy has extensive interaction with global markets and will therefore be adversely affected by factors or events leading to protectionism of commodities and restriction of free-market trading. Global markets and trade are also heavily reliant upon infrastructure. Finance, insurance, trading and other non-physical commodities require stock exchanges and communications networks, while the trade of physical commodities requires ports, airports and distribution centres[127].

Until recently, the global financial sector has, in general, grown rapidly during the past two decades of relatively benign economic conditions. There have been low interest rates and inflation, and economies have expanded, particularly in the rapidly growing emerging markets in Brazil, India and China[128]. Climate change impacts that adversely affect these conditions could damage the sector significantly, through, for example, greater uncertainty and rising inflation, causing interest rates to increase and a new global recession. However, other drivers of instability in global markets, such as fluctuations in supply and demand, international trade relationships and confidence are likely to be more important than climate

116 International Financial Services of London (2009), *Economic Contribution of UK Financial Services*. Available at: http://www.thecityuk.com/media/197387/economic%20contribution%20of%20uk%20fin%20servs%202010.pdf, accessed 28/03/11.

117 City of London (2010), *The Total Tax Contribution of UK Financial Services*. London.

118 *ibid.*

119 Z/Yen Group (2010), *Global Finance Centres 7*. Available at http://www.zyen.com/long-finance/global-financial-centres-index-gfci.html, last accessed 21/06/11.

120 Data from TheCityUK. Available from: http://www.thecityuk.com/what-we-do/the-research-centre/key-facts-and-figures-about-uk-financial-services.aspx#Role of financial services in the UK (last accessed 21/06/11).

121 *ibid.*

122 Yeandle, M., Mainelli, M. and Harris, I. (2007), *The Global Financial Centres Index 2*. Z/Yen Group.

123 Yeandle, M., Horne, J., Danev, N., Knapp, A. and Morris, B. (2008), *The Global Financial Centres Index 4*. Z/Yen Group.

124 Yeandle, M., Mainelli, M. and Harris, I. (2008), *The Global Financial Centres Index 3*. Z/Yen Group.

125 Yeandle, M., Horne, J., Danev, N., and Knapp, A. (2009), *The Global Financial Centres Index 6*. Z/Yen Group.

126 Yeandle, M., Horne, J., Danev, N., and Knapp, A. (2009), *The Global Financial Centres Index 5*. Z/Yen Group.

127 The potential effects of climate change on physical infrastructure such as ports and communications networks are discussed in Section 4.1.

128 HM Treasury (2009), *UK international financial services – the future. A report from UK based financial services leaders to the government*, London.

change. The global financial downturn that began in 2007 demonstrated the fragility of international markets. Many of the risks highlighted below identify existing weaknesses in global systems against which climate change impacts must be considered alongside other relevant threats to global economic stability.

UK exposure to overseas markets

The impacts of climate change overseas are likely to have significant implications for UK financial services owing to their high level of exposure to foreign markets. For example, a projected increase in extreme weather events could lead to increased insurance premiums in vulnerable regions. Such exposure of UK insurers and other financial services may lead to impacts on the following areas:

- **Risk transfer and pooling services:** UK-based risk transfer and pooling services are exposed to risks and opportunities in international markets to the extent of the international insured risk managed by UK financial services. Total international insured risk managed in the UK was about £65 billion in 2008[129].
- **Access to capital services:** The financial service sector is unique amongst global financial centres in the extent of its international lending; UK banking services in 2009 had the highest global exposure to foreign borrowing and lending, managing 22% of cross-border borrowing worldwide and 18% of international bank lending[130].
- **Asset management services:** Asset management in the UK is exposed to international risks and opportunities by the amount of foreign assets managed by UK financial services. UK fund management was £3.7 trillion in 2008[131], 30% of which was estimated to be overseas assets[132]. Using UK-based Foreign Direct Investment as a proxy for distribution of UK-managed overseas assets, Europe is the location of more than 50% of these assets, followed by the Americas, Asia and Australia and Oceania.
- **Direct inflow:** The sector is exposed to and shaped by foreign markets through a significant international presence within UK financial services. More than 50% of insurance firms and nearly 80% of banking firms authorised to operate in the UK are foreign entities. Nearly 50% of the banking assets held in the UK are held by foreign banks and deposits held in UK bank accounts contain significant shares of foreign currency. The UK banking sector facilitates more cross-border bank lending than any other country[133].
- **Indirect exposure:** While assessing the international exposure (for example through supply chains, operations and consumer markets) of UK-based clients of UK financial services is difficult, data on the UK's import and export share illustrate the magnitude of global linkages to which domestic clients of UK financial services are exposed. In 2010, total UK imports were worth £363 billion, while its exports were worth £266 billion[134]. Assuming the geography of indirect exposure will reflect the global geography of GDP to some degree[135], the highest levels of indirect exposure will be found in countries and regions with the highest GDP, such as the USA, the EU and China.

The UK financial sector and its inward and outward investments are substantially inter-connected with and dependent on global markets, and are heavily affected by global climate change impacts.

129 Including Lloyds and the London Market. International Financial Services of London (2009), Insurance 2009. Available at: http://www.thecityuk.com/research/our-work/reports-list/ (last accessed 21/06/11).

130 International Financial Services of London (2009), *Economic Contribution of UK Financial Services*. Available at: http://www.thecityuk.com/research/our-work/reports-list/ (last accessed 21/06/11).

131 Not inclusive of all alternative asset categories.

132 International Financial Services of London (2009) *Fund Management 2009*. Available at: http://www.thecityuk.com/research/our-work/reports-list/ (last accessed 21/06/11).

133 International Financial Services of London (IFSL) (2010) *Banking 2010*. Available at: http://www.thecityuk.com/research/our-work/reports-list/banking-2010/ (last accessed 21/06/11).

134 Office for National Statistics (2010), *UK Trade: December 2010 Statistical Bulletin*. Available at: http://www.statistics.gov.uk/pdfdir/trd0211.pdf (last accessed 21/06/11).

135 R:8 (Annex B refers).

Vulnerabilities of financial services

UK financial services are, as a system characterised by market competition and global linkages, globally competitive. But system-wide vulnerabilities could impede the UK's ability to manage the risks of climate change[136]. An analysis[137] commissioned by this project identified these vulnerabilities as:

- **Structure of global financial services:** in the financial crisis of 2009, new levels of globalisation exposed weak links within financial services that had been manageable under previous conditions. Similarly, the physical impacts of climate change may expose vulnerabilities in the financial service sector that have been largely unproblematic under previous climatic conditions. For example, projections of climatic system changes beyond 2030, such as water stress and sea level rise, are likely to push the bounds of insurability as uncertainty levels around the timing and extent of expected losses diminish[138]. As the physical impacts of climate change become clearer, uninsurable areas may develop in risk pooling and transfer services, and current financial risk management strategies might be unable to cope. In another example, loans serviced by capital access and provision rely on evidence of insurability as a condition of credit worthiness. Climate change may alter the availability and price of insurance (as above) during the duration of many loan types. For loan types that do not require periodic insurability updates, such as many home mortgages, diminished credit worthiness may go unchecked in loan portfolios, exposing reserves to greater amounts of risk than modelled for per contract or portfolio[139].

Climate change exposes new vulnerabilities within the financial services sector that have been unproblematic in the past, such as an inability of risk management strategies to cope with the implications of climate change on the nature of financial risk.

- **Sustainability in the financial services sector:** Sustainability may be defined as the use of resources at a rate which does not exceed the capacity to replace them[140]. Although modified risk modelling techniques have been developed by insurers and reinsurers to take into account climate change risk in their overall estimation of risk (see Box 3.2), consideration of sustainability in other areas of the sector is bound by several different, but relatively short, timescales.

136 R:8 (Annex B refers).
137 *ibid.*
138 *ibid.*
139 *ibid.*
140 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability.* Report available at: http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/11-546-future-of-food-and-farming-report.pdf (last accessed 21/06/11).

Box 3.2 Adapting insurance modelling to the climate change context[141]

As an industry that prices events yet to occur, insurers invest a great amount of resources in modelling risk as robustly as possible. Traditionally, this has involved examination of historical loss data. Concerned that climate change may be exacerbating the vulnerability that climate risk is not uniformly based on previous claims, insurers are increasingly adjusting their methodologies by utilising:

- statistical techniques that extrapolate trends of insured loss and estimate projected total risk for likely future conditions[142];
- catastrophe models that simulate realistic events for given locations based on potential hazard frequencies and magnitudes[143] by overlaying financial exposure with potential hazards; and
- scenario testing[144].

These modified risk modelling techniques illustrate the types of development in risk modelling that will become more relevant to other parts of the financial services sector[145].

Strategic and operational decision-making in financial services tends to be based on time horizons of 10 or more years, and one to three or five years, respectively[146]. This relatively short-term view is likely to compromise the sector's ability to manage climate change risks and opportunities in at least two ways[147]: first, failure to incorporate climate change risks into present-day decisions, or at least begin to incorporate this requirement over the next few decades, increases the level and extent of overall risk that the sector faces over the longer term; secondly, failure to break from the systematic short-term view held by global financial services minimises any potential early mover and market share advantages the UK might benefit from.

A short-term view of strategic and operational decision-making in financial services risks prevents threats of and responses to climate change from being recognised and managed.

- **Scope of data considered to be financially relevant:** While a core competency of financial services worldwide is research and analysis, one of the problems of financial risk modelling is that most of the tools are backwards looking, testing portfolios against known historical stress points. Consequently, traditional approaches often fail to take account of climate change risks[148,149]. The uncertainties of a changing climate, combined with issues arising from the need to move radically and rapidly to a low-carbon world economy, challenges the traditional, quantitative approach of risk management in financial service portfolios, and raise questions about the level of relevant expertise held in the risk pooling and transfer services[150,151,152,153].

141 R:8 (Annex B refers).
142 Allianz (2008), *Allianz Climate Solutions GmbH.* Paper presented at Allianz, February 2009, Munich.
143 Grossi, P. and Kunreuther, H. (2005), *Catastrophe Modelling: A New Approach to Managing Risk.* New York: Springer Science+Business Media, Inc.
144 More information available at: http://www.lloyds.com/The-Market/Tools-and-Resources/Research/Exposure-Management/Realistic-Disaster-Scenarios (last accessed 28 March 2011).
145 Although not all insurers include climate change data in their overall estimations as the related margins of error are wider than the modelled impacts of climate change.
146 R:8 (Annex B refers).
147 *ibid.*
148 Mercer (2011), *Climate Change Scenarios – Implications for strategic asset allocation.* Report available at: http://www.ifc.org/ifcext/sustainability.nsf/AttachmentsByTitle/p_ClimateChangeSurvey_report/$FILE/ClimateChangeSurvey_Report.pdf (last accessed 21/06/11).
149 R:8 (Annex B refers).
150 *ibid.*
151 Blunk, T. (2009), *The Insurance Industry and Climate Change.* Paper presented at The Geneva Association: Climate Change and Insurance Media Conference, 2 July 2009, London.
152 Dlugolecki, A. (2001), *Climate Change and the Financial Services Industry*. Insurance Economics, **43**.
153 Hoskins, B. (2009), *Modelling Climate Variability & Change.* Paper presented at Interpreting Models in a Climate Change Context, 20 July 2009, London.

The scope of data considered to be financially relevant – as used in financial sector modelling – is insufficient for forward testing of portfolios against the longer-timescale uncertainties of climate change. Analysts risk taking insufficient account of the structural changes and other implications of a radical switch to a low-carbon world economy.

- **Financial service assumptions:** Similar to how the drivers behind the recent financial crisis were not unknown, but were viewed in the sector as insignificant, the types of assumptions held about how the sector may be affected by climate change may be also be incorrect[154]. They include, for example, the assumption that climate change impacts can be anticipated in timescales suitable for annual risk review practices, and that investments can avoid vulnerable regions, or be taken out of affected areas as climate change impacts become financially unsustainable. These types of assumptions do not take into account the scope, severity and non-linear nature rate of climate change impacts[155,156]. In addition, the global nature of climate change presents new types of correlated risks for financial portfolios that analysts are currently inexperienced in estimating[157,158]. With the tendency growing amongst financial service practitioners to view risk and capital through individual lenses of carbon asset, litigation and water scarcity perspectives[159,160,161] rather than considering the wider, indirect impacts upon complex global systems, plausible climate change risks might be overlooked. This may be a concern to large institutional investors such as pension funds, which are increasingly turning their attention to investments in large infrastructure projects to broaden their portfolios[162]. Incorrect assumptions in risk management may expose these investments to significant risks from climate change.

Incorrect assumptions pervasive in financial services about the implications of climate change effects and options for response (such as assuming investments can avoid vulnerable regions, or failure to take into account the global, correlated nature of climate change risks) lead to significant financial shocks.

Open economy

If resources become in short supply and prices of key commodities rise, nations may look to initiate protectionist measures, either in response to short-term crises or as more enduring measures. Such a response was demonstrated by the 2010 Russian ban on exporting grain (see Section 4.2.2), and by other countries previously during the 2007/8 food price shock.

'Protectionist-type' mechanisms could also be introduced as a response to concerns about competitiveness, where policies for emission reduction are asymmetric, negatively affecting open markets. The concern, whether real or perceived, is that domestic industries will relocate to countries with weaker environmental policies, and that the direction of future investments will be similarly influenced. These concerns are likely to compound other current issues about competitiveness in some countries, where other requirements on manufacturers are already lower[163]. As one response to these threats, carbon tariffs have been proposed where costs (equal to the amount that would have been paid in emission

154 R:8 (Annex B refers).

155 Carbon Disclosure Project. (2009), *Global 500 Report*. Report available at: https://www.cdproject.net/en-US/Results/Pages/Investors-2009-Reports.aspx (last accessed 21/06/11).

156 Dlugolecki, A. (2001), *Climate Change and the Financial Services Industry*. Insurance Economics, **43**.

157 Cooke, R.M. and Kousky, C. (2009), *Are Catastrophes Insurable?* Resources, **172**. Available at: http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=20871 (last accessed 21/06/11).

158 Kousky, C. and Cooke, R.M. (2009), *Climate Change and Risk Management: Challenges for Insurance, Adaptation and Loss Estimation*. RFF Discussion paper 09-03-REV, available at: http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=20716 (last accessed 21/06/11).

159 Carbon Disclosure Project. (2009), *Global 500 Report*. Report available at: https://www.cdproject.net/en-US/Results/Pages/Investors-2009-Reports.aspx (last accessed 21/06/11).

160 Dlugolecki, A. (2001), *Climate Change and the Financial Services Industry*. Insurance Economics, **43**.

161 Dlugolecki, A. *et al.* (2009), *Coping with climate change: risks and opportunities for insurers*. Report for the Chartered Insurance Institute, available at: http://www.cii.co.uk/pages/research/climatechangereport.aspx (last accessed 21/06/11).

162 Inderst, G (2009), *Pension fund investment in infrastructure*. OECD Working Papers on Insurance and Private Pensions, No. 32, OECD Publishing, © OECD. doi:10.1787/227416754242. Available at: http://www.oecd.org/dataoecd/41/9/42052208.pdf (last accessed 21/06/11).

163 WTO-UNEP (2009), *Trade and Climate Change*. Report available at: http://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf (last accessed 21/06/11).

allowances if manufactured domestically) would be imposed on imported goods from nations with lower emissions standards[164]. Such policies could risk triggering wider trade disputes and reciprocal measures[165], further damaging an open global economy and market-based approach. However, a distinction should be made between this potential reduction in trade liberalisation and a reduction in free capital flow, for which there is less evidence.

Short supply of resources and increases in commodity prices driven by climate change, and competition from nations with less stringent environmental policies, leads to more protectionist trade measures, adversely affecting global markets, and so UK competitiveness.

3.2.2 UK business

A risk to UK competitiveness lies in the lack of international agreements over emissions targets for combating climate change. It is not clear that the path leading to any post-2012 agreement will be similar to the one that led to the adoption of the Kyoto Protocol, with some developed countries having rejected the 'top-down' approach the Protocol adopted. Others, which supported strong rules and institutions during the negotiations, have been disappointed by the performance of the institutions created under the Kyoto Protocol[166]. Moreover, efforts by developed countries to include more specific commitments by developing countries have dampened the enthusiasm of the latter for a legally binding regime with a strong compliance mechanism. As a result, confidence in UN-level negotiations to agree timely and effective actions remains tentative, though the UNFCCC remains the only international framework with the legal basis to deliver a binding global deal. Even if all countries were to deliver fully their commitments in the Copenhagen Accord to reduce emissions, this is very unlikely to be sufficient to keep global temperature rise below the stated 2°C target, leaving more substantial (and possibly more costly) action to be taken post-2020[167].

Absence of a global deal on emissions reduction

Discussion in the Major Economies Forum on Energy and Climate (MEF), progress within the EU, and individual country and sector actions, suggests that it is currently regional, national, state level and sectoral initiatives supported and enforced, for example, by national institutions, that are the main engines for progress on emissions reduction[168]. As a consequence of such a heterogeneous approach, concerns about state legislation on the global position and competitive advantage of firms rank high. Countries seriously engaged in mitigation might decide to couple their domestic policies with trade measures such as border tax adjustments. This would lead in turn to an expanded role for the World Trade Organization (WTO) in determining the legality of climate change policies[169]. Such an outcome might act as a deterrent for countries considering stringent mitigation policies, and lead to a reduction in their ambition and effectiveness.

In the absence of a global deal on carbon constraints, the UK itself will need to continue to consider the competitive position of domestic firms in affected sectors, particularly if an imbalance persists between stringent domestic mitigation targets and more limited steps in competitor countries. A concern over leakage, whereby application of carbon taxation within a region causes certain industries to move elsewhere, has been highlighted by the EU Emissions Trading Scheme (ETS). It is thought that such leakage will be small (less than 2% overall emissions would be driven from the ETS zone), and would not be sufficient to undermine the overall benefits of the scheme to EU members[170]. Nevertheless, some

164 Ekins, P. & Barker, T. (2002), *Carbon taxes and carbon emissions trading*. In: Hanley, N. & Roberts, C. (eds.), *Issues in Environmental Economics*, Blackwell Publishing, UK.

165 Izard, C., Weber, C. & Matthews, S. (2009), *Scrap the Carbon Tariff*. Nature Reports Climate Change, **4**: 10-11.

166 R:4 (Annex B refers).

167 International Energy Agency (2010), *Executive Summary of the World Energy Outlook*. Available at: http://www.iea.org/weo/docs/weo2010/WEO2010_ES_English.pdf (last accessed 21/06/11).

168 Werksman, J. and Herbertson, K. (2009), *The Legal Character of National Actions and Commitments In a Copenhagen Agreement: Options and Implications*. World Resources Institute Working Papers. Washington, World Resources Institute: **30**.

169 Biermann, F. & Brohm, R. (2005), *Implementing the Kyoto Protocol without the USA: the strategic role of energy tax adjustments at the border*. Climate Policy, **4**: 289-302.

170 Carbon Trust (2010), *Tackling carbon leakage: Sector-specific solutions for a world of unequal carbon prices*. Report available at: http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=CTC767 (last accessed 21/06/11).

industries (such as cement and steel production, which may experience up to 10% leakage) and regions (such as coastal areas) will be affected more than others[171]. Affected industries are estimated to only make up about 1% of UK GDP, although this impact will be unevenly spread and may be significantly greater in some regions[172]. The UK Committee on Climate Change has recently called for government to consider how to mitigate the risk of leakage in industrial and agricultural sectors, but have emphasised the overall neutral or beneficial fiscal impacts of the ETS[173].

A lack of a legally binding international agreement on climate change leads to a high level of reliance on national mitigation targets in the UK and elsewhere, decoupled from an international system and potentially putting UK businesses in affected sectors at a global disadvantage.

Investment in green technologies

The lack of an international agreement on climate change would also affect decisions by companies to commit to particular strategies on climate change such as the carbon cap. The UK financial sector is leading the world in carbon trading; however, markets will exist only if there is a desire to set a limit, or a cap, on the amount of greenhouse gases companies, or other entities, are allowed to emit[174]. Whilst such a framework now operates in the EU[175], a global cap is yet to be agreed. There is also significant uncertainty around the future growth and opportunities of green technologies[176] and a risk that policies underpinning low-carbon investments could be reversed[177]. Case studies from Asia in 2008 suggest that while carbon reporting and mitigation in the region is making progress, regulatory risk remains high and companies with more limited resources are struggling to detect changing policy directions[178]. Following the lack of consensus at the Copenhagen summit, this has led to a "bottom-up" approach to limiting emissions across the region[179]. For example, the IT sector operates across Asia and is covered by a number of different regulations on national emissions, putting the sector at high risk from changes to regulation[180]. The lack of an international policy framework that provides the degree of direction and stability needed for companies to commit to low-carbon technologies or strategies, leads to uncertainty, which deters decisive action[181,182,183].

Lack of an international agreement and limits on global emissions does not provide the direction and stability needed for companies to take decisive action, and deters UK companies and those of other nations from investing in green technologies.

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171 *ibid.*

172 Committee on Climate Change (2008), *Building a low-carbon economy – the UK's contribution to tackling climate change*. Report available at: http://www.theccc.org.uk/reports/building-a-low-carbon-economy (last accessed 21/06/11).

173 Committee on Climate Change (2010), *The fourth carbon budget: Reducing emissions through the 2020s*. Report available at: http://www.theccc.org.uk/reports/fourth-carbon-budget (last accessed 21/06/11).

174 Rippey, P. (2009), *Microfinance and Climate Change: Threats and Opportunities*, Focus Note 52, Consultative Group to Assist the Poor (CGAP).

175 Information on the EU Emissions Trading Scheme (EU ETS) is available at: http://ec.europa.eu/clima/policies/ets/index_en.htm (last accessed 21/06/11).

176 Cambridge Programme for Sustainability Leadership (2008), *Market barriers and signals (deal flow) – Mapping research summary (draft)*. The Prince of Wales' P8 Group.

177 UN Environment Programme (UNEP) and partners (2009), *Catalysing low-carbon growth in developing economies, Public Finance Mechanisms to scale up private sector investment in climate solutions.*

178 Association for Sustainable and Responsible Investment in Asia (2008), *Carbon Disclosure Project Report 2008 – Asia ex-Japan*, Research Institutions Carbon Disclosure Project, in *The materiality of climate change, How finance copes with the ticking clock*, a 2009 report by the Asset Management Working Group of the UNEP Finance Initiative. Available at: https://www.cdproject.net/CDPResults/67_329_148_CDP6_Asia_Report_2008.pdf (last accessed 21/06/11).

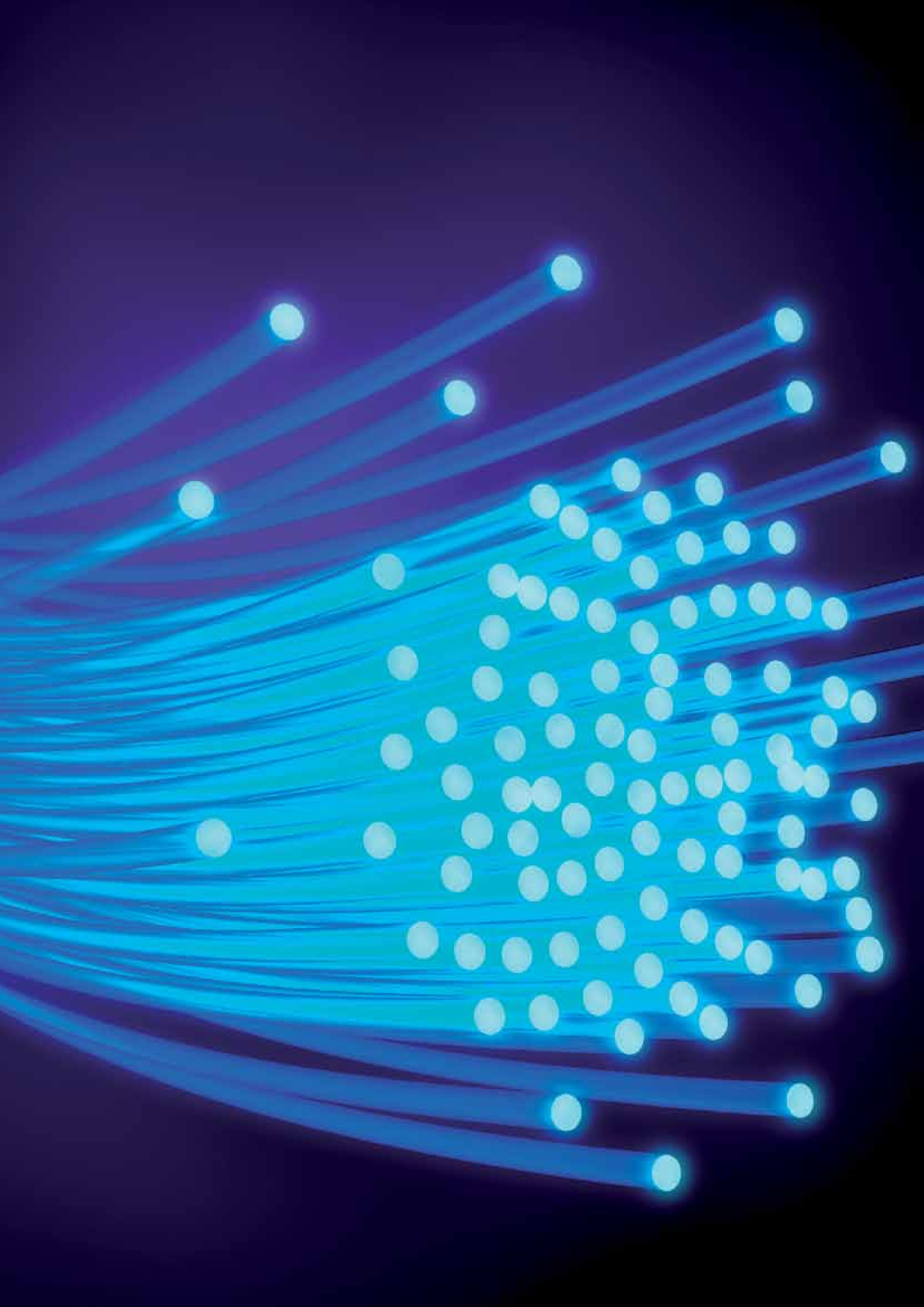
179 Association for Sustainable and Responsible Investment in Asia (2010), *Carbon Disclosure Project Report 2010 – Asia ex-Japan*, Carbon Disclosure Project. Available at: https://www.cdproject.net/CDPResults/CDP-2010-Asia-ex-Japan-Report.pdf (last accessed 21/06/11).

180 *ibid.*

181 International Investors Group on Climate Change (2008), *Investor Statement on a Global Agreement on Climate Change*. Available from: http://www.iigcc.org/__data/assets/pdf_file/0010/460/InvestorPolicyStatement8Dec08.pdf (last accessed 14/04/2011).

182 International Investors Group on Climate Change (2009). Available from: http://www.unepfi.org/fileadmin/documents/need_agreement.pdf (last accessed 14/04/2011).

183 International Investors Group on Climate Change (2010). Available from: http://www.unepfi.org/fileadmin/documents/InvestorStatement_ClimateChange.pdf (last accessed 14/04/2011).



4 UK threats and challenges part B

Chapter 4 continues the exploration of the threats to the UK from climate change impacts overseas, and focuses on threats to international infrastructure, resources and commodities, and human health.

4 UK threats and challenges part B

This chapter identifies threats to the UK from the impacts of global climate change on critical infrastructure located in other countries. It also highlights specific risks relating to the availability of a wide range of resources and commodities on which the UK relies, and explores possible risks to human health.

4.1 Infrastructure

The UK relies heavily on a wide range of global infrastructure to provide international transportation, energy security, and communications networks. This infrastructure, which is distributed across many countries in different parts of the world, is likely to be at risk from the effects of global climate change. Sea-level rise will affect ports, airports and oil refineries in densely populated and economically diverse coastal zones, while increasing storm intensity by the 2040s may have adverse impacts on global shipping and aviation[1]. Changing precipitation levels or intensities could negatively affect data and communications networks, either by flooding of hubs or through droughts reducing their operating efficiency. Because many global infrastructure networks are interdependent, there is a risk of 'cascade failure', where damage to one network has negative implications for others[2]. For example, transportation is heavily reliant upon communications infrastructure, which is itself reliant on power networks. This section explores risks to the UK through its dependence on global coastal infrastructure, transportation and communications networks and energy transportation.

4.1.1 Coastal infrastructure

The Low Elevation Coastal Zone (LECZ) is defined as any coastal area below 10m, and evidence suggests that between 557 and 709 million people worldwide live within it[3]. These areas also contain significant economic assets and activities, including, for example, 35% of the world's oil refineries, 11% of airports and all seaborne trade[4,5,6,7,8] (see Table 4.1). Asia accounts for about a third of the LECZ, and three-quarters of the total population in the zone[9].

1 R:3 (Annex B refers).

2 Royal Academy of Engineering (2011), *Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future.* Report available at: http://www.raeng.org.uk/news/publications/list/reports/Engineering_the_future_2011.pdf (last accessed 21/06/11).

3 Lichter, M., Vafeidis, A.T., Nicholls, R.J., Kaiser, G.(2010), *Exploring data-related uncertainties in analyses of land area and population in the 'Low Elevation Coastal Zone' (LECZ).* Journal of Coastal Research, in press.

4 Bijlsma, L., Ehler, C.N., Klein, R.J.T., Kulshrestha, S.M., McLean, R.F., Mimura, N., Nicholls, R.J., Nurse, *et al.* (1996), *Coastal zones and small islands*. In: R.T. Watson, M.C. Zinyowera and R.H. Moss (eds), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 289–324.

5 Sachs, J.D., Mellinger, A.D. and Gallup, J.L. (2001), *The Geography of Poverty and Wealth*. Scientific America, **284**: 70-75.

6 Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R. (2008). *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1.

7 Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and Yan, J. (2007), *The Impact of Sea-Level Rise on Developing Countries: A Comparative Analysis.* World Bank Policy Research Working Paper 4136, February, World Bank, Washington.

8 Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and Yan, J. (2009), *The impact of sea level rise on developing countries: a comparative analysis*. Climate Change, **93**:379-388. DOI 10.1007/s10584-008-9499-5.

9 McGranahan G., Baulk D., Anderson B. (2006). *Low Coastal Zone Settlements.* Tiempo.

Table 4.1: Global infrastructure within the Low Elevation Coastal Zone[10]

Infrastructure	Global Total+	LECZ Total	Percentage (%)
Cities (with population > 100,000)	1113	170	15
Airports	9915	1083	11
Nuclear power stations	249	30	12
Oil refineries	505	177	35
Ports	2658*	–	–

+ Note: these numbers represent the total number included in the dataset sources used for this analysis.
** Refers all sea/coastal ports (excluding river ports) – as all ports are potentially threatened by sea-level rise.*

It is unclear how much of the LECZ is at risk of flooding from sea level rise and storm surges. The potential direct physical impacts of sea-level rise include inundation of low-lying areas, loss of coastal wetlands, increased rates of shoreline erosion, saltwater intrusion, higher water tables and higher extreme water levels leading to coastal flooding[11]. The magnitude of the potential damages and costs will depend, not only on the extent of sea-level rise, but on social and economic change. For example, growth in coastal populations and coastal infrastructure, and rising subsidence will increase the vulnerability of LECZ[12]. One study estimates that population exposure to extreme water levels could rise from 40 million (in 2005) to 150 million (by the 2070s), and exposure of assets could reach US$35 trillion (by the 2070s)[13]. For both types of exposure, this increase is associated with population growth, economic growth and urbanisation[14]. Figure 4.1 shows the estimated global distribution of assets exposed to coastal flooding in large port cities[15] for 2050 and 2070, illustrating the concentration of exposed infrastructure and populations in Asia.

10 R:6.1 (Annex B refers).

11 Nicholls, R.J. (2010), *Impacts of and Responses to Sea-Level Rise*. In: J.A. Church, P.L. Woodworth, T. Aarup and S. Wilson (eds.), *Understanding sea-level rise and variability*. Wiley-Blackwell, London.

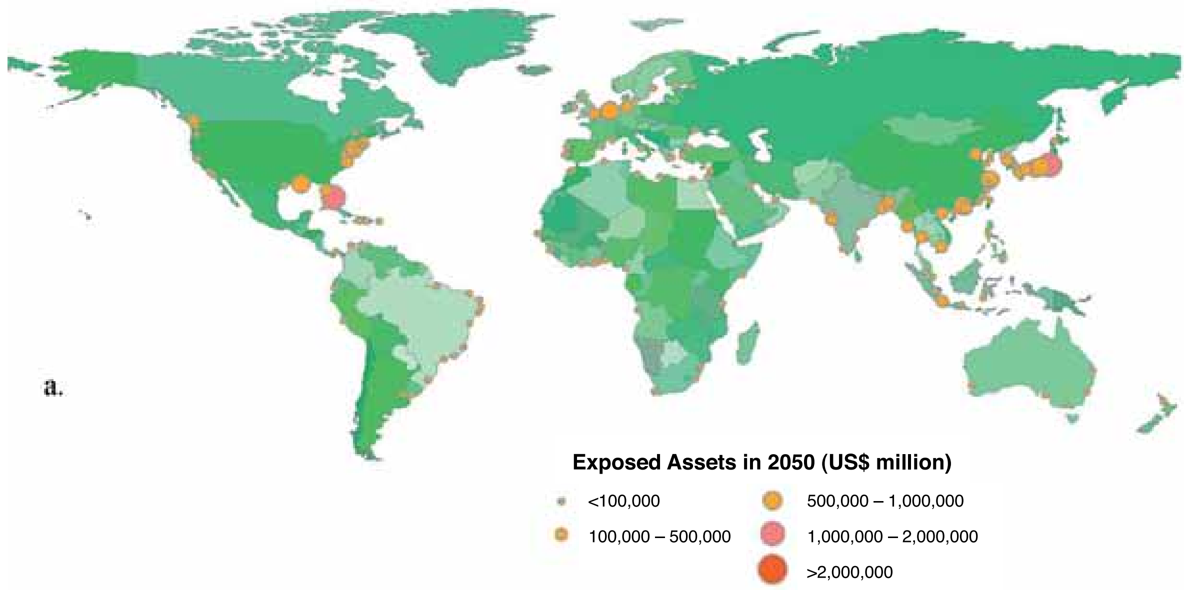
12 R:6.1 (Annex B refers).

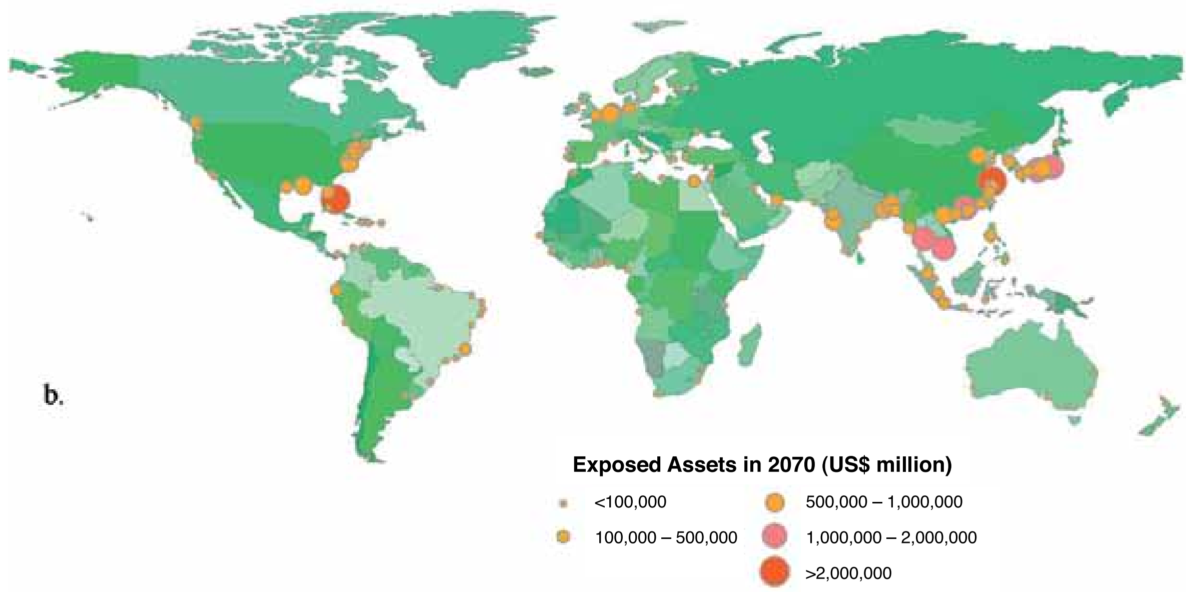
13 Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R., 2008a. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1.

14 Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R., 2008a. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1.

15 Port cities are defined as those with a population of over 1 million in 2005.

Figure 4.1: Global distribution of assets exposure in large port cities under the medium emissions scenario and the 'Future City, All Changes' water level scenario: Future socio-economic situation with natural subsidence/uplift and human-induced subsistence: (a) by 2050 and (b) by 2070.[16]





Rises in sea level of up to 0.5-0.6m (relative to the 1980-1999 average) are projected for some areas by 2040[17] under the medium emissions scenario[18]. Even without any changes to storm frequency or intensity, sea level rise will increase the risk of coastal flooding. Existing flood defences in some locations will help reduce the scale of possible damage. Cities in high-income countries have (and are more likely to have in the future) much better protection than those in the developing world. For example, London, Tokyo and Amsterdam are protected to above the '1 in 1000 year' standard[19], while many low-income

16 Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R., 2008a. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1.

17 Average rises are projected to be significantly lower than these extremes – by 2100 under the medium emissions scenario, the average global rise is projected at 0.23-0.43m (2090-2099 compared with 1980-1999 average) – see Section 2.4.2.

18 R:3 (Annex B refers).

19 1 in 1000 chance of a surge-induced flood event occurring each year.

countries have far lower levels of protection, if any formal flood defences at all[20]. Significant additional adaptation efforts, either 'hard' (such as seawalls and sluice gates) or 'soft' (such as beach nourishment), will be needed and solutions may be highly region-specific[21]. Insufficient investment in coastal adaptation for low-income countries will expose them to significantly greater risk.

About 10% of the world's population[22], a similar or greater proportion of the infrastructure (see Table 4.1) and many of the great trading hubs and world cities are in low-lying coastal regions. This suggests vast investments will be required, and justified, to upgrade, move and protect coastal infrastructure[23]. A global investment cost for coastal adaptation of between US$28 billion and US$90 billion per year up to 2050 was estimated across a range of sea level scenarios up to a 1.26m rise by 2100[24]. By 2070, the top 10 cities in terms of asset exposure to sea level rise are expected to be Miami, Shanghai, Guangdong, Tokyo, New York-Newark, Ho Chi Minh City, Osaka-Kobe, Bangkok, Amsterdam and Rotterdam[25]. Many of these cities are important hubs in terms of financial and transport infrastructure, and their exposure to climate change effects could therefore have substantial implications for UK trade, finance and industry.

Where coastal adaptation planning is inadequate, vulnerabilities to both higher sea levels and possibly more intense storms[26] will remain. This may lead to repeated temporary disruption to infrastructure delivery systems, resulting in, for example, disrupted transport routes, temporary increases in commodity prices, and higher energy costs (see Sections 4.1.2 and 4.2.1). The case of Hurricane Katrina in 2005 shows how a chain of multiple impacts across different sectors can cause major economic and social damage, not only in the immediate coastal area but also at national and global levels (see Section 4.1.4). There is also the potential for direct impacts on UK-owned businesses and infrastructure, which are in vulnerable coastal areas overseas.

Increased flooding and storm surges affecting coastal areas lead to disruption of UK supply chains and assets, and affect coastal-based UK business and infrastructure.

4.1.2 Transportation

The UK depends upon international transportation for the movement of physical resources and commodities to the UK. It is also an essential component of the overseas manufacturing processes of critical goods that the UK depends upon. A range of climate change impacts could affect overseas transportation hubs, particularly ports and airports, as well as transportation networks involving shipping routes, air routes and road and rail networks. Most of these impacts are likely to be negative, arising from increased average temperatures, higher or more frequent extreme temperatures, and sea level rise[27].

Air transportation

Eleven per cent of the world's airports are within the LECZ and would therefore be at risk from sea level rise (see Table 4.1). Climate change is also likely to affect aircraft performance, and the infrastructure and operations of airports. For example, reduction in snow and frost cover will reduce the need for de-icing as temperatures rise. Flooding could create access problems for staff and freight deliveries, and reduce airport energy security if substations are inundated[28]. Alterations in wind speed and direction are

20 Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. & Muir-Wood, R., 2008a. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1.

21 Nicholls, R., Brown, S., Hanson, S. & Hinkel, J. (2010), *Economics of Coastal Zone Adaptation to Climate Change.* World Bank report, available at: http://beta.worldbank.org/sites/default/files/documents/DCCDP_10_CoastalZoneAdaptation.pdf (last accessed 21/06/11).

22 An estimated 67-153 million people live within 1m of sea level, and 557-709 million live within 10m. R6.1: IDCC Review on Impacts of Climate Change on Coastal Infrastructure.

23 R:6.1 (Annex B refers).

24 Nicholls, R.J., Brown, S., Hanson, S. & Hinkel, J. (2010), *World Bank: Economics of Adaptation to Climate Change: Aggregate Track Infrastructure – Coastal Component.* World Bank Report.

25 Hanson, S., Nicholls, R.J., Hallegatte, S. & Corfee-Morlot, J. (2010). *The effects of climate mitigation on the exposure of the world's large port cities to extreme water levels.* Report for the AVOID Programme, Met Office.

26 R:6.1 (Annex B refers).

27 Hanson, S., Nicholls, R.J., Hallegatte, S. & Corfee-Morlot, J. (2010). *The effects of climate mitigation on the exposure of the world's large port cities to extreme water levels.* Report for the AVOID Programme, Met Office.

28 R:3 (Annex B refers).

projected to alter, as the position of jet streams and storm tracks change[29], may affect transit times and fuel requirements either positively or negatively. Severe storminess could delay or ground flights and pose a risk to airplane safety[30].

Rail and road transportation

To reach ports and airports, commodities and resources need to be transported by rail and road. An important threat to the railway network in many regions (including North America; Northern Europe; Central, North, East and South Asia) by the 2040s is an increase in extreme rainfall, which will lead to a greater risk of flooding of tracks and depots, damage to bridges and the subsidence of embankments[31]. Rail networks in those regions with significant increases in extreme temperatures or heat waves may experience buckling of rail lines where design specifications are exceeded. In areas where rail lines have been built on permafrost (e.g. Russia, Canada and the Tibetan Plateau), increased temperatures by the 2040s could lead to subsidence or the need for expensive engineering solutions to manage the effects of permafrost thaw (see Section 4.1.4). Overseas road networks also face similar risks by the 2040s, of flooding, landslides and melting of tarmac roads[32].

Marine transpotation

Sea freight makes the biggest contribution to global transportation of commodities and resources, carrying over 80% of the volume of world trade[33]. It has been estimated that between 2000 and 2015, the volume of goods transported by sea will have increased by 2.5 times, to 600 million TEUs[34] (Twenty-foot Equivalent Units). The trend in global demand for expansion and building of new ports is expected to continue through this century[35]. The precise impacts of sea level rise on sea freight will depend on the port structures and infrastructure: for some it will increase their access for deep draft ships, while for others it could render existing infrastructure unsuitable. Changes in patterns of erosion and sedimentation around harbours and access channels could also complicate operations[36].

There are a number of major potential points for congestion on the global shipping routes (see Figure 4.2), including the Strait of Hormuz, between Iran, United Arab Emirates and Saudi Arabia; the Suez Canal in Egypt, connecting the Mediterranean and Red Seas; and the Panama Canal, connecting the Pacific and Atlantic Oceans. Increased storminess at sea and changes in the zones through which storms travel could lead to disruption of supply chains through longer transit times and the need for re-routing during stormy weather, which would slow the delivery of commodities and increase their cost. Increases in storminess could also have an impact on ports, although port infrastructure is generally considered resilient to all but the most severe storms. Storm surges around ports could become more damaging, as the current infrastructure would not be adequate to cope with the consequences of the expected rise in sea levels in the 2040s.

Sea level rise and possible changes in storm frequencies and intensities are likely to have adverse impacts on global transport routes and infrastructure, and hence UK business and trade.

29 R:3 (Annex B refers).

30 European Union (2010), *Effects of Climate Change on Aviation Safety*. Available from: http://www2.icao.int/en/HLSC/Information%20Papers/HLSC%2010%20IP%20016%201%20Rev%20en%20%282%29.pdf (last accessed 21/06/11).

31 R:3 (Annex B refers).

32 R:3 (Annex B refers).

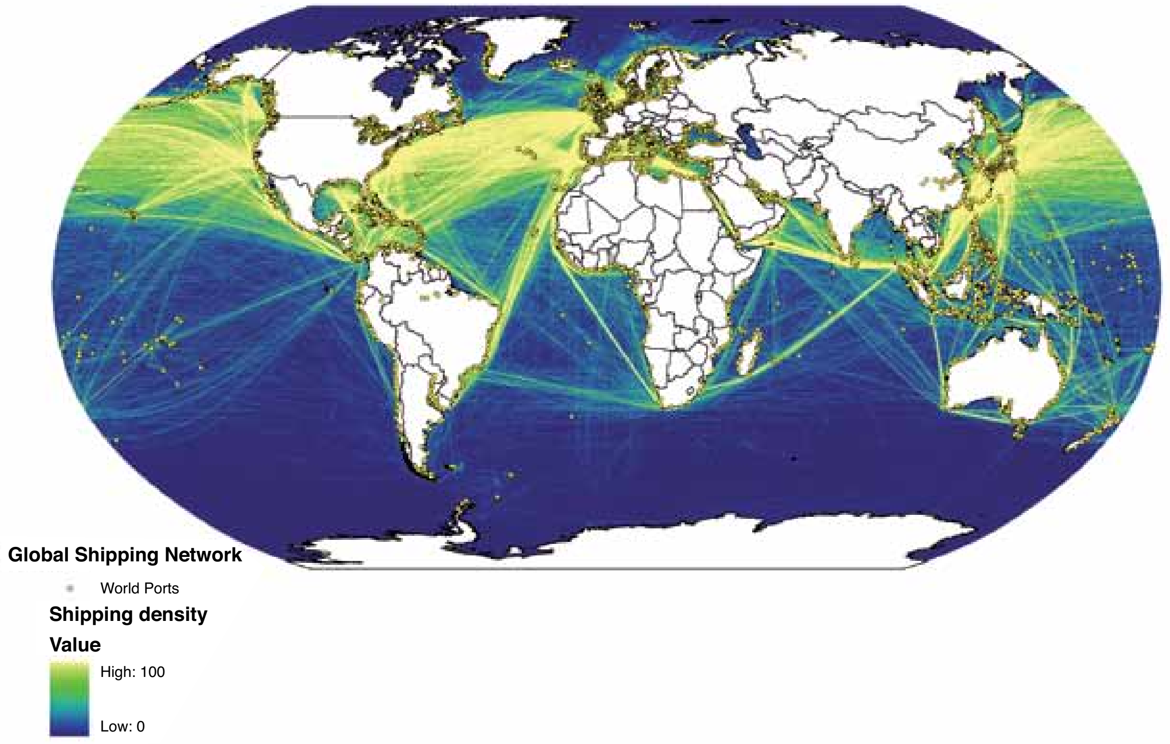
33 UN (2009), *Multi-Year Expert Meeting on Transport and Trade Facilitation – Maritime Transport and the Climate Change Challenge*. Geneva: UN.

34 Lloyd's List (2009), *Ports of the World 2009: Volume 1: Albania – Lithuania, and Volume 2: Madagascar – Yemen*. London, Informa Maritime and Professional.

35 R:6.1 (Annex B refers).

36 UN (2009), *Multi-Year Expert Meeting on Transport and Trade Facilitation – Maritime Transport and the Climate Change Challenge*. Geneva: UN.

Figure 4.2: Major shipping routes and ports. Sources: NCEAS (shipping routes), FAO (ports)[37]



4.1.3 Communications

With the increase of off-shoring IT- and ICT-enabled services and an expansion of international data centres, the UK could experience a significant new vulnerability in the face of climate change. Cloud computing (delivering software and services to consumers over the Internet)[38] is predicted to grow dramatically over the next few years. One estimate[39] suggests the growth of cloud computing services will be 27% per year, reaching over $55 billion by 2014[40]. This shift will require investment in the construction of new data storage sites as services and processing power are increasingly supplied to end-users from remote, distributed server centres rather than being stored on desktop computers[41]. The relatively high costs of construction, land and electricity make the UK an expensive location for data centres[42]. These factors have already driven a significant amount of data storage off-shore in the private sector. For example, Iceland is increasingly recognised as a good location for data centres due to extensive renewable power resources and its perceived security[43].

The growing provision of digital services and moves to a 'government of the web' in combination with cost-saving pressures may drive the location of data centres overseas. UK government procurement for critical services will generally consider resilience of proposed offshore data centres, and analysts have speculated about alternative European locations such as France or Germany[44].

37 R:3 (Annex B refers).

38 Cloud computing is a general term for anything that involves delivering hosted services (e.g. business applications such as office suites, online gaming, etc.) over the internet. For more information, see: Foresight Horizon Scanning Centre (2010), *Technology and Innovation Futures: Technology Annex*, section 4.2. URN 10/1252, available at: http://www.bis.gov.uk/foresight/our-work/horizon-scanning-centre/technology-and-innovation-futures (last accessed 21/06/11).

39 International Data Corporation, (2010*), IDC's Public IT Cloud Services Forecast: New Numbers, Same Disruptive Story*, July 2010, available at http://blogs.idc.com/ie/?p = 922. (last accessed 21/06/11).

40 Conversions based on Her Majesty's Revenue & Customs' yearly average exchange rate for 2009, available at http://www.hmrc.gov.uk/exrate/yearly_rates.htm (last accessed 21/06/11).

41 Bein, D., Bein, W., & Phoha, S. (2010), *Efficient Data Centers, Cloud Computing in the Future of Distributed Computing*. (pp. 70-5). IEEE Computer Society.

42 Webster, D. (2009*). Digital Britain: red electricity and server huggers stand in the way*. Database and Network Journal. **39**: 13.

43 For further information see: http://www.invest.is/investment-opportunities/data-centers-in-iceland/ (last accessed 21/06/11).

44 Webster, D. (2009). *Digital Britain: red electricity and server huggers stand in the way*. Database and Network Journal. **39**: 13.

A number of data storage facilities have already suffered from flooding, including the Vodafone data centre in Ikitelli, Turkey, which was affected by flash flooding in 2009. This event put a quarter of the local network at risk, although the incident response team prevented any significant loss of service[45].

Box 4.1 Typhoon Morakot – cable disruption

Between the 5th and 11th of August 2009, Typhoon Morakot led to 3m of rainfall over the central mountainous areas of Taiwan, causing rivers to flood and the displacement of large volumes of sediment into the ocean. The large volumes of sediment led to several submarine landslides and the formation of sediment-laden 'turbidity currents', which broke at least nine cables off Taiwan at depths of 4000m and over 300km from the coastal area[46]. This resulted in disruptions to the Internet and telecommunications between Taiwan, China, Hong Kong and other parts of Southeast Asia. Services were restored quickly through the rerouting of traffic via other cables, albeit with slower access due to congestion.

The transfer of data might also be affected by climate change. Over 95% of global traffic is handled by approximately one million kilometres of submarine fibre-optic cables which achieve data and voice transfer more cheaply and quickly than satellites. Rising sea levels not only increase the risk of erosion and flooding of coastal cable facilities[47], but might also affect the stability of the continental shelf seabed through the formation of eroding currents and waves (see Box 4.1)[48]. In turn, cables on the seabed could become more vulnerable to abrasions from suspensions[49] and sand and gravel movements[50], resulting in chafe and fatigue. Greater precipitation, leading to higher levels of river sediment being delivered to the continental shelf, may also damage cables through increased 'seabed-hugging' mud flows[51,52].

UK overseas data storage centres and infrastructure for international communications networks will be at increasing risk of disruption from flooding and other extreme weather events.

4.1.4 Energy transportation

The UK is highly reliant on international infrastructure for energy transportation. Since 2004 the UK has been a net importer of fuels and in 2009 had an energy trade deficit of £8.2 billion[53] (see Figure 4.3).

45 Vodafone, Nokia Siemans Network (2010). *Vodafone Turkey's flooded network brought to life in one day*. Available from http://www.nokiasiemensnetworks.com/sites/default/files/document/Vodafone_Turkey_Flood-success_story.pdf (last accessed 21/06/11).

46 Carter, L., Burnett, D., & Drew, S. (2009). *Submarine Cables and the Oceans – Connecting the World*. UNEP-WCMC. Report available at: http://www.iscpc.org/publications/ICPC-UNEP_Report.pdf (last accessed 21/06/11).

47 *ibid.*

48 *ibid.*

49 Summers, M. (2001), *Review of deep-water submarine cable design*. Proceedings SubOptic 2001, Kyoto, 4 pp.

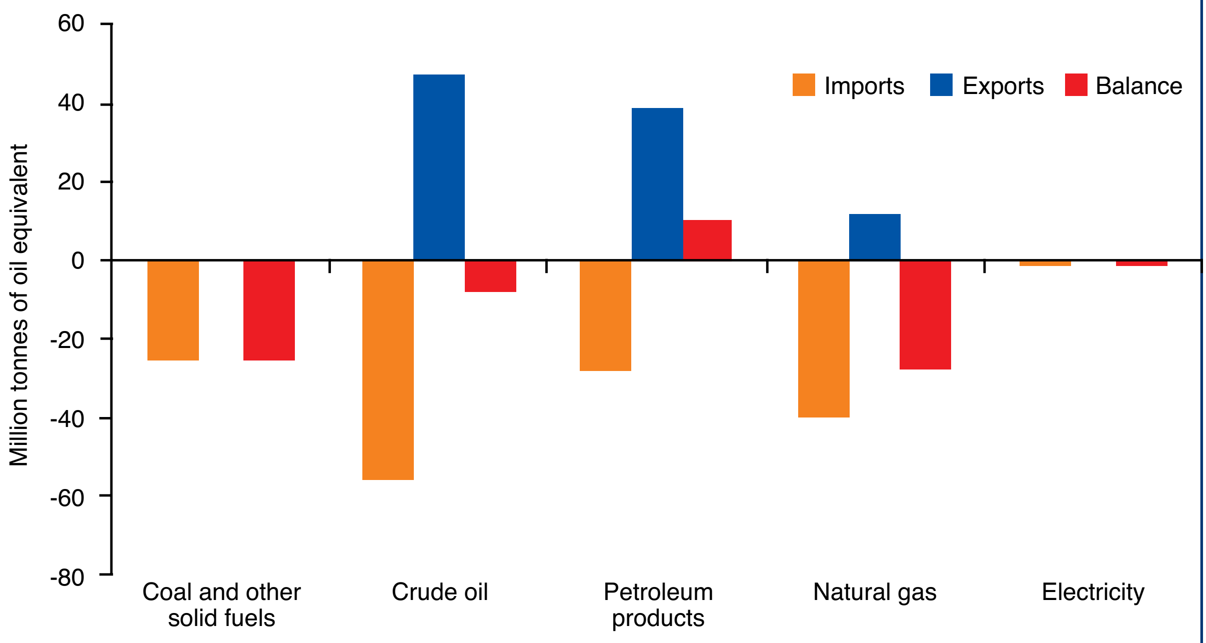
50 Carter, L., (1987). *Geological hazards and their impact on submarine structures in Cook Strait, New Zealand*. Proceedings 8th Australasian Conference on Coastal and Ocean Engineering, Launceston, 30 Nov–4 Dec 1987, pp. 410–414.

51 Milliman, J.D. and Kao, S.J., (2005). *Hyperpycnal discharge of fluvial sediment to the ocean: Impact of super-typhoon Herb (1996) on Taiwanese rivers*. Journal of Geology **113**: 503–516.

52 Carter, L.., Burnett, D., & Drew, S. (2009). *Submarine Cables and the Oceans- Connecting the World*. UNEP-WCMC.

53 DECC (2010). *Digest of United Kingdom Energy Statistics (DUKES), Annex G – Foreign Trade*. Available at: http://decc.gov.uk/assets/decc/Statistics/publications/dukes/320-dukes-2010-ann-g.pdf (last accessed 21/06/11).

Figure 4.3: The UK's trade in 2009 of individual fuels



Forecasts point towards the development of extensive changes to energy infrastructure across the world through the first half of this century. Estimates suggest that $6.8 trillion (£3.4 trillion) investment in the transmission and distribution of energy will be required worldwide by 2030[54]. Much of the developed world's existing infrastructure is becoming obsolete and will have to be replaced, while massive new demand will drive the creation of new energy infrastructure in the developing world[55,56], particularly in the emerging economies, but also in Africa where the population is predicted to double to approximately one billion by 2050[57]. Much of this growth will be based in urban areas[58]. The UK is amongst those countries needing to replace much of its domestic energy infrastructure, as the more polluting fossil fuel plants are unable to meet new EU environmental standards, and most of the UK's nuclear power stations reach the end of their operational lives[59]. Globally, more easily exploitable fossil fuel reserves (such as those in the North Sea) are becoming more depleted, despite technological advances that have enabled increased extraction, and deep water drilling. The supply of oil and gas is becoming concentrated in a small number of producer nations, such as Middle East states and Russia, affecting the UK and other countries[60].

The UK's dependence on the international infrastructure that delivers primary energy is already high and increasing. Despite a major shift towards renewables and plans for new nuclear build in the UK, significant reliance on fossil fuel sources is expected to continue for several more decades or longer (potentially with carbon capture and storage technologies applied[61]). By 2030 the Organization of the Petroleum Exporting Countries (OPEC) of the Middle East are expected to produce 51% of the world's oil, up from 44% in 2007, with the next largest producers being Africa and Russia[62]. The growing global reliance

54 Figures based on 2007 dollar, and the IEA Reference Scenario. IEA (2008) *World Energy Outlook*. Available at: http://www.iea.org/textbase/nppdf/free/2008/weo2008.pdf (last accessed 21/06/11). Conversions based on Her Majesty's Revenue & Customs' yearly average exchange rate for 2007, available at http://www.hmrc.gov.uk/exrate/yearly_rates.htm (last accessed 21/06/11).

55 Foresight (2010), *Technology Innovation Futures: Technology Annex*. Foresight, UK.

56 Umbach, F. (2010). *Global energy security and the implications for the EU*. Energy Policy, **38**: 1229-1240.

57 Wolfgang Lutz and Samir KC (2010). Dimensions of global population projections: what do we know about future trends and structures? *Phil. Trans. R. Soc. B* **365**: 2779-2791.

58 *ibid*.

59 All but one of the UK's existing nuclear power reactors are expected to shut down by 2023, representing almost 90% of total nuclear generating capacity. Information from the World Nuclear Association, available at: http://www.world-nuclear.org/info/inf84.html (last accessed 21/06/11).

60 BP (2009). *World Statistical Energy Review*. London: British Petroleum.

61 DECC (2010), *Updated energy and emissions projections*. URN 10D/510, report available at: http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx (last accessed 21/06/11).

62 IEA (2008). *World Energy Outlook*. International Energy Agency.

on these reserves is leading to longer, more complex supply chains which are inherently more vulnerable to disruption[63].

Vulnerabilities of international infrastructure for energy transportation

New pipeline projects in the Arctic have become important to regional energy strategies, and illustrate the growing trend for transporting primary energy sources over greater distances[64]. Thawing of permafrost in high northern latitudes, particularly in the Russian Federation, is projected to advance towards the 2040s, and to become progressively more severe towards 2100 in North America and Central and North Asia under both the medium emissions and aggressive mitigation scenarios[65]. This could have a significant impact on pipelines and other infrastructure built on a permafrost foundation, affecting the supply and distribution of oil and gas to Europe. In the USA, the Joint Pipeline Office has estimated that approximately 28% of the trans-Alaska oil pipeline's vertical support structures are at risk of thawing permafrost and soil subsidence[66]. Underwater pipelines might also be at risk of being damaged by the force of extreme weather events. A category-4 hurricane, Ivan, was found to have scoured the seabed 90 metres below the surface[67], and Hurricanes Katrina and Rita caused significant damage to oil platforms and pipelines in the Gulf of Mexico, although overall the pipeline network was considered to have performed well[68]. Although these threats are not new, the potential for disruption may increase beyond current contingencies if such events become more severe.

The supply of natural gas in particular has traditionally been determined largely by the availability of pipeline infrastructure, which is expensive to construct and must be planned well in advance. In 2008, 72% of the UK's gross gas imports were by pipeline from Norway[69]. Natural gas is essential to power industrial processes in the UK, enable electricity generation and provide heating. It has been estimated that, in addition to the social impacts and the risk to vulnerable members of the community, an unexpected physical disruption in the supply of gas could cost the UK economy up to £600 million in terms of lost output[70].

Major ports which handle large-scale goods (such as Singapore, Shanghai and Rotterdam) are likely to adapt to sea-level rise. However, the risk of temporary disruption to the infrastructure that provides energy supplies (such as oil refineries, natural gas terminals, and the physical infrastructure in port facilities which service them) will increase with rising sea levels[71,72].

Although an individual event cannot be ascribed with certainty to climate change, Hurricane Katrina in 2005 shows that major events in specific regions can have global consequences. The UK can be affected by both the disruption of supply from a specific area, and through rising prices triggered by a temporary decline in supply. Hurricane Katrina in 2005 was the most destructive and costliest[73] natural disaster in US history, claiming over 1800 lives and causing damage estimated at US $142 billion[74]. It led to the closure of significant pipeline networks (leading to shortages of natural gas and petroleum products), disrupted electrical system infrastructure (at its peak 2.7 million people were affected), forced nuclear

63 Wicks, M. (2009). *Energy Security: A National Challenge in a Changing World*. London: DECC.

64 Instanes, D. I. (2006). *Impacts of a changing climate on infrastructure: Buildings, support systems, and industrial facilities*. (pp. 47-50). IEEE.

65 R:3 (Annex B refers).

66 US ARC (2003), *Climate Change Permafrost and Impacts on Civil Infrastructure*. Washington DC: US Artic Research Commission.

67 Wijesekera, H.W., Wang, D.W., Teague, W.J. & Jarosz, E. (2010), *High sea-floor stress induced by extreme hurricane waves*. Geophysical Research Letters, **37**: L11604.

68 Det Norske Veritas (2007), *Pipeline damage assessment from Hurricanes Katrina and Rita in the Gulf of Mexico*. Report no. 44814183 to the US Dept. of the Interior's Mineral Management Service. Available at: http://www.boemre.gov/tarprojects/581.htm (last accessed 21/06/11).

69 Wicks, M. (2009). *Energy Security: A National Challenge in a Changing World*. London: DECC.

70 Oxera (2007). *An assessment of the potential measures to improve gas security of supply*. London: DECC.

71 R:6.1 (Annex B refers).

72 As referred to in Section 4.1, rises of up to 0.5-0.6m are possible by the 2040s (relative to 1980-1999 levels) under the medium emissions scenario, along with weaker signals for increased storm intensity (and hence potential for greater storm surges) on the same timescale under the same scenario.

73 Blake, E. *et al*. (2007). *The Deadliest, Costliest, and Most Intense United States Tropical Cyclones From 1851 to 2006 (and Other Frequently Requested Hurricane Facts)*, National Hurricane Center, Miami. Available at: http://www.nhc.noaa.gov/Deadliest_Costliest.shtml (last accessed 21/06/11).

74 R:6.1 (Annex B refers).

plants to run at a reduced level, and shut down about 28%[75] of the USA's total oil refining capacity[76,77]. These events in turn led to a reduction in exports of petroleum and coal, raised oil prices on global markets[78], and caused an estimated decline in US GDP of 0.7 and 0.5 percentage points in the third and fourth quarters of 2005, respectively[79].

Thawing permafrost and rising sea levels have a negative impact on infrastructure for energy transportation, affecting the prices and security of UK energy and fuel imports.

4.2 Resources and commodities

This section explores risks posed to the UK through its trade in and use of a variety of resources and commodities in five sectors: energy (incorporating fossil fuels as well as electricity imports), agriculture, fishing and aquaculture, rare earth elements and manufacturing (see Box 4.2). The impacts identified here are exclusively related to climate change. A wide range of additional factors that will affect the demand, supply, production and transportation of physical resources and commodities are not covered in this Report. Some are likely to have a larger impact on the availability and price of commodities imported to the UK than climate change, but the purpose of this analysis is to allow assessment of the relative contribution of climate change alone. The further distribution and volume of trade in commodities will also be influenced by developments in technology, and social and political changes. However, given that these changes are difficult to quantify, the risks presented here are based on the assumption that current trade patterns and trends provide a reasonable basis on which to make an estimate of the potential impact of climate change.

Box 4.2 Data sources

This section is based primarily on the analysis by the Met Office Hadley Centre commissioned for this Report[80]. The Hadley Centre HadCM3[81] general circulation model was used to forecast effects of climate change on resources and commodities to the 2040s. Over this timescale, the uncertainty in climate changes due to the choice of emissions scenario is small and largely irrelevant. Consequently, all projections presented here are based on the medium emissions scenario[82]. The 2008 data on commodities from the Office for National Statistics' SIC(92)[83] were used, as 2009 data were incomplete[84].

The commodities analysed are the five main commodity sectors as defined by the Office of National Statistics Standard Industrial Classification (SIC) system[85], namely: A) Agriculture, hunting and forestry; B) Fishing; C) Mining and quarrying; D) Manufacturing; and E) Electricity and gas supply.

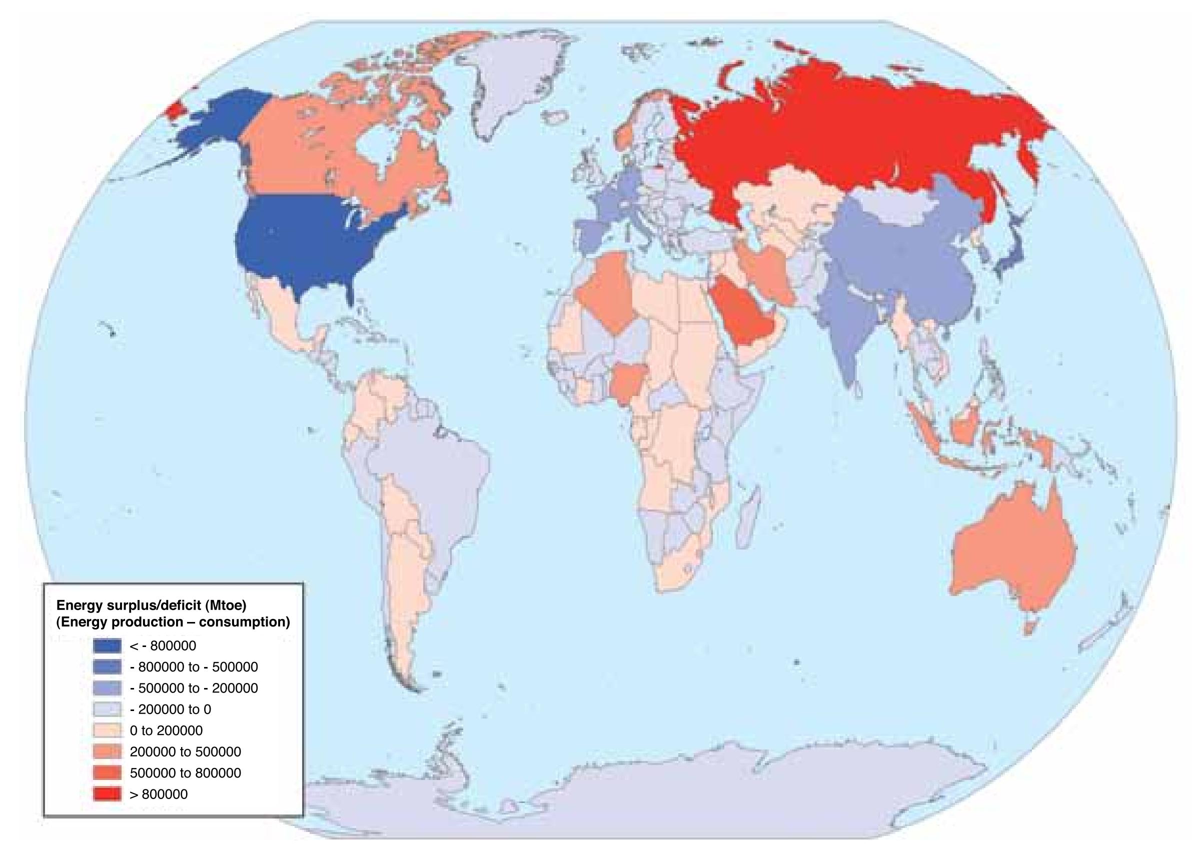
4.2.1 Petroleum, gas, and electricity

The potential risks to international infrastructure for energy transportation that could affect the UK were discussed in Section 4.1.4. Climate change may also pose problems for the extraction of imported petroleum and gas, and the generation of imported electricity on which the UK and many other countries depend. In 2006, the USA, Japan, China and Europe had energy deficits, and the UK was a net

75 By the end of 2005 less than 10% of total oil refining capacity remained offline.
76 R:6.1 (Annex B refers).
77 US Congress (2006). *A Failure of Initiative: Select Bipartisan Committee Investigation in the Preparation and Response for Hurricane Katrina*. Washington, DC: US Congress. Report available at: http://www.gpoaccess.gov/katrinareport/mainreport.pdf (last accessed 21/06/11).
78 R:6.1 (Annex B refers).
79 US Council of Economic Advisers (2006), *Economic Report of the President*. US Government Printing Office, Washington, DC. Available at: http://www.gpoaccess.gov/eop/2006/2006_erp.pdf (last accessed 21/06/11).
80 R:3 (Annex B refers).
81 More information on the model is available at: http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3 (last accessed 21/06/11).
82 R:3 (Annex B refers).
83 For information on ONS' SIC(92) classification system, see: http://www.statistics.gov.uk/methods_quality/sic/contents.asp (last accessed 21/06/11).
84 R:3 (Annex B refers).
85 For information on SIC(92), see: http://www.statistics.gov.uk/methods_quality/sic/contents.asp (last accessed 21/06/11).

energy importer. In contrast, countries such as Russia, Saudi Arabia and Canada had large energy surpluses (Figure 4.4).

Figure 4.4: Global energy surplus/deficits in 2006 (Mtoe), calculated from data on total energy production and total energy consumption from the US Energy Information Administration. UK area is expanded for clarity[86]



The current projection for the global energy sector over the next 20 years is broadly one of OECD countries curbing growth in their energy use while demand from developing nations is expected to increase considerably[87]. By 2030, $6.8 trillion (£3.4 trillion) worldwide investment in power generation may be required, alongside a further $4.5 trillion (£2.2 trillion) investment in additional capacity[88]. While renewables could potentially account for at least 25% of global energy by 2030, all of the IEA's World Energy Outlook suggests that fossil fuels will make up the majority of the global energy mix[89]. Although fossil fuels occupy a diminishing share of the UK energy mix, declining domestic production will mean the UK will be increasingly dependent on imported gas and oil throughout the first half of this century[90]. Even if the UK were to meet the target of an 80% emissions reduction by 2050, there will still be a need for fossil fuels; ranging from approximately 12% of supply where there is a large supply of renewable energy to 40% with limited global bioenergy availability[91]. The actual proportion and quantity of future fossil fuel use will depend on numerous factors, such as population and economic growth, behavioural change, and technological developments.

86 R:3 (Annex B refers).

87 OECD (2008) *Infrastructure to 2030*. Policy brief, available at: http://www.oecd.org/dataoecd/24/1/39996026.pdf (last accessed 21/06/11).

88 Figures based on 2007 dollar and the IEA Reference Scenario. IEA (2008) *World Energy Outlook*. Available at: http://www.iea.org/textbase/nppdf/free/2008/weo2008.pdf (last accessed 21/06/11). Conversions based on Her Majesty's Revenue & Customs' yearly average exchange rate for 2007, available at http://www.hmrc.gov.uk/exrate/yearly_rates.htm (last accessed 21/06/11).

89 IEA (2008) *World Energy Outlook*. Available at: http://www.iea.org/textbase/nppdf/free/2008/weo2008.pdf (last accessed 21/06/11).

90 Ofgem (2009). *Project Discovery: energy market scenarios*. London: Ofgem. Report available at: http://www.ofgem.gov.uk/Markets/WhlMkts/Discovery/Documents1/Discovery_Scenarios_ConDoc_FINAL.pdf (last accessed 21/06/11).

91 DECC (2010), *2050 Pathways Analysis*. Available at: http://www.decc.gov.uk/assets/decc/What%20we%20do/A%20low%20carbon%20UK/2050/216-2050-pathways-analysis-report.pdf (last accessed 21/06/11).

Petroleum and gas extraction

The direct impact of climate change on the extraction of petroleum and gas is likely to be less than for agricultural commodities[92]. However, sea level rise is likely to have an impact on coastal oil and gas facilities[93] (see Section 4.1.4). Any associated changes in ocean swell height or storm surges could bring an increased risk to rigs and infrastructure across the world by the 2040s, affecting off- and on-shore operations and resulting in a decrease in coastal oil extraction[94]. This risk will increase as sea levels continue to rise up to 2100 (more so under the medium emissions scenario than the aggressive mitigation scenario).

Historically, the oil and gas sector, which has very high water requirements, has operated on the assumption of ready access to a plentiful supply of freshwater[95]. Decreasing water availability and the increasing propensity for drought predicted for mid and semi-low latitudes could constrain the activities of oil and gas industries in these regions by the 2040s[96]. Alternative sources of fossil fuel also have very high water requirements. For example, estimates indicate that between 2 and 4.5 barrels of water are extracted from Canada's Athabasca River to produce one barrel of synthetic crude oil from oil sands[97]. Small positive impacts on operations may be experienced in Central and North Asia by the 2040s owing to rises in mean temperature, reducing the number of days that ice will form on the decks of offshore facilities[98]. However, up to the 2040s, climate change is likely to be only a minor factor influencing the security and price of oil and gas, which is likely to be more significantly affected by resource availability, technological and cultural change and geopolitical factors. Beyond the 2040s, global trade in oil and gas could alter dramatically as a result of changes to international policy, economic growth and technological developments, and, consequently, impacts beyond this period are difficult to predict[99].

Extreme weather events and decreasing availability of water adversely affects the extraction of petroleum and gas, resulting in a negative impact on prices in the UK and security of supply.

There is a further risk that the UK will fail to reduce its energy dependence on international markets. The UK and the EU's indigenous reserves of oil and gas are dwindling, and estimates suggest that the EU might need to import 65% of its energy by 2030[100]. Imported total energy in 2025 by the UK is predicted to rise to 47-50% of total consumption as North Sea gas and oil reserves decline[101]. Forecasts also suggest that global growth in oil production to 2035 will be strongly dominated by nationalised oil companies[102]. If impacts of climate change cause nations to pursue more protectionist policies, the supply of state-owned oil could be used to influence foreign policy and trade agreements (the use of oil to achieve national foreign policy goals is well documented[103]). Furthermore, as the UK's domestic sources of oil and gas decline, its sources of energy will become increasingly concentrated in unstable regions of the world such as the Middle East, which is predicted to dominate future production[104,105]. A growing mismatch between the location of oil and gas and regions with the highest energy requirements may

92 R:3 (Annex B refers).
93 *ibid.*
94 *ibid.*
95 Robinson, D. (2010). *Oil and gas: Water treatment in oil and gas production – does it matter?* Filtration and Separation **47**: 14-18.
96 R:3 (Annex B refers).
97 Canada National Energy Board (2006), *Canada's Oil Sands. Opportunities and challenges to 2015: an update*. Report available at: http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/lsnd/lsnd-eng.html (last accessed 21/06/11).
98 R:3 (Annex B refers).
99 *ibid.*, p169.
100 IEA (2008). *World Energy Outlook.* International Energy Agency. Report avaiable at: http://www.worldenergyoutlook.org/2008.asp (last accessed 21/06/11).
101 Wicks, M. (2009), *Energy Security: A national challenge in a changing world*, p.57. Report available at: http://www.decc.gov.uk/publications/ (last accessed 21/06/11).
102 IEA (2010). *World Energy Outlook*. International Energy Agency. Report avaiable at: http://www.worldenergyoutlook.org/2010.asp (last accessed 21/06/11).
103 Congressional Research Service (2007), *The Role of National Oil Companies in the International Oil Market*. CRS report for Congress, available at: http://www.fas.org/sgp/crs/misc/RL34137.pdf (last accessed 21/06/11).
104 Wicks, M. (2009), *Energy Security: A national challenge in a changing world*. Report available at: http://www.decc.gov.uk/publications/ (last accessed 21/06/11).
105 IEA (2008). *World Energy Outlook.* International Energy Agency.

lengthen supply chains, and thus increase the risk of disruption[106]. This could include, for example, the targeting of oil and gas infrastructure and transportation by terrorist groups[107], or physical disruption as a result of the changing climate (see Section 4.1.4). This consolidation of energy resources sourced from a decreasing number of regions presents new energy risks relating to price volatility, geopolitics, resource nationalism and physical disruptions to supply chains[108]. Some of these risks would be alleviated by a transition to a domestic, low-carbon energy-generating infrastructure.

The decline in global oil reserves and other fossil fuel supplies is independent of climate change. However, national and international agreements[109] to stabilise CO_2 emissions require the UK to move to a more carbon-neutral energy-generating system. Failure to achieve this, setting aside climate change goals, risks maintaining reliance on these increasingly limited resources, and exposes the UK to greater risk and instability in its energy networks[110].

Alternative sources of fossil fuels, such as shale gas and tar sands, could provide options to increase resilience and security of supply as conventional reserves decline over time. The USA is currently the only large-scale producer of shale gas[111], and forecasts suggest that shale gas will make up 45% of US dry gas production by 2035[112]. But assessments indicate that shale gas resources are available elsewhere, with 48 shale gas basins in 32 countries having the potential to boost gas reserves by 40%[113]. A report for the Department for Energy and Climate Change has noted that northern England is thought to have significant promising areas for exploitation, with the UK as a whole thought to have shale gas reserves of around 150 billion cubic metres (bcm), compared with only 2-6 bcm projected undiscovered onshore conventional gas reserves[114]. However, the same report notes that "*it is not clear that UK shales have the right rock properties to exploit for shale gas*"[115].

Failure to move to a low-carbon domestic energy system increasingly exposes the UK to fuel supply risks where these are sourced from unstable regions, and further increases reliance on vulnerable energy supply infrastructure.

Electricity imports

Alongside fossil fuels, supplies of electricity imported to the UK might be affected by climate change. In 2009 only about 1% of the UK's consumption was met by imported electricity (99% of which was from continental Europe)[116]. The extent of future electricity imports from France and elsewhere in Europe will be determined by the mix of energy sources and generation for UK consumption. A report from the UK Department of Energy and Climate Change[117] suggests that significant amounts of electricity could be imported from Europe and beyond via additional undersea interconnectors[118]. However, this analysis considers only the contribution of concentrated solar power, and not other energy sources.

106 DTI (2007), *Meeting the Energy Challenge: A White Paper on Energy*. Department for Trade and Industry. Available at: http://www.berr.gov.uk/files/file39387.pdf (last accessed 21/06/11).

107 Blanche, E. (2002), *Terror Attacks Threaten Gulf's Oil Routes*. Jane's Intelligence Review, **14**: 6-11.

108 Wicks, M. (2009). *Energy Security: A National Challenge in a Changing World*. London: DECC.

109 For example, the Climate Change Act (2008) and the adoption of the Kyoto Protocol in 1997.

110 DTI (2007), *Meeting the Energy Challenge: A White Paper on Energy*. Department for Trade and Industry. Available at: http://www.berr.gov.uk/files/file39387.pdf (last accessed 21/06/11).

111 IEA (2008), *World Energy Outlook 2008*. Report available at: http://www.worldenergyoutlook.org/2008.asp (last accessed 21/06/11).

112 US Energy Information Administration (2011), *Annual Energy Outlook 2011*. Available at: http://205.254.135.24/forecasts/aeo/ (last accessed 21/06/11).

113 US Energy Information Administration (2011). *World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States*. US Department of Energy, Washington. Report available at: http://www.eia.gov/analysis/studies/worldshalegas/ (last accessed 21/06/11).

114 DECC (2011). *The Unconventional Hydrocarbon Resources Of Britain's Onshore Basins – Shale Gas*. Report available at: https://www.og.decc.gov.uk/UKpromote/onshore_paper/UK_onshore_shalegas.pdf (last accessed 21/06/11).

115 *ibid*.

116 HMG (2010). *Digest of UK Energy Statistics. Chapter 5: Electricity*. Available at: http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx (last accessed 21/06/11).

117 HMG (2010), *2050 Pathways Analysis*. Available at: http://www.decc.gov.uk/assets/decc/What%20we%20do/A%20low%20carbon%20UK/2050/216-2050-pathways-analysis-report.pdf (last accessed 21/06/11).

118 More information on current and future planned interconnectors is available at: http://www.nationalgrid.com/uk/Interconnectors/ (last accessed 21/06/11).

Imports of electricity to the UK are primarily enabled by a link (the interconnector) between the UK's domestic electricity transmission system to the transmission system of France. France currently generates over 75% of its electricity using nuclear generation, and is the world's largest net electricity exporter[119]. This makes UK imports of electricity (admittedly small at present) particularly dependent upon nuclear generation and at risk from climate change impacts where operational problems occur[120].

In Europe (unlike the UK[121]), the majority of nuclear reactors are cooled using river water (Figure 4.5). During the 2003 European heat wave, French nuclear power stations were shut down as environmental safety levels for the temperature of cooling water outflows into rivers were exceeded in some areas, whereas in others, river levels fell so low that cooling became impossible. Special measures had to be introduced by the French Government to allow continued operation[122]. Buying energy from neighbouring markets to cover the ensuing shortfall cost Électricité de France (EDF) €320 million[123]. Moreover, had the heat wave continued, 30% of French domestic production would have been at risk[124]. By 2040, mean temperatures in France may be 2-3°C warmer than the mean for 1970-2000[125]. This increase would reduce the margins between normal operating temperatures and the environmental temperature levels for outflows[126]. Any change in rainfall-driven runoff resulting in lower average river levels would affect year-round availability of cooling water. Extreme temperatures during heat waves in France are expected to exceed those seen in 2003, increasing the likelihood of power station closures and disruptions to supply unless mitigating steps are taken. Such outcomes could affect the availability and price of electricity for import to the UK. If suitable adaptive engineering measures cannot be found (or have not been applied) to increase the cooling capacity of nuclear power stations, then by the 2040s some may be forced to operate at lower outputs. Governments might also need to consider more frequent special measures for temporarily relaxing operating temperature restrictions at affected plants[127].

119 World Nuclear Association (2010), Nuclear Power in France. Website is available at: http://www.world-nuclear.org/info/inf40.html (last accessed 21/06/11).

120 R:3 (Annex B refers).

121 All currently operating and future planned UK nuclear sites are sea- or estuary-cooled. More information is available at: http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/nuclear/nuclear.aspx (last accessed 21/06/11).

122 UN Environment Programme (2004), *Impacts of Summer 2003 Heat Wave in Europe*. Environment Alert Bulletin, available at: http://www.grid.unep.ch/product/publication/download/ew_heat_wave.en.pdf (last accessed 21/06/11).

123 EDF (2006). *2005 Document De Reference*. EDF Group, Paris. Available at: http://www.edf.com/html/finance/edf_ddr_2006_va.pdf (last accessed 21/06/11).

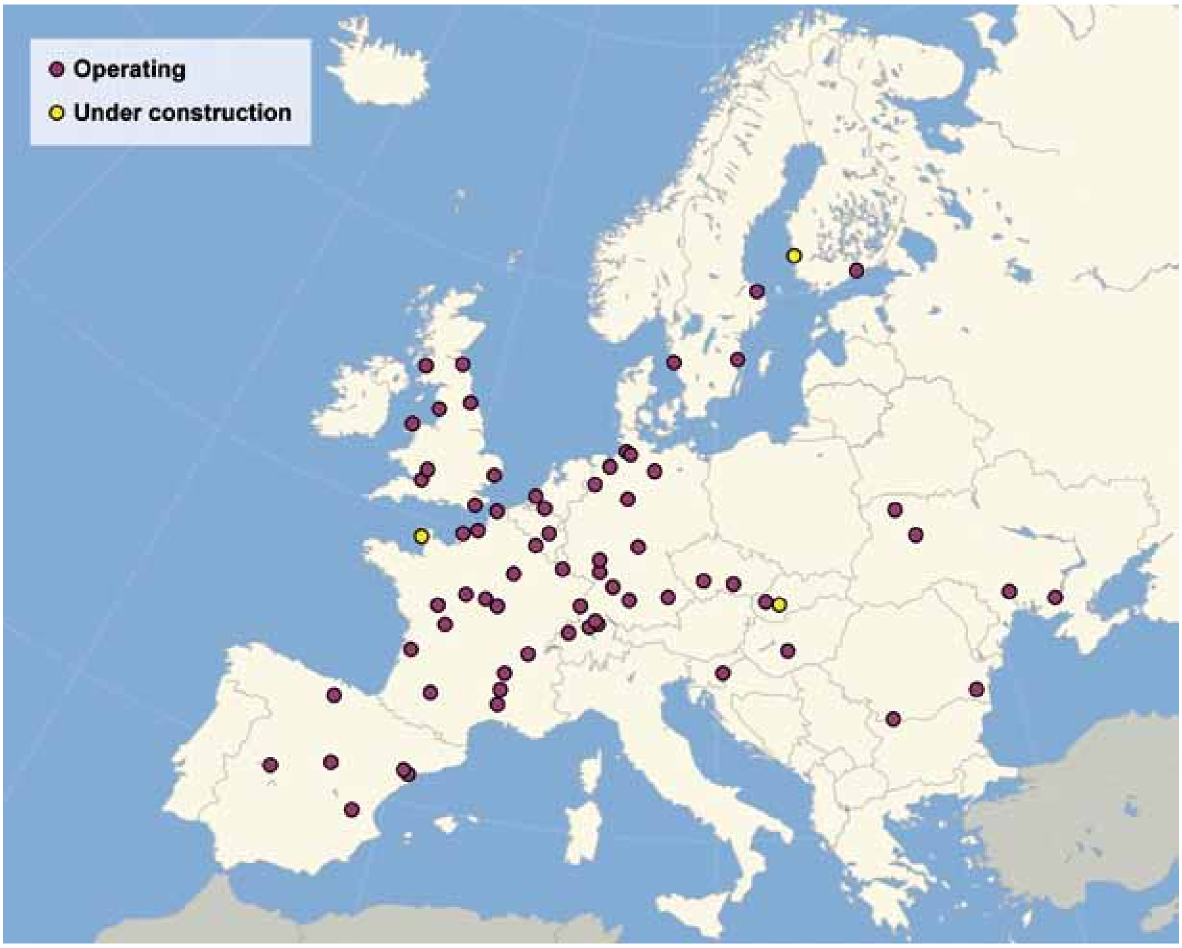
124 Letard, V., Flandre, H. & Lepeltier, S. (2004). *La France et les Francais face a la canicule: les lecons d'une crise*. Report No. 195 (2003-2004) to the Sénat, Government of France.

125 R:3 (Annex B refers).

126 *ibid*.

127 *ibid*.

Figure 4.5: Map of European nuclear power reactor sites, operational and under construction: many of these are inland and reliant on river-water cooling which could be vulnerable to climate-induced water shortages. Locations from the World Nuclear Association Reactor Database, available at: http://world-nuclear.org/NuclearDatabase/ (last accessed 23/03/11)[128].



Water is also important for renewable power generation, and the French and European energy markets have significant contributions from hydropower, with nearly 60% of European renewable electricity consumption in 2007 coming from this source[129]. Water availability for hydropower may be affected by climate change. By the 2040s, under the medium emissions scenario, mean precipitation over Southern Europe and the Mediterranean is expected to decrease and drought conditions are projected to be more frequent[130]; parts of the EU are forecast to experience decreases in their mean annual runoff by 2050[131]. The net impact could therefore be less water available for all uses, including power generation. However, increased melt from Alpine areas and more rapid snow melt in spring would increase seasonal river flows with consequent risks to hydropower dams on rivers fed by melt water[132]. Without careful management, water availability for power station cooling and hydropower generation could decrease by

128 Blank Map of Europe from Wikimedia Commons (Author: Ssolbergj), used under the Creative Commons Attribution-Share Alike 3.0 Unported license. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.3 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license may be found at: http://www.gnu.org/licenses/fdl.html (last accessed 21/06/11).

129 Not including pumped storage. EC (2010). *EU Energy and Transport in Figures. Statistical Pocketbook 2010.* Available at: http://ec.europa.eu/energy/publications/statistics/statistics_en.htm (last accessed 21/06/11).

130 R:3 (Annex B refers).

131 Strzepek, K. & Boehlert, B. (2010), *Competition for water for the food system*. Philosophical Transactions of the Royal Society B, **365**: 2927-2940. Driver review DR12 of the Foresight Global Food and Farming Futures project, available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

132 R:3 (Annex B refers).

the 2040s in the summer months, thus reducing available energy supplies[133]. Further increases in mean and extreme temperatures by 2100 would exacerbate these impacts[134].

As a consequence, an increase in extreme weather alongside other long-term climate changes could disrupt even low carbon energy generation[135], and potentially affect the levels and prices of supply of imported electricity from continental Europe. However, the development of a European "super grid", connecting low-carbon energy generation across the continent[136], may help mitigate this risk.

The price and security of supply of UK electricity imports from France and elsewhere in Europe are negatively affected by increases in mean and extreme temperatures, and increases in drought frequency and reductions in precipitation over Southern Europe and the Mediterranean.

4.2.2 Agriculture

Some of the largest impacts of climate change are likely to occur in agricultural commodities, where, for some crop types, there is likely to be a mix of positive and negative impacts by the 2040s[137]. The 2011 Foresight Report *The Future of Food and Farming* (Box 4.3) found that the extent to which a rise in atmospheric concentrations of CO_2 will interact with plant physiology and so affect agricultural productivity is highly uncertain[138]. Some studies have indicated that some plants (known as C3 plants, including wheat, rice, soya, potatoes and oilseed rape) are able to benefit physiologically from higher concentrations of CO_2 in the atmosphere[139], independent of other environmental conditions. Any benefits from CO_2 will only occur if plant growth is not limited by other factors, including water and nutrient availability, as well as biotic stress caused by pest attack, diseases and competition from weeds[140]. Other possible benefits, strongly influenced by location and existing conditions, include the expansion of areas suitable for crop production, longer growing seasons, and, for some regions, potential increases in rainfall.

133 *ibid.*, p.172.

134 *ibid.*, p.172.

135 R:3 (Annex B refers).

136 MacIlwain, C. (2010), *Supergrid*. Nature, **468**: 624-625.

137 R:3 (Annex B refers).

138 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability*. Synthesis Report C2: *Changing pressures on food production systems*, p22. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

139 Long, S.P., Ainsworth, E.A., Rogers, A. & Ort, D.R. (2004), *Rising atmospheric carbon dioxide: Plants face the future*. Annual Review of Plant Biology, **55**: 591-628.

140 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability*. Synthesis Report C2: *Changing pressures on food production systems*, p26-27. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

Box 4.3 The Future of Food and Farming

The Foresight Future of Food and Farming Report[141], published in January 2011, argues that urgent action is needed to ensure that an estimated 9 billion people in 2050 can be fed. It found that:

- **The current food system is failing**. It is unsustainable, and there are currently a billion hungry people, a billion people suffering from "hidden hunger" (not having enough vitamins and minerals), and a billion people who are over-consuming.
- **The era of cheap food is over**. Food prices will increasingly need to take account of the full cost to the environment, and the consumption of natural resources.
- **Multiple threats are converging on the food system.** The increasingly prosperous BRICs (and others), population growth, availability of water, energy and land, as well as climate change, are all having an impact on global food production.
- **The food system is more than just about feeding people.** A failing food system can reduce social mobility, increase social tension, fuel migration and conflict, and degrade the environment. These other factors must all be considered in any redesign of the global food system.
- **Substantial changes will be required** throughout food and water systems, such as energy use, sharing water and addressing climate change. Sustainable intensification of agricultural production needs to be embedded in policies and practices throughout high-, middle- and low-income countries. Technological adaptations will be essential, and no one technology should be rejected *a priori*.

However, benefits will be more than offset by some of the predicted negative impacts of climate change, such as changes in precipitation patterns, more frequent droughts in some regions, increased stress in crop, animal and fish production systems in response to extremes in temperature, and the reduced reliability of water availability[142]. It has been proposed that, by 2050, there will be, on average, 18% less water available worldwide for agriculture[143], due to pressures from environmental flow requirements (EFR), and municipal and industrial water demands.

Beyond the 2040s, the negative consequences of climate change on agriculture are expected to become increasingly significant, particularly the effects of extremes of heat and water availability. Sea level rise and any changes in the intensity of storms could also have serious consequences for agricultural productivity. In the short term, climate change could affect the security of supply and price of some agricultural commodities more than others, and this may encourage nations to protect their own agricultural markets through subsidies or export bans. For example, the Met Office assessment commissioned for this project[144] highlights the particular sensitivity of rice crops to climate change, compared with more temperate crops such as wheat and barley. Some regions that are currently very suitable for particular crops, such as the warm, wet conditions found in Southeast Asia for rice cultivation (in 2008, around a third of global rice production was from India and Bangladesh[145]), may not be so in the future, while other areas could become more suitable for these crops as regional temperatures increase and precipitation patterns change.

Natural variability of the climate may continue to cause fluctuations in agricultural commodity prices[146], leading to sharp fluctuations in food production. Food price volatility would be exacerbated if some countries focused on more immediate national concerns, and implemented protectionist responses that inhibit usual market adjustments. This was the outcome of the Russian ban on exporting wheat from

141 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability.* Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

142 R:3 (Annex B refers).

143 Strzepek, K. & Boehlert, B. (2010), *Competition for water for the food system.* Philosophical Transactions of the Royal Society B. **365**; 2927-2940. Review commissioned for the UK Government's Foresight Global Food and Farming Futures project.

144 R:3 (Annex B refers).

145 UN Food and Agriculture Organization statistics (countries sorted by commodity) available at: http://faostat.fao.org/site/339/default.aspx (last accessed 21/06/11).

146 R:3 (Annex B refers).

August to December 2010, which followed a severe drought and wildfires[147]. Periods of food price volatility disproportionately affect low-income countries and poor communities in all countries[148]. Between 2005 and 2009, the rate of increase in hunger jumped to 25 million per year, and the number of hungry people reached 915 million in 2009[149]. By the beginning of 2010 this figure was 1.02 billion, before falling back to 925 million[150]. Malnutrition on this scale, and any future potential increases[151], is likely to have significant impacts on UK humanitarian aid provision, and may interact with other drivers triggering localised unrest, requiring UK peacekeeping or stabilisation interventions (see Section 3.1.2).

As temperatures increase globally up to 2040, potential negative impacts are likely to include increases in heat stress in livestock, particularly during transportation. However, in some areas, such as Canada, regions of China and some parts of Europe, this impact is likely to be offset by decreases in the very coldest temperatures, which have an adverse effect on livestock[152]. Water availability is also important for livestock, and although changes in precipitation are uncertain, there is potential for water stress to limit livestock production in some areas, particularly Brazil, where there is some evidence from climate modelling for reduced precipitation and increased drought[153]. Sea level rise may also have a negative impact on livestock production where grazing land is situated in coastal regions. Changes in precipitation and water availability are projected to become more severe out to 2100, with an even stronger signal for drying over Brazil[154]. These changes are present in both the medium emissions and aggressive mitigation scenarios, although more severe in the case of the former.

Agricultural pathogens, parasites and pests are also likely to be affected by climate change. Although poorly understood, there is evidence that climate change is changing disease distributions and their severity, as species are stressed by rising temperatures[155]. For example, higher concentrations of atmospheric CO_2 increases the risk of fungal infection with rice blast, and sheath blight, affecting crop production[156]. In livestock, modelling shows that some areas of sub-Saharan Africa are becoming increasingly suitable for the tick-borne disease East Coast Fever, one of the most significant in Africa, killing 1.1 million cattle and causing losses of $168 million each year[157]. Predicted temperature increases are also likely to enhance the potential insect damage on vegetation growth and productivity in Europe[158].

Implications for the UK

The implications for the UK of climate change on global agriculture need to be viewed in the context of other drivers of change. As set out in the Foresight report[159], up to the mid-century, the global food system will need to make significant changes to address not only climate change but a confluence of

147 *Russia grain export ban sparks price fears*, Financial Times, 05/08/10. Available at: http://www.ft.com/cms/s/0/485c93ae-a06f-11df-a669-00144feabdc0.html (last accessed 21/06/11).

148 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability. Executive Summary*. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

149 *ibid.*

150 *ibid.*

151 The Foresight *Future of Food and Farming* report identifies six key drivers acting on the future food system, all of which may impact on future levels of hunger and malnutrition: i) Global population increases; ii) Changes in size and nature of per capita demand; iii) Future governance of the food system at both national and international levels; iv) Climate change; v) Competition for key resources; and vi) Changes in values and ethical stances of consumers. In-depth analysis of the future of global hunger may be found in: Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability. Executive Summary*. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

152 R:3 (Annex B refers).

153 *ibid.*

154 *ibid.*

155 Campbell, A., *et al.* (2009). *Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation*. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series No. 42, 124 pages.

156 Kobayashi T *et al.* (2006). *Effects of elevated atmospheric CO_2 concentration on the infection of rice blast and sheath blight.* Phytopathology **96**: 425–431.

157 Olwoch, J.M. *et al.* (2008). *Climate change and the tick-borne disease, Theileriosis (East Coast Fever) in sub-Saharan Africa*. Journal of Arid Environments, **72**: 108-120.

158 Wolf, A. (2008). *Impact of non-outbreak insect damage on vegetation in Northern Europe will be greater than expected during a changing climate*. Climatic Change, **87**: 91-106.

159 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability. Executive Summary*. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

pressures including: global population increases; changes in size and nature of per capita demand; future governance of the food system at both national and international levels; competition for key resources; and changes in values and ethical stances of consumers.

Modelling carried out for this project[160] suggests that, out to the 2040s, there will be a mix of positive and negative impacts on agriculture as a result of climate change[161], and that over this timescale other drivers of change are likely to be the source of major impacts on UK agricultural imports. However, if periods of price volatility or food shortages trigger regional crises or tensions, the UK is likely to be affected indirectly through its role in international aid provision, humanitarian assistance and peacekeeping interventions.

Beyond the 2040s, climate change's projected negative impacts, particularly extremes of heat and water availability, become increasingly important. Whether future changes will affect security of supply and price of agricultural commodities to the UK is unclear because of the complexity of change and length of timescales involved[162].

The negative effects of climate change, such as a growing frequency and duration of extreme weather events and reduced water availability, have an adverse impact on global agricultural production. This affects both the level and volatility of global agricultural prices, and in turn the security of supply and price of imported UK agricultural commodities, while increasing the requirement for UK aid and assistance.

4.2.3 Fishing and aquaculture[163]

The UN Food and Agriculture Organization estimated that in 2007, fish was responsible for 15.7% of global daily protein intake[164]. In low-income food-deficient countries (LIFDCs)[165], this figure was 20.1% in 2010, and considerably more in countries with high fish dependency[166]. Global marine capture fisheries are thought to be very near their maximum productive capacity[167], but global demand is predicted to rise along with expanding populations and incomes[168]. Climate change has the potential to have serious impacts on fishing and aquaculture[169,170]: rising atmospheric CO_2 will increase ocean acidification, which can affect breeding cycles, shell and skeleton formation, and the development of plankton, small organisms essential in aquatic food chains[171]. The impact of acidification on individual species will vary and is not yet well understood, and the consequence for marine ecosystems as a whole is subject to substantial uncertainty[172]. Warming of the oceans and other aquatic bodies also has potentially severe consequences for both farmed and wild fish production. Changing temperatures and locations of warmer

160 R:3 (Annex B refers).

161 *ibid*.

162 *ibid*.

163 Aquaculture is understood to be the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants.

164 UN FAO (2010), *The State of World Fisheries and Aquaculture 2010*. Report available at: http://www.fao.org/docrep/013/i1820e/i1820e00.htm (last accessed 21/06/11).

165 Definition and list of current LIFDCs may be found at: http://www.fao.org/countryprofiles/lifdc.asp (last accessed 21/06/11).

166 UN FAO (2010), *The State of World Fisheries and Aquaculture 2010*. Report available at: http://www.fao.org/docrep/013/i1820e/i1820e00.htm (last accessed 21/06/11).

167 NRC (2006), *Dynamic changes in marine ecosystems: fishing, food webs and future options*. Washington, DC: National Research Council. Available at: http://www.nap.edu/catalog.php?record_id=11608 (last accessed 21/06/11).

168 Garcia, S.M. & Rosenberg, A.A. (2010), *Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives*. Philosophical Transactions of the Royal Society B. **365**: 2869-2880. Driver review commissioned for the UK Government's Foresight Global Food and Farming Futures project.

169 FAO (2009). *Report of the Expert Workshop on Climate Change Implications for Fisheries and Aquaculture*. Rome, Italy, 6-9 April 2008. *FAO Fisheries Report*. Available at: http://www.fao.org/docrep/011/i0203e/i0203e00.htm (last accessed 21/06/11).

170 Perry, R.I (2011). *Potential impacts of climate change on marine capture fisheries: an update*. Journal of Agricultural Science, **149**: 63-75

171 Troccoli, A. (2008). *Users requirements capture*. European Coastal-shelf sea operational observing and forecasting system integrated project (ECOOP IP), Deliverable report ECOOP WP09-02, EU FP6 Contract No. 036355.

172 R:3 (Annex B refers).

or cooler water influence the location of food sources, early survival, later feeding and growth, and migratory movements, and sudden temperature changes can lead to heavy mortalities[173,174].

Climate change effects on ocean circulation can be particularly important, as shown by the example of the El Niño Southern Oscillation (ENSO), a natural climate phenomenon associated with fluctuations of sea surface temperatures in the Pacific Ocean, and their effects on fisheries. Species such as the Chilean jack mackerel, and the Peruvian anchovy, an important source of fishmeal and fish oil, show significant fluctuation in catch associated with El Niño events[175,176]. The possible amplification of such effects, or an increase in their frequency, could have a substantially negative impact, not just on regional food supply and exports, but also on global markets for fishmeal and fish oil, on which aquaculture is heavily dependent.

In inland and coastal areas, changing patterns of freshwater runoff, droughts and floods, and rising sea levels, together with impacts on infrastructure described earlier, all have the potential to have a significant effect on fisheries and aquaculture, and on post-harvest and distribution networks[177]. Inland fisheries are particularly vulnerable to low water levels, changes in spawning grounds, water abstraction and modifications to river courses, including dam construction. Aquaculture is heavily dependent on adequate water exchange, and vulnerable to temperature extremes, and, in coastal areas, to storm damage.

The effects of acidification of the oceans, changing hydrological balances, and temperature changes are progressive and long term, and the impacts beyond the 2040s under the medium emissions scenario are likely to be increasingly severe depending on the ability of individual species, ecosystems and aquaculture methods to cope and adapt. Given high levels of dependence of some communities and economies, there may be limited potential for adaptation. The location of sites for aquaculture and production approaches can be modified, but impacts on wild fisheries, though potentially serious, are far less understood.

One potential adaptation measure would be to increase the proportion of farmed fish, as this is, in any case, likely to be required to meet growing food demand. However, the close linkages with wild fish as a primary food source farmed fish[178] need to be considered, and though this dependence has greatly reduced and is likely to fall further, there may be constraints in some aquaculture sectors[179].

Implications for the UK

The UK imports 4-5% of the global fish exports[180]. Currently, only a very small amount of the UK's traded fish are farmed, with the majority of imports coming from wild fish stocks (in 2008, UK capture fishing imports totalled £367 million, and farmed fish £11 million[181]), though UK aquaculture exports, mainly to Europe, are significant and could be affected by competing supplies into these markets. Important UK fishery exports to Europe may be subject to similar effects. Analysis carried out for this Report suggests that by 2050, many of the biggest exporters of fish and aquaculture products[182], such as China, South East Asia and the USA, appear likely to be negatively affected by increases in ocean temperature, acidification and sea level rise[183]. The ability of capture fisheries stocks, or indeed the wider

173 Troccoli, A. (2008). *User requirements capture*. European Coastal-shelf sea operational observing and forecasting system integrated project (ECOOP IP), Deliverable report ECOOP WP09-02, EU FP6 Contract No. 036355.

174 Gai, N. S. & Taylor, P. (2006). *Impact of the use of meteorological and Climatological data on fisheries and aquaculture*. *CAgM Report No. 100*, Commission for Agricultural Meteorology, World Meteorological Organization, WMO/TD No. 1342, 32pp. Available at: http://www.wmo.int/pages/prog/wcp/agm/publications/cagm_reports.html (last accessed 21/06/11).

175 Peña-Torres, J., Agostini, C. & Vergara, S. (2007), *Fish stock endogeneity in a harvest function: 'El Niño' effects on the Chilean jack mackerel fishery*. Revista de Analisis Economico – Economic Analysis Review, **22**: 75-99.

176 R:3 (Annex B refers).

177 FAO (2009) *Report of the Expert Workshop on Climate Change Implications for Fisheries and Aquaculture*. Rome, Italy, 6–9 April 2008. *FAO Fisheries Report*. Available at: http://www.fao.org/docrep/011/i0203e/i0203e00.htm (last accessed 21/06/11).

178 R:3 (Annex B refers).

179 Garcia, S.M. & Rosenberg, A.A. (2010), *Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives*. Philosophical Transactions of the Royal Society B. **365**: 2869-2880. Driver review commissioned for the UK Government's Foresight Global Food and Farming Futures project.

180 R:3 (Annex B refers).

181 *ibid*.

182 The ONS Standard Industrial Classification (SIC) code used in the export and import analysis supporting this Report incorporates data on "fishing" and "operations of fish hatcheries and farms". See R:3 (Annex B refers).

183 R:3 (Annex B refers).

ecosystems from which aquatic foods are derived, to adapt to the combined impacts of climate change is unknown, but with timescales shorter than evolutionary change, considerable changes in species composition, spatial distribution and stock vulnerability to fishing pressure are likely to occur.

The full impact for the UK of changes in fish yields by the 2040s can only be assessed in the context of other changes. For example, in some regions fish stocks are already over-exploited. The impacts of fuel and energy prices could also be very significant, particularly if fishing effort has to increase and/or fishing areas are further away from established ports and processing facilities. While improvements in fisheries management may counter some of the more negative aspects, the potential for capture fishing to adapt would be much more limited than for aquaculture or for other food and farming processes, and climate change impacts could therefore pose a significant threat to the security of supply and price of fish imports[184].

However, a greater threat may involve wider issues of food supply and political security. As noted above, LIFDCs are much more heavily reliant than other countries on fish and fish products for income and daily protein intake. More generally, Asia also has a higher reliance (23.3% daily animal protein intake) than the average for LIFDCs (20.6%)[185], particularly in countries such as Bangladesh and Sri Lanka, where, between 2000 and 2006, 46-58% of daily protein intake was derived from fish and fishery products, and possibly more in rural areas[186,187]. Hence, while it is not possible to predict from the emissions scenarios which communities will be affected by declining marine fish stocks, it is reasonable to expect that those regions currently highly reliant on fish and fish products, such as Asian LIFDCs, are most at risk. This threat has the potential to increase social and economic vulnerability, as well as having significant implications for public health and nutrition, depending on the extent to which other options are available.

The effects of ocean acidification, hydrological changes and temperature variations are likely to have an increasingly negative impact upon fisheries and create constraints for future growth in aquaculture, exacerbating other pressures on fish stocks and ecosystems and dependent communities overseas. This outcome affects the security of supply and price of imported fish to the UK.

4.2.4 Rare earth elements

The future supply of rare earth elements has become a recent focus of attention. They are vital components of some communications-related infrastructure, and they are important for a number of technological applications, including use in some semiconductors and technologies associated with low-carbon applications (such as magnets and batteries for electric motors). Extraction of the metals is often very difficult and has recently consolidated in a small number of mines, particularly in China[188]. Despite their name they are fairly ubiquitous, being found in low concentrations in many countries. China dominates the global supply because of economic, rather than physical, factors and currently supplies about 95% of global demand[189]. However, it is unlikely that much meaningful insight into the security of supply or price of rare earth elements would be obtained by isolating climate change impacts beyond the existing analysis for all mined materials from China. Economic drivers and international governance are likely to be far more critical[190], although climate change may act as a multiplier due to secondary effects. Were rare earth supplies interrupted for a long enough period it might become economically viable for new mines to open in other regions, and hence an interruption should be of only short-term concern. However, the use of rare earth metals in some applications of low-carbon technologies could lead to a global shift increasing demands for these metals. This could affect the potential of the UK to

184 R:3 (Annex B refers).

185 FAO (2005), *A review of stock enhancement practices in the inland water fisheries of Asia*. RAP Publication 2005/12. Available at: http://www.fao.org/docrep/008/ae932e/ae932e02.htm (last accessed 21/06/11).

186 National Aquatic Resources Research & Development Agency (2007), *Sri Lanka Fisheries Year Book 2007*. Available at: http://www.nara.ac.lk/Year%20Book-2007/index.html (last accessed 21/06/11).

187 FAO (2005), *A review of stock enhancement practices in the inland water fisheries of Asia*. RAP Publication 2005/12. Available at: http://www.fao.org/docrep/008/ae932e/ae932e02.htm (last accessed 21/06/11).

188 European Commission (2010), *Critical raw materials for the EU: Report of the Ad-Hoc Working Group on defining critical raw materials*. Available at: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf (last accessed 21/06/11).

189 Haxel, G., Hedrick, J. & Orris, J. (2006). *Rare earth elements critical resources for high technology*. Reston (VA): United States Geological Survey. USGS Fact Sheet: 087:02. Available at: http://pubs.usgs.gov/fs/2002/fs087-02/fs087-02.pdf (last accessed 21/06/11).

190 R:3 (Annex B refers).

meet its low-carbon targets by constraining options for manufacture of low-carbon technologies, as well as restricting production in those countries that currently supply them (see Chapter 5).

Although climate change effects are unlikely to have a large impact upon the extraction of rare earth elements, lack of security of supply could impact on the UK's ability to employ low-carbon technologies and meet low-carbon aims.

4.2.5 Manufacturing

The UK has had a generally expanding trade deficit of goods (in value) since the early 1980s[191]. The UK is therefore increasingly reliant on overseas manufacturing. Manufacturing processes typically require a secure energy supply, water and a transportation network. This section treats manufacturing as a whole and assesses the risks posed to these requirements by climate change.

Security of energy supply depends not only on the climate change impacts that could occur in any given region, but also on the individual energy mix of countries within that region. For most methods of energy production there is a relationship between efficiency and temperature, with the cooling of power plants affected by both high temperatures and availability of water[192]. In many regions where manufacturing takes place, temperature increases by the 2040s could affect security of the electricity supply by reducing the operating efficiency of power stations. Regional transportation could also be affected by increases in temperature through the melting of road surfaces or the buckling of rail tracks[192]. For countries such as Russia, the thawing of permafrost has the potential to undermine transportation infrastructure[192]. Sea level rise will affect ports (see Section 4.1.2) and may damage wider coastal infrastructure as a result of storm surges and coastal erosion[193]. However, it is likely that coastal regions with large amounts of critical infrastructure, or areas of high manufacturing capability, will be protected where possible. This is likely to be nation-specific, and will be based on the ability of individual nations or regions to invest in adaptation measures. Areas with little infrastructure or economic worth, or those simply too expensive to protect or adapt, may (in the long term) need to be abandoned[193]. Hence, any interruption in manufacturing due to coastal flooding is likely to be sporadic, if increasingly common.

As discussed earlier, water security is likely to become an increasingly important issue in many regions of the world. In 2000, municipal and industrial water use was 4.3% of global total mean annual runoff, compared with 10.3% for agriculture[194]. Industrial requirements for water are predicted to increase by more than 200% in developing countries by 2050[195]. Water security also has a great impact on societal health and wellbeing (see Section 4.3). In general, potential changes in precipitation at regional levels are harder to predict than changes in temperature, but by the 2040s, under the medium emissions scenario, some regions, such as Brazil, Southern Africa, Eastern Australia and the Mediterranean, show weak signals in climate models for decreases in precipitation[196]. In countries such as China and India, which rely on glaciers for some of their water resource, there will be issues with security of supply if those glaciers melt[197]. The glaciers act as a water store and provide a constant and reliable source of water. Over time, these regions are expected to become increasingly dependent on annual rainfall, which may vary considerably from year to year.

Rising demands for water from industry in the 2050s, as well as pressure to maintain environmental flow requirements[198] could directly affect the ability of affected countries to run manufacturing operations

191 Office for National Statistics BOKI series – Trade in goods (balance). Available at: http://www.statistics.gov.uk/statbase/tsdataset.asp?vlnk=375&More=Y (last accessed 21/06/11).

192 R:3 (Annex B refers).

193 R:6.1 (Annex B refers).

194 Strzepek, K. & Boehlert, B. (2010), *Competition for water for the agricultural system*. Philosophical Transactions of the Royal Society B, **365**: 2927-2940. Driver Review DR12 of the Foresight *Global Food and Farming Futures* report, available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

195 *ibid*.

196 R:3 (Annex B refers).

197 *ibid*.

198 These are the minimum flows allocated for the maintenance of aquatic ecosystem services. Strzepek, K. & Boehlert, B. (2010), *Competition for water for the agricultural system*. Philosophical Transactions of the Royal Society B, **365**: 2927-2940. Driver Review DR12 of the Foresight Global Food and Farming Futures report, available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

(such as textile and paper mills, steel works and others) and conduct business, while also maintaining the significant flow requirements of agriculture in countries requiring increasing amounts of food as populations increase[199].

Overall, the impacts of climate change are likely to present challenges to manufacturing in many regions, with increasing instability of water supply often being a key factor. However, the interaction between climate and manufacturing is extremely complicated and will also depend on the preparedness and resilience of individual countries to interruption or damage to power and water networks[200]. Manufactured products are by far the largest import group to the UK, accounting for about 4% of the total world exports of manufactured goods and chemicals. The main sources are Germany (~20% of UK imports by value), China (~15%), France (~10%) and the USA (~10%)[201], and any disruption to overseas manufacturing processes would have a negative impact on the UK's source and security of supply of manufactured goods.

Interruptions to energy supply, water and transportation caused by climate change increasingly subjects overseas manufacturing processes on which the UK relies to short-term interruption.

4.3 Health

The total global population is predicted to reach nine billion people by the middle of this century[202]. Much of this growth is predicted to occur in low-income countries and will exacerbate the current poor provision of healthcare services, food and water security, and shelter, all of which are likely to result in significantly reduced health and wellbeing[203].

The World Health Organization estimates that in 2000, climate change was responsible for 6% of global malaria cases, approximately 2.4% of global diarrhoea, and was implicated in 154,000 deaths[204]. Rising global temperatures could increase regional levels of pollutants, as well as potentially reducing crop yields (see Section 4.2.2) and hence increasing malnutrition[205]. Changing rainfall patterns causing localised droughts are likely to increase the occurrence of diarrhoea, while an increase in extreme weather and coastal flooding would be likely to lead to increased mortality, both from the event and from ensuing outbreaks of infectious disease[206].

There are a number of overseas health effects attributable to climate change which could directly or indirectly impact upon the UK and its health services, either through the arrival of affected individuals from overseas visiting, returning or migrating to the UK or through increased pressure on aid and humanitarian assistance provided by the UK (see Section 3.1.2). This section considers those effects but does not consider the domestic impacts of climate change on the health of UK citizens[207] as such, nor does it consider the health and wellbeing impacts arising from migration to the UK (Foresight will report separately on Global Environmental Migration in autumn 2011)[208].

199 Foresight (2011), *The Future of Food and Farming: Challenges and choices for global sustainability. Executive Summary*. Report available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications (last accessed 21/06/11).

200 R:3 (Annex B refers).

201 *ibid.*

202 Godfray, H.C.J., Beddington, J.R., Crute I.T., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. Science, **327**: 812-818.

203 Lancet/UCL (2009), *The Lancet Commissions: Managing the health effects of climate change*. The Lancet, **373**: 1693-1733.

204 WHO (2002), *The World Health Report 2002: Reducing risks, promoting healthy life*. World Health Organization: Geneva. Report available at: http://www.who.int/whr/2002/en/ (last accessed 21/06/11).

205 WHO (2009), *Protecting Health from Climate Change: Connecting Science, Policy and People*. World Health Organization: Geneva. Report available at: http://www.who.int/globalchange/publications/reports/9789241598880/en/index.html (last accessed 21/06/11).

206 *ibid.*

207 UK domestic health and wellbeing will be investigated in detail by the forthcoming Climate Change Risk Assessment. More information on the UK Climate Change Risk Assessment, including details of publication, is available at: http://www.defra.gov.uk/environment/climate/ (last accessed 21/06/11).

208 More information on the Foresight Global Environmental Migration report, due for publication in late 2011, is available at: http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-environmental-migration (last accessed 21/06/11).

Human movement

Possible population movement, such as migration due to gradual environmental change, displacement following extreme weather events, and resettlement as a consequence of mitigation and adaptation measures, may have a negative impact on population health. This could be due to sustained periods of impoverishment and the destruction of support networks, or to unsanitary conditions, which can increase exposure to infectious disease and chemical pollution, such as 'displacement' camps and under-developed urban areas[209]. Adverse psychological outcomes are well documented in the aftermaths of natural disasters, for example major depression and post-traumatic stress disorder[210]. Migration due to coastal change and sea-level rise could also lead to more mental illness in the affected populations[211].

Heatwaves

The European heatwave of 2003, which led to tens of thousands of excess deaths[212], is an example of the type of extreme high temperature event expected to become more common and severe as a result of climate change[213]. The main causes of illness and death during a heatwave are respiratory and cardiovascular diseases[214]. Some of this rise in mortality may be attributable to air pollution making respiratory symptoms worse, but the main contributor is the strain that extreme heat places on the heart, precipitating a cardiac event[215]. Living in urban areas (where temperatures are higher due to 'city heat islands') also puts people at greater risk[216].

Flooding

The effects of increased flooding could affect people's health in many ways, including deaths from drowning, injuries, electrocution, a risk of infectious disease, chemical contamination, longer term mental health issues, and exacerbation of pre-existing conditions and delayed treatment and healthcare delivery[217,218]. For example, the Pakistan flooding in 2010 highlighted the very significant health impacts of the floods, with estimations that around 5,000 people were killed or injured in the floods, while around 25% of health provision facilities were partially functional or not functioning at all. Approximately 10% of the total population was displaced leading to an increase in communicable diseases, disrupted management of chronic diseases and increased levels of mental stress[219].

Droughts

Droughts can have severe health impacts, in particular as a consequence of water and food scarcity and poor sanitation (increased by water scarcity). These impacts can create long-term endemic health problems associated with chronic malnutrition. A review of the Ethiopian famines[220], for example, points to malnutrition complicated by infectious disease as the main cause of increased mortality, with young

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209 R:1.1.1 (Annex B refers).

210 Galea, S. (2007), *The long-term health consequences of disasters and mass traumas*, Canadian Medical Association Journal, **176**: 1293-1294.

211 Page, L. A. & Howard, L. M. (2010), *The impact of climate change on mental health (but will mental health be discussed at Copenhagen?)*, Psychological Medicine, **40**: 177-180.

212 United Nations Environment Programme (2004). *Impacts of Summer 2003 Heat Wave in Europe*. Environment Alert Bulletin 2. Available from: http://www.grid.unep.ch/product/publication/download/ew_heat_wave.en.pdf (last accessed 21/06/11).

213 Intergovernmental Panel on Climate Change. Climate Change, 2007: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry ML, Canzani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Cambridge (UK) and New York (USA): Cambridge University Press.

214 Semenza, J.C., McCullough, J.E., Flanders, W.D., McGeehin, M.A. & Lumpkin, J.R. (1999). *Excess hospital admissions during the July 1995 heatwave in Chicago*. American Journal of Preventative Medicine, **16**: 269-277.

215 Havenith, G. (2001). *Individualized model of human thermoregulation for the stimulation of heat stress response*. Journal of Applied Physiology, **90**: 1943-1954.

216 Shimoda Y (2003), *Adaptation measures for climate change and the urban heat island in Japan's built environment*. Building Research and Information, **31**: 222-230

217 Ahern, M., Kovats, R.S., Wilkinson, P., Few, R. & Matthies, F. (2005), *Global health impacts of floods: epidemiologic evidence*. Epidemiol Rev; **27**:36-46.

218 Ohl, C. & Tapsell, S. (2000), *Flooding and Human Health*. British Medical Journal **321**; 1167-1168.

219 WHO (2011), *Pakistan Floods 2010: Early recovery plan for the health sector*. Report available at: http://www.who.int/hac/crises/pak/en/ (last accessed 21/06/11).

220 Taye, A., Haile Mariam, D. & Murray, V. (2010) *Interim report: Review of evidence of the health impact of famine in Ethiopia*. Perspectives in Public Health, **130**: 222-226.

children particularly vulnerable. Other health impacts were long-lasting, including restricted growth, negative effects on mental health development, and shortened life expectancy.

Water security

Availability of clean water is an essential element of domestic life, and has profound impacts on societal health and wellbeing. It has been estimated that approximately 1000 cubic metres of freshwater are required per person per year to avoid water stress. A lack of clean domestic water adversely affects health by causing acute and chronic infectious diarrhoea, as well as preventing effective personal hygiene[221]. Large numbers of regions around the world are experiencing water stress, which is predicted to increase[222]. As water security has been identified in earlier sections as an area of concern in a climate-changing world, it may represent significant threats to the health and wellbeing of significant numbers of people worldwide in the decades ahead.

Increased occurrence and severity of severe weather events has negative health implications for UK nationals based or travelling overseas, placing increased pressure on health services.

Infectious diseases

The distribution, incidence, and impact of infectious diseases overseas could be influenced by climate change, and in turn could have a negative impact on the UK in a number of ways. These would include implications for UK international aid budgets (in 2008/9 the UK gave £104 million to combat these diseases[223]), the UK overseas workforce, and the potential for introduction of new infectious diseases to the UK.

Rising global temperatures, changes in precipitation patterns and increased incidence of extreme weather will influence how and where infectious diseases develop. Vector-borne diseases, such as malaria and dengue, make a major contribution to the global burden of disease. Half of the world's population is at risk of malaria and estimates indicate that 243 million cases led to 863,000 deaths in 2008[224]. An increase in ambient temperature and rainfall is generally thought to increase breeding grounds for mosquitoes[225,226], although it is important to note that there are likely to be mixed effects on malaria[227], with observations that droughts have decreased incidence in Senegal and Niger over the last decade[228]. Recent evidence also suggests that non-climatic factors may be more important in the global spread of malaria[229]. Outbreaks of malaria in the UK as a result of climate change are predicted to be small[230]. Vector-borne diseases more generally are considered unlikely to present major burdens to UK health services[231], at least by 2080[232]. However, as the geographical spread of disease vectors is multi-factorial and complex, case-by-case analysis of diseases is required to identify those more likely to be affected by regional changes in climate[233].

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221 Hunter, P.R., MacDonald, A.M. & Carter, R.C. (2010), *Water supply and health*. PLoS Medicine, **7**: e1000361.

222 Lancet/UCL (2009), *The Lancet Commissions: Managing the health effects of climate change*. The Lancet, **373**: 1693-1733.

223 Comprising of 'Infectious disease control' (£69.1 million, sector code 12250) and 'Malaria control' (£35 million, sector code 12262) of DFID Bilateral Expenditure, Table A3 from the Additional Tables of the Statistics on International Development 2010 report (DfID).

224 WHO (2009), *World Malaria Report 2009*. Geneva: WHO. Report available at: http://www.who.int/malaria/world_malaria_report_2009/en/index.html (last accessed 21/06/11).

225 Bouma, M.J. & Dye, C. (1997), *Cycles of malaria associated with El Nino in Venezuela*. Journal of the American Medical Association; **278**: 1772-1774.

226 Depradine, C. & Lovell, E. (2004), *Climatological variables and the incidence of Dengue fever in Barbados*. International Journal of Environmental Health Research; **14**: 429-441.

227 IPCC (2007) Working Group 2. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. IPCC, Geneva, Switzerland, p393.

228 Mouchet, J., Faye, O., Juivez, J. & Manguin, S. (1996). *Drought and malaria retreat in the Sahel, west Africa*. Lancet; **348:**1735-1736.

229 Gething, P.W., Smith, D.L., Patil, A.P., Tatem, A.J., Snow, R.W. & Hay, S.I. (2010), *Climate change and the global malaria recession*. Nature, **465**: 342-346.

230 Health Protection Agency/Department of Health (2008), *Health Effects of Climate Change in the UK 2008: An update to the Department of Health report 2001/2002*. Available at: http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_080702 (last accessed 21/06/11).

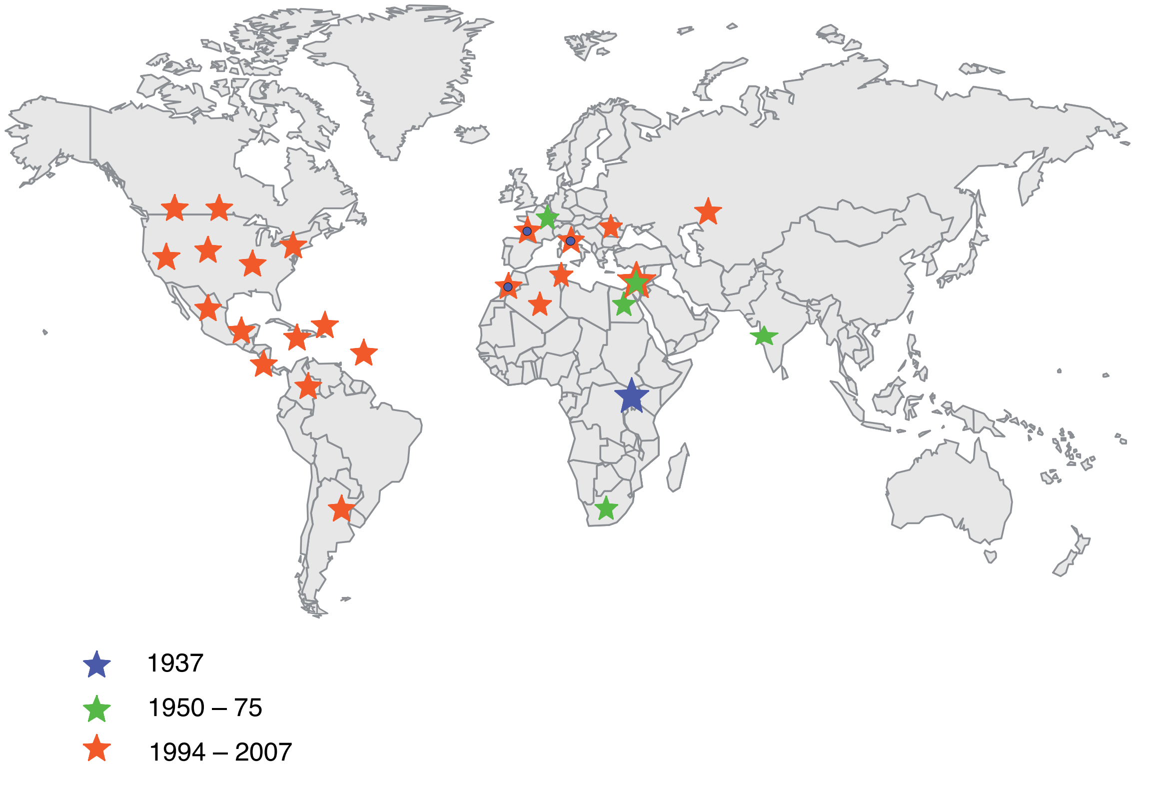
231 *ibid.*

232 Foresight (2006), *Infectious diseases: preparing for the future. Executive Summary*. Office of Science & Innovation: London. Available at: http://www.bis.gov.uk/foresight/our-work/projects/published-projects/infectious-diseases/reports-and-publications (last accessed 21/06/11).

233 Semenza, J.C. & Menne, B. (2009), *Climate change and infectious diseases in Europe*. Lancet Infectious Diseases, **9**: 365-375.

Climate change has been postulated as a potential cause (amongst others) for the expanding geographical distribution and increased epidemic activity of West Nile Virus (see Figure 4.6). This virus is largely transmitted by insects, with much of the expansion of activity thought to be caused by infected migrating birds flying from areas with known virus activity[234]. In 2008/9 increased West Nile Virus activity was reported in Southern Europe, including human cases in Italy, Hungary, and Romania[235].

Figure 4.6: Epidemics caused by West Nile virus, 1937–2006, associated with severe and fatal neurologic disease in humans, birds, and/or equines (reproduced with permission)[236]



In 2004, Kenya experienced an outbreak of Chikungunya fever, a viral infection that can cause prolonged and painful joint pain, and in rare cases can be fatal. In total, 13,500 people were infected[237]. Retrospective analysis linked this outbreak to severe drought conditions in the area[238]. Outbreaks of Rift Valley fever, a zoonotic virus capable of infecting livestock and humans, have been linked to heavy rain and flooding in East Africa as a result of the El Niño/Southern Oscillation periodic weather system[239]. With extreme weather events predicted to increase due to climate change[240], such outbreaks could be expected to become more common. Requests for medical aid would also rise as states struggle to cope with the increased health burden of these events.

234 Information from HPA website, available from: http://www.hpa.org.uk/Topics/InfectiousDiseases/InfectionsAZ/WestNileVirus/GeneralInformation/wnile01WestNileVirusGeneralInformation/ (last accessed 21/06/11).

235 *ibid.*

236 Gubler, D.J. (2007) *The Continuing Spread of West Nile Virus in the Western Hemisphere*. Clinical Infectious Diseases, **45**: 1039-1046.

237 Sergon, K. *et al.* (2008), *Seroprevalence of Chikungunya virus (CHIKV) infection on Lamu Island, Kenya, October 2004.* American Journal of Tropical Medicine and Hygiene, **78**: 333-337

238 Chretien, J.P. *et al.* (2007), *Drought-associated chikungunya emergence along coastal East Africa*. American Journal of Tropical Medicine and Hygiene, **76**: 405-407.

239 Chretien, J.P. *et al.* (2008), *Extreme weather and epidemics: Rift Valley fever and Chikungunya fever*. Part of *2. Climate, Ecology and Infectious Disease* in *Global Climate Change and Extreme Weather Events. Understanding the Contributions to Infectious Disease Emergence: Workshop Summary*. Institute of Medicine (US) Forum on Microbial Threats. Washington, DC: National Academies Press.

240 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p46.

It is anticipated that there may be an increased risk of diarrhoeal diseases in developing countries[241], arising from a combination of factors, but particularly because of shortages of clean water. Heavy rain and flooding can produce runoff with surface contaminants, leading to subsequent contamination of water supplies[242]. Droughts can also be associated with water-borne diseases because in some cases reductions in rainfall leads to low river flows and an increase in the concentration of pathogens[243].

Changes in the regional climate of Northern Europe may lead to an increased risk of the introduction of infectious diseases to the UK which are currently absent. This could be due to immigration and international travel, with the arrival of affected persons in the UK; a domestic outbreak, due to imported vectors (such as insects) or person-to-person spread; or through the import of contaminated food products to the UK ('autochthonous cases')[244]. However, it is important to note that the relevance of environmental change to patterns of disease depends on the susceptibility of local populations to the disease, the robustness of local food and water safety measures, vector control measures and communicable disease surveillance and control arrangements (e.g. vaccination programmes, legislation).

Increases in average temperatures and extreme weather events, as well as changing precipitation patterns, lead to increased transmission of infectious diseases to the UK.

241 McMichael AJ, Campbell-Lendrum D, Kovats S, Edwards S, Wilkinson P, Wilson T, Nicholls R, Hales S, Tanser F, Le Sueur D, Schlesinger M and Andronova N, (2004), *Chapter 20: Global climate change in WHO Comparative Quantification of Health Risks*. Geneva: WHO. Available from: http://www.who.int/healthinfo/global_burden_disease/cra/en/ (last accessed 21/06/11).

242 Intergovernmental Panel on Climate Change. *Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry ML, Canzani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. 2007. Cambridge (UK) and New York (USA), Cambridge University Press.

243 Senhorst HA, & Zwolsman JJ (2005), *Climate change and effects on water quality: a first impression*. Water Science and Technology; **51**: 53-59.

244 R:1.1.1 (Annex B refers).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5 Building on UK strengths

The previous two chapters discussed the threats to and challenges for the UK. Chapter 5 considers how the impacts of climate change overseas may present opportunities for the UK to build on its strengths and contribute towards global efforts to tackle climate change.

5 Building on UK strengths

The UK has made a long-term and challenging commitment to reduce its GHG emissions by 80% by 2050 in order to combat climate change. This long-term target set out in the Climate Change Act (2008) aims to provide a clear framework for business that will allow the UK low-carbon sector to thrive, ensuring that it will be well placed internationally. By taking the lead and making the economic advantages clear to others, the UK can encourage global action on climate change.

This chapter focuses on the potential of the UK to make a strong contribution to help the world tackle climate change by building on its strengths in research in key technologies such as wave and tidal energy, and in its global financial centre with unparalleled expertise in carbon trading and other financial instruments. Other opportunities that may present themselves are also discussed.

5.1 The UK's role in global governance

Climate change may affect the UK's international role, influencing how it operates and the partners it works with (see Chapter 3). By taking a lead on climate change, the UK can help ensure that the global policy agenda and international community is proactively combating climate change, as well as being effective in coping with its effects. The adoption of the Fourth Carbon Budget[1] by the Government in May 2011 marked the world's first legally-binding target on GHG emissions for the 2020s[2], and demonstrates the UK's commitment to global leadership in tackling climate change.

In a speech to the Council on Foreign Relations in September 2010, Foreign Secretary William Hague said in relation to the UK's security and prosperity that "*global action on climate change is essential to that agenda*". He argued that establishing coherent UK domestic and foreign policy on climate change was essential "*to ensure that our domestic action reflects our level of international ambition*"[3]. The UK has demonstrated its commitment to climate leadership not only through the adoption of the Fourth Carbon Budget (see above), but also in its commitment of £2.9 billion for climate finance to developing countries from 2011 to 2015, which puts it at the forefront of international donors[4].

Despite the failure of the 2009 UNFCCC summit at Copenhagen to agree a framework for mitigating climate change, the Cancun conference in 2010 has been viewed as restoring confidence in the UN as a forum where progress can be made. The UK continues to pursue a global agreement of a 'rules-based system' where nations agree a common approach to mitigating climate change, enforced through international regulation and supported by a global carbon market[5].

Although any global, legally binding agreement on climate change is likely to focus on the UNFCCC process[6], there are opportunities for the UK to influence regional policy on climate change through the EU (see Box 5.1), and globally through other alternative forums[7,8], including the Major Economies Forum, the Clean Energy Ministerial process which built on this, and the G20[9] (see Box 5.2). Although these

1 Committee on Climate Change (2010), The Fourth Carbon Budget: Reducing emissions through the 2020s. Available at: http://www.theccc.org.uk/reports/fourth-carbon-budget (last accessed 21/06/11).

2 Fourth Carbon Budget: Oral Ministerial Statement (Chris Huhne), 17/05/11. Available at: http://www.decc.gov.uk/en/content/cms/news/cb_oms/cb_oms.aspx (last accessed 21/06/11).

3 William Hague, UK Foreign Secretary. Speech entitled "The Diplomacy of Climate Change", given to the Council on Foreign Relations in New York on 27 September 2010. Available at: http://www.fco.gov.uk/en/news/latest-news/?view=Speech&id=22933444 (last accessed 21/06/11).

4 HM Treasury (2010), *Spending Review 2010*. HM Stationery Office: UK. Report available at: http://www.hm-treasury.gov.uk/spend_sr2010_documents.htm (last accessed 21/06/11).

5 R:8 (Annex B refers)

6 The Harvard Project on Climate Agreements (2010), *Institutions for International Climate Governance*. Policy Brief 2010-01. Available at: http://belfercenter.ksg.harvard.edu/files/HPCA-Policy-Brief-2010-01-Final.pdf (last accessed 21/06/11).

7 Bodansky, D. (2010), *The International Climate Change Regime: The Road from Copenhagen*. Policy brief, Harvard Project on International Climate Agreements, Belfer Center for Science and International Affairs, Harvard Kennedy School, October 2010. Available at: http://belfercenter.ksg.harvard.edu/files/Bodansky-VP-October-2010-3.pdf (last accessed 21/06/11).

8 Stavins, R. (2010), Another Copenhagen Outcome: Serious Questions About the Best Institutional Path Forward. Post on the "An Economic View of the Environment" blog. Belfer Center for Science and International Affairs, Harvard Kennedy School. January 2010. Available at: http://belfercenter.ksg.harvard.edu/analysis/stavins/?p=496 (last accessed 21/06/11).

9 The Harvard Project on Climate Agreements (2010). *Institutions for International Climate Governance*. Policy Brief 2010-01. Available at: http://belfercenter.ksg.harvard.edu/files/HPCA-Policy-Brief-2010-01-Final.pdf (last accessed 21/06/11).

forums lack the mandate and membership required to progress legal negotiations on a global agreement, the members account for over 80 per cent of global emissions[9]. Therefore any agreement between them to cut levels would be significant, and could be extended to the UNFCCC as a 'building block' towards a formal, global agreement[9]. Working through separate institutions and organisations that consider 'fragmented' elements of climate change policy is another possibility. For example, Norway is working in partnership with tropical low-income countries, as well as organisations such as the World Bank and United Nations (outside the UNFCCC), to develop co-operation on international policies on forest carbon[9].

Box 5.1 European climate change policy

The ability of the UK to respond to the challenges and opportunities identified in this Report is tightly bound with the UK's membership of the EU. The EU can act as a force multiplier, helping to deliver UK climate objectives within the EU (thereby protecting UK competitiveness), and influencing internationally. The EU Emissions Trading System (ETS)[10] will become the single most important driver of reduced emissions in the UK over the next decade and beyond.

In 2008, the EU made a commitment to reduce GHG emissions by 20% (from 1990 levels) by 2020. This will be mostly achieved through increased use of renewables, improved energy efficiency and ETS targets. In particular, the UK will be affected through[11]:

- **the EU Emissions Trading System Directive:** the main instrument for reducing CO_2 emissions in energy-intensive sectors. It will deliver two-thirds of the EU's GHG reduction commitments to 2020, and cover approximately 48% of the UK's national CO_2 emissions as well as accounting for two-thirds of the UK's first three carbon budgets[12].
- **the Greenhouse Gas Effort Sharing Decision:** sets reduction targets for those sectors not covered under the EU ETS (mainly transport and residential). This is a 16% reduction in emissions (from 2005 levels) by 2020 for the UK's non-ETS sectors.
- **the Renewables Directive:** sets member state targets for the proportion of energy generation from renewable sources[13]. The UK's legally binding target is 15% by 2020 – a seven-fold increase from 2008 levels of renewable energy consumption. Investment and job opportunities for the UK will also be created.
- **the Directive on the geological storage of CO_2:** outlines a regulatory framework for the capture and storage of CO_2 in the EU. The UK is committed to supporting four commercial-scale Carbon Capture and Storage (CCS) demonstration plants with up to £1 billion available for the first project[14].
- **funding schemes such as the European Energy Programme for Recovery (EEPR) and the New Entrants Reserve (NER).** Three UK projects have already received some funding from the EEPR, and applications for Carbon Capture and Storage and innovative renewables projects have been made to the NER scheme. The NER is a fund worth around €5 billion and successful projects will secure funding for up to 50% of their relevant costs over a specified time period.

10 Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance).

11 Information taken from DECC's website. Available from: http://www.decc.gov.uk/en/content/cms/what_we_do/change_energy/european/cepackage/cepackage.aspx (last accessed 15/04/2010).

12 Climate Change Act (2008). The Act may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

13 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

14 HM Treasury (2010), *Spending Review 2010*. Available from: http://cdn.hm-treasury.gov.uk/sr2010_completereport.pdf (last accessed 21/06/11).

Box 5.2 Alternative international forums

Opportunities for action also exist outside of the UNFCCC: for example, climate change is likely to have a significant impact on global health, influencing international health agreements and institutions[15]. At the 61st World Health Assembly in 2008, the 193 Member States of the World Health Organization (WHO) adopted a resolution on climate change and health, which called for intensified action to strengthen adaptation policies and plans, and asked the WHO to support these efforts through a working plan for scaling up the WHO's activities in this area[16,17]. There is an opportunity for the UK to use its experience of domestic climate change policy (e.g. the Climate Change Act (2008)[18], and the Climate Change Risk Assessment[19]) to provide leadership on a range of international health and public health issues to support the international community[20].

Another (possibly complementary) approach would be for the UK to extend more direct engagement with emerging powers and low-income countries on a bilateral or multilateral basis[21]. This is particularly important for countries that may feel a lack of representation within the international system, and who view key institutions (e.g. the UN, the IMF and the World Bank) sceptically because Western interests remain embedded in their articles and statutes[22,23]. In some respects the UK is in a more favourable position than many other high-income countries to take on this role because of its close working relations with like-minded states in the Commonwealth. The UK also has much to offer the developing world in terms of technology and financial expertise to decrease vulnerability to the worst consequences of climate change[24].

Whether through the UNFCCC, alternative forums, or bilateral or multilateral relationships, there is an opportunity for the UK to play a similar global role on adaptation as it has done with mitigation, where it has highlighted the need for action on emissions. The recent formulation of the 'Cancun Adaptation Framework' at the 2010 Conference is a clear sign that adaptation is becoming a more significant issue in the global effort to respond to climate change. The Framework aims to enhance international action on adaptation through the establishment of the Adaptation Committee to ensure that action by the UNFCCC is carried out in a coherent and focused manner. It also establishes a work programme "*to consider approaches to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change*"[25]. This growing movement to act on adapting to climate change offers an important prospect for the UK to contribute on global adaptation.

By taking an active role in particular aspects of mitigation and adaptation to global climate change, the UK can help other countries gain from its expertise and experience, and so influence international responses and organisations in a way that supports UK approaches and in which UK institutions and business sectors can thrive.

The UK can work with the international community through multiple institutional linkages with individual countries to tackle mitigation and adaptation challenges and, through leadership and example, shape international policy and direction.

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15 R:1.1.1 (Annex B refers).

16 WHO (2008), *World Health Assembly resolution WHA61.19 on climate change and health.* Geneva, World Health Organization. Available at: http://www.who.int/globalchange/A61_R19_en.pdf (last accessed 21/06/11).

17 WHO (2008), *Climate change and health. Report by the Secretariat.* Geneva, World Health Organization (document EB124/11).

18 The Climate Change Act (2008) may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

19 CCRA homepage available at: http://www.defra.gov.uk/environment/climate/adaptation/ccra/index.htm (last accessed 21/06/11).

20 WHO (2008), *World Health Assembly resolution WHA61.19 on climate change and health.* Geneva, World Health Organization.

21 R:2 (Annex B refers).

22 Held, D., Kaldor, M. & Quah, D. (2010), *The Hydra-Headed Crisis – pamphlet produced by LSE Global Governance.* Available at: http://www.lse.ac.uk/Depts//global/5publications2.htm (last accessed 21/06/11).

23 Saxer, M. (2010), *The Comeback of Global Governance. Ways Out of the Crisis of Multilateral Structures, Dialogue on Globalisation Briefing Papers, 2009.* Available from: http://www.fes-globalization.org/dog_publications/global_governance.htm (last accessed 21/06/11).

24 R:2 (Annex B refers).

25 UNFCCC (2010), *Outcome of the work of the Ad Hoc Working Group on long-term Cooperative Action under the Convention.* Available at: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2 (last accessed 21/06/11).

5.2 Business

Significant financial investment is likely to be required for effective climate change mitigation and adaptation. Given the long lead-in time for new technologies, some of this investment will need to take place well in advance of the technologies being deployed (see Box 5.3). Well-directed private capital will be essential to achieving this goal. Many of the investment opportunities may be in low-income and emerging economies, where investment can drive economic and social development but where UK-based investors currently have less experience. The dominance of mitigation-related methods such as green energy generation and carbon capture should not mask the opportunities presented by adaptation. Coastal engineering, insurance, infrastructure development and the opening of new trade routes all represent significant opportunities for UK businesses to benefit from a global approach to adapt to the changing climate. In its "Trade and Investment for Growth" White Paper, the UK government committed to "*strengthen our support for UK LCEGS [low-carbon and environmental goods and services sector] exports, particularly through UKTI [UK Trade and Investment] and ECGD [the Export Credits Guarantee Department]*", and highlights the importance of a low-carbon economy to the UK's long-term sustainability and global competitiveness[26].

Box 5.3 Social discount rate

A major consideration when allocating resources to tackle climate change is the social discount rate used in the cost–benefit analysis of relevant projects. This is, broadly, society's relative valuation of current wellbeing against wellbeing in the future. A high discount rate for a project puts less weight on benefits occurring in the distant future, and vice-versa for a project with a lower discount rate.

In the context of climate change impacts in the future, the measured cost–benefit of current spending on climate change adaptation and mitigation takes into account the social discount rate based on intergenerational equity, i.e. the valuation placed on the welfare of future generations by the current generation. The Stern Review[27] utilised a discount rate of 1.4% which is lower than most other rates used in other climate change-related cost–benefit analysis[28], and which asserts that there is very little distinction to be made between the values for current and future generations' welfare[29]. However, this measure of intergenerational weighting is contentious and there is currently no agreement on a discount rate for this purpose.

Most interpretations of sustainable development suggest that the reach of past and current environmental impacts into the far future implies a need for policies for intergenerational equity, enabling those unborn to inherit ecological services at least as resilient and healthy as those that had been enjoyed previously[30]. But the status of future generations is unclear in law and still more so in politics and policymaking: can people 'in' the future be said to have rights and claims on the present? How does the demand for intergenerational equity fit with demands for intragenerational equity within and between countries in the present day? To what extent should a public policymaker adopt a different view of the future than might be common among individuals? And how far into the future would responsibilities of people alive today be reasonably thought to extend, given that it is often argued that future generations might be reasonably expected to have access to new technology and more wealth to deal with the problems they face[31]?

26 Department for Business, Innovation & Skills (2011), *Trade and investment for growth.* CM8015. The Stationery Office: London. Available at: http://www.bis.gov.uk/policies/trade-policy-unit (last accessed 21/06/11).

27 Stern, N. (2006), *The Economics of Climate Change: The Stern Review.* Cambridge, UK: Cambridge University Press.

28 Dietz, S. (2008), *A long-run target for climate policy: the Stern Review and its critics.* Supporting research for the Committee on Climate Change's report, *Building a low-carbon economy – the UK's contribution to tackling climate change.* Available at: http://www.theccc.org.uk/reports/building-a-low-carbon-economy/supporting-research (last accessed 21/06/11).

29 Nordhaus, W. (2007), *The Stern Review on the Economics of Climate Change.* Available at: http://nordhaus.econ.yale.edu/stern_050307.pdf (last accessed 21/06/11).

30 World Commission on Environment and Development (WCED) (1987), *Our Common Future.* Oxford: Oxford University Press.

31 R:1.3 (Annex B refers).

The IEA has estimated that the total investment required to secure a reasonable chance of avoiding the most serious effects of climate change would be more than US$1 trillion per annum[32], and estimates that approximately US$475 billion of this total annual investment must occur within developing countries, 85% of which would be required for mitigation and the remainder for adaptation measures[33]. However, current contributions to investment funds to tackle climate change in the developing world amount to less than 2%[34].

According to a UNEP report in 2009, approximately 80% of leading companies around the world recognise climate change as both a risk and opportunity[35]. A more recent study carried out on behalf of UK Trade and Investment found that 64% of surveyed global businesses consider climate change an opportunity, and 19% of firms have already generated new income from adaptation[36]. These demonstrate that businesses are already moving to act on climate change, despite the present lack of an internationally agreed, legally binding framework for mitigation. Emerging economies are of particular significance to private investors (see Box 5.4). Strategic investors[37] may discriminate between sectors and companies[38] based on their understanding of, and preparedness for, climate change implications. However, given the major uncertainties around the nature and timing of regulatory initiatives to drive the transition to a low-carbon economy, as well as the scale and probability of climate change impacts, investors and asset owners may lack the motivation to provide the levels of investment necessary[39,40]. Despite this, sentiment is rapidly changing: in 2009, US$162 billion was invested in sustainable energy around the world (with the G20 nations accounting for more than 90% of this) – representing a 230% increase from 2005[41]. A further US$243 billion of investment was made in 2010[42].

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32 United Nations Environment Programme (UNEP) and Partners (2009), *Catalysing low carbon growth in developing economies, Public Finance Mechanisms to scale up private sector investment in climate solutions.* Nairobi: Kenya. Report available at: http://www.unep.org/PDF/PressReleases/Public_financing_mechanisms_report.pdf (last accessed 21/06/11).

33 *ibid.* Figures from the World Bank Group.

34 United Nations Environment Programme (UNEP) and Partners (2009), *Catalysing low carbon growth in developing economies, Public Finance Mechanisms to scale up private sector investment in climate solutions.* Nairobi: Kenya. Report available at: http://www.unep.org/PDF/PressReleases/Public_financing_mechanisms_report.pdf (last accessed 21/06/11).

35 United Nations Environment Programme Finance Initiative (UNEP FI) (2009), *The materiality of climate change, How finance copes with the ticking clock.* A report by the Asset Management Working Group of the UNEP FI. Geneva: Switzerland. Report available at: http://www.unepfi.org/fileadmin/documents/materiality3.pdf (last accessed 21/06/11).

36 UKTI/Economist Intelligence Unit (2011), *Adapting to an uncertain climate: A world of commercial opportunities*. URN 11/791. UKTI: London. Report available at: http://www.ukti.gov.uk/es_es/uktihome/item/128100.html?null (last accessed 21/06/11).

37 Strategic investments aim to provide value beyond simple finance. They often provide companies with relevant sectorial experience while giving the investor a strategic advantage.

38 The Carbon Trust (2008), *Climate change – a business revolution? How tackling climate change could create or destroy company value* (CTC740). Available at: http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=CTC740 (last accessed 21/06/11).

39 United Nations Environment Programme (UNEP) and Partners (2009), *Catalysing low carbon growth in developing economies, Public Finance Mechanisms to scale up private sector investment in climate solutions.* Nairobi: Kenya. Report available at: http://www.unep.org/PDF/PressReleases/Public_financing_mechanisms_report.pdf (last accessed 21/06/11).

40 Association for Sustainable and Responsible Investment in Asia (ASRIA) (2008), *Carbon Disclosure Project Report 2008 – Asia ex-Japan,* Research Institutions Carbon Disclosure Project, in UNEP FI, October 2009.

41 UNEP (2010), *Global Trends in Sustainable Energy Investment 2010*. Nairobi: Kenya. Report available at: http://sefi.unep.org/english/globaltrends2010.html (last accessed 21/06/11).

42 Bloomberg New Energy Finance (2011). Available at: http://www.bloomberg.com/news/2011-01-11/low-carbon-energy-investment-hit-a-record-243-billion-in-2010-bnef-says.html (last accessed 13/04/2011).

Box 5.4 Investment opportunities in Brazil, India and China

Together, Brazil, India and China currently emit one-quarter to one-third of the world's GHGs[43], and their emissions are expected to continue to grow rapidly. However, during 2009, China (1), Brazil (5), and India (8) also ranked in the top 10 countries for investment in clean energy, representing 37% of the global total[44]. A brief synopsis of short-term investment opportunities in each of these economies is provided below[43,44,45].

Country	Opportunities
Brazil	• In 2009, invested US$7.4 billion (£4.8 billion) in clean energy and possessed current renewable energy capacity of 9GW. • High potential renewable energy markets, particularly bio-energy, with ambitious targets set for ethanol fuel. • Significant biomass and small-hydropower capacities. • Significant gains yet to be realised in energy efficiency. • Key clean energy targets in wind (1,422MW), ethanol (25% of total gasoline consumption), and biodiesel (5% of total diesel consumption) for 2012. • Subsidies/preferential loans for wind, small-scale hydropower and biomass.
India	• Already spending 2.6% of GDP on adaptation to climate vulnerability. • Invested US$2.3 billion (£1.5 billion) in clean energy in 2009. • Leading in wind (11GW), hydro and biomass (5GW each) installed capacities. • Good prospects for companies in the renewables sector. • Estimated US$150 billion (£97 billion) investment to be made between 2008-2017 in reducing carbon intensity and carbon demand. • Key investment incentives: wind and solar feed-in tariffs; accelerated depreciation of 80% in 1 year for small hydropower and biomass; preferential tax rate of 15% (instead of standard 30%) for all renewable projects.
China	• 52.5GW installed capacity of renewable energy in 2009, second only to USA. • Clean energy investments increased by more than 50% in 2009 to US$35 billion (£22 billion) – world leading. • Stringent regulations in energy efficiency and renewables well understood and driving action. • Up to 2015, half of the world's new buildings will be constructed in China. • China has set ambitious targets for wind (30GW by 2020), biomass (30GW by 2020) and solar energy (1.8GW by 2020) and, for the first time, led the G20 and the world for total clean energy finance and investment in 2009. • Adopted national renewable energy and energy efficiency standards, feed-in tariffs, carbon reduction targets and/or financial incentives for investment and production. • Leads G20 in small hydropower capacity. • Key investment incentives include: fixed feed-in tariff for wind; renewable energy surcharge and subsidy scheme generally; and rooftop- and building-integrated photovoltaic tax subsidies in solar.

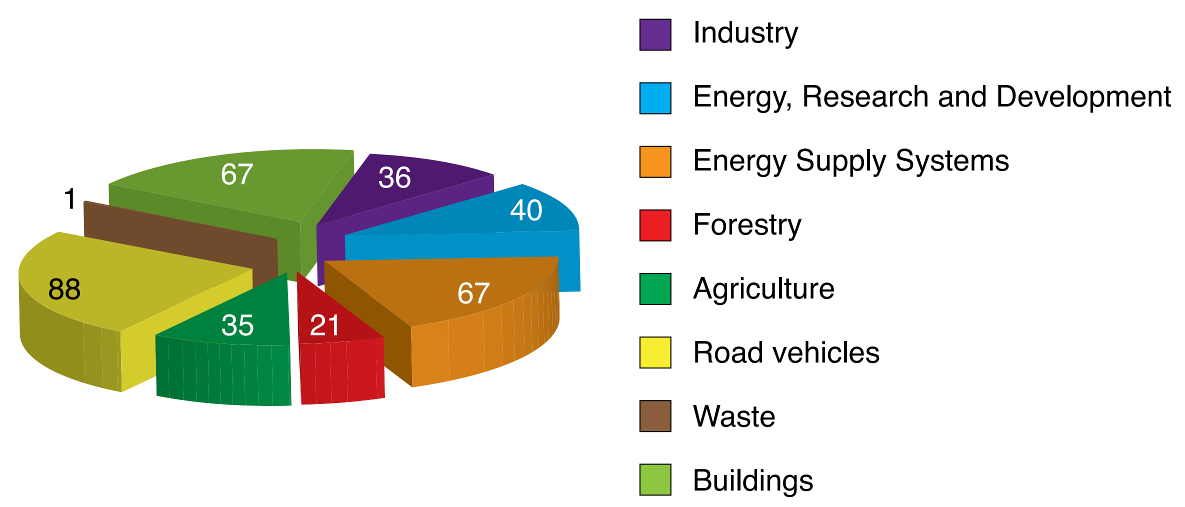
43 United Nations Environment Programme Finance Initiative (UNEP FI) (2009), *The materiality of climate change, How finance copes with the ticking clock*, A report by the Asset Management Working Group of the UNEP FI. Geneva: Switzerland. Report available at: http://www.unepfi.org/fileadmin/documents/materiality3.pdf (last accessed 21/06/11).

44 UNEP (2010), *Global Trends in Sustainable Energy Investment 2010.* Nairobi: Kenya. Report available at: http://sefi.unep.org/english/globaltrends2010.html (last accessed 21/06/11).

45 Data from the Bloomberg New Energy Finance database, current as of March 2010. More information on the BNEF database is available at: http://bnef.com/bnef/ (last accessed 21/06/11).

The economic robustness of the clean energy sector was recently demonstrated by a relatively small 6.6% decline in investments during the financial downturn of 2009, outperforming the oil and gas industry, which experienced an investment decline of 19%[46]. Further, many governments prioritised clean energy within funding provided for economic recovery[46]. In the UK 2010 Spending Review, the government committed to a range of measures to "reduce the UK's carbon emissions", including £1 billion for a Green Investment Bank to finance green infrastructure (increased to £3 billion following the 2011 Budget[46]), £1 billion for a commercial-scale carbon capture and storage (CCS) demonstration plant, and more than £200 million for development of low-carbon technologies[47]. Between 2009 and 2010, UK government funding for low-carbon research and development totalled about £550 million[48]. There is less certainty about the potential scale of investment opportunities from adaptation given the uncertainties that exist around estimated adaptation costs for climate change[49]. However, UK business opportunities do exist across a range of sectors, especially in the construction and retrofit of long-lived assets, and in introducing resilience in infrastructure and supply chains[50].

Figure 5.1: Estimated funding cost for global mitigation in 2030 (US$ billion global investment)[51,52]. This analysis uses a scenario that would return the levels of emissions in 2030 to the 2004 level[53].



46 HM Treasury (2011), *Budget 2011*. Available at: http://www.hm-treasury.gov.uk/2011budget_documents.htm (last accessed 21/06/11).

47 HM Treasury (2010), *Spending Review 2010*. Available at: http://cdn.hm-treasury.gov.uk/sr2010_completereport.pdf (last accessed 21/06/11).

48 Committee on Climate Change (2010), *Building a low-carbon economy – the UK's innovation challenge*. Available from: http://www.theccc.org.uk/reports/low-carbon-innovation (last accessed 21/06/11).

49 Parry, M. *et al.* (2009), *Assessing the costs of adaptation to climate change: A critique of the UNFCCC estimates*. International Institute for Environment and Development, London: UK. Report available at: http://pubs.iied.org/11501IIED.html (last accessed 21/06/11).

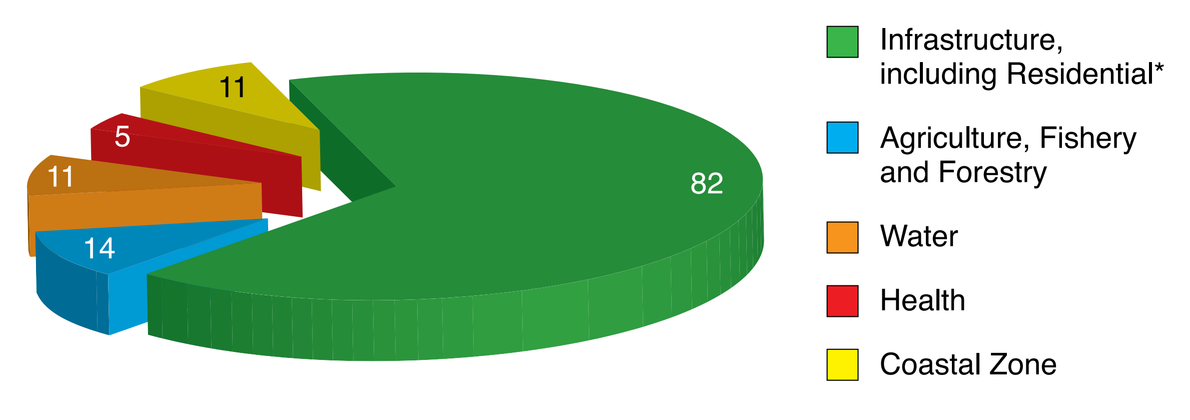
50 GHK Consulting (2009), *Opportunities for UK Business from Climate Change Adaptation* – GA0403. Report prepared for the Department for Environment, Farming and Rural Affairs. Report available at http://www.defra.gov.uk/news/2010/08/04/uk-businesses-climate-change/ (last accessed 21/06/11).

51 United Nations Environment Programme Finance Initiative (UNEP FI) (2009), *The materiality of climate change, How finance copes with the ticking clock*, A report by the Asset Management Working Group of the UNEP FI. Geneva: Switzerland. Report available at: http://www.unepfi.org/fileadmin/documents/materiality3.pdf (last accessed 21/06/11).

52 United Nations Framework Convention on Climate Change (UNFCCC) (2007), *Working paper 8. Dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention.* Fourth workshop, Vienna, 27-31 August 2007.

53 United Nations Environment Programme Finance Initiative (UNEP FI) (2007), *Investment and financial flows to address climate change*. Geneva: Switzerland. Report available at: http://unfccc.int/cooperation_and_support/financial_mechanism/items/4053.php (last accessed 21/06/11).

Figure 5.2: Estimated funding cost for global adaptation in 2030 (US$ billion global investment)[53]. This analysis was based on emissions scenarios for which climate change impacts could be inferred and responses to the climate impacts could be projected, allowing the associated investment and financial flows to be estimated[53].



** Average provided – range from US$33 – 130 billion.*

Figures 5.1 and 5.2 provide UNFCCC estimates of the global funding required in 2030 for mitigation ($355 billion) and adaptation ($123 billion) measures respectively. However, these are considered low estimates as a number of sectors have been omitted, and even within those sectors considered by the UNFCCC, the true costs for adaptation may be 2 to 3 times greater than projected[54].

The Carbon Trust estimated that companies could, in some sectors[55], increase their value by as much as 80% by being proactive and well positioned to move towards a low-carbon economy. Conversely, as much as 65% of a company's value could be threatened if it were poorly positioned or a market laggard[56]. A report from 2008 concluded that UK businesses[57] were confident they were "ahead of the curve" on climate change. Eighty-five per cent considered that they had a responsibility to help manage the impacts of climate change and 45% considered themselves to be innovators on climate change[58]. This would suggest that UK businesses are addressing potential impacts of climate change proactively, and consider themselves well placed to take advantages of any opportunities that are presented. However, the report also noted that UK businesses do not feel that they fully understand the implications of climate change, and that uncertainty over the views and concerns of government and consumers prevent them from making decisions on substantial investments[58].

Clean energy and investment opportunities around climate change adaptation are fairly recent concepts for many institutional investors who are still in the process of understanding these emerging sectors and their associated risks[59]. There is therefore a significant opportunity for the UK to lead in the development of this understanding, and to take advantage of the long-term investment opportunities that exist around climate change.

There exist substantial, long-term investment opportunities for the UK relating to climate change adaptation and mitigation.

54 Parry, M. *et al.* (2009), *Assessing the costs of adaptation to climate change: A critique of the UNFCCC estimates.* International Institute for Environment and Development, London: UK. Report available at: http://pubs.iied.org/11501IIED.html (last accessed 21/06/11).

55 The analysis considered six industry sectors: Aluminium, Automotive, Beer, Building insulation, Consumer electronics and Oil & Gas. These sectors each have high value to institutional investors, the potential for significant change resulting from the move to a low-carbon economy and are otherwise different in terms of their exposure to different climate change-related drivers, reflecting different parts of the wider economy.

56 The Carbon Trust (2008), *Climate change – a business revolution? How tackling climate change could create or destroy company value* (CTC740). Available at: http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=CTC740 (last accessed 21/06/11).

57 The UK companies consulted ranged from small (fewer than 200 employers) to major (more than 10,000 employers), had annual revenues of at least $50 million, and were from five broad industry sectors: Communications and High Tech, Consumer and Industrial, Financial Services, Government, and Resources.

58 Accenture (2008), *Achieving high performance in an era of climate change.* Available at: http://www.accenture.com/us-en/research/institute-high-performance/pages/insights-achieving-high-performance-in-era-climate-change-summary.aspx (last accessed 21/06/11).

59 Cambridge Programme for Sustainability Leadership (CPSL), October 2009, *Climate solution investments made to date,* The Prince of Wales' P8 Group.

5.3 Capitalising on leadership in areas of professional specialism

The global response to the challenges of climate change in the areas of mitigation and adaptation will demand skills and capabilities from many areas of professional specialism, ranging from financial services to engineering. This presents the UK with opportunities to capitalise on its strengths in these areas as climate change manifests itself across the world. This may take the form of exports of knowledge, products and engineering, as well as international scientific collaborations.

5.3.1 Financial services

London has been rated as the world leader in financial services in terms of its breadth, depth and connectivity with global markets[60]. The strong global characteristic of UK financial services is rooted in Britain's 19th century trade expansion, the dominance of the English language, and the use of English contract law in international trade markets[61], and its global position (and that of the wider EU economy) between Asian and American time zones[61,62].

The global character of UK financial services offers multiple benefits, including competitive costs of capital, low transaction costs and a broad range of analysts familiar with international issues. Ratings place London in the top or second-leading global position across functions of risk pooling and transfer, capital access and provision and asset management[63]. The UK financial services sector is also a specialist market for private equity, foreign exchange trading, commodity trading, bond issuance, wholesale market debt financing, maritime insurance, international insurance and reinsurance, and insurance advisory services[64]. Additionally, the large pool of capital and risk managed from the UK presents opportunities to UK financial service firms and clients to participate directly in global markets, a distinct advantage in diversifying risk and asset portfolios. This also means that innovation and first-mover advantage (i.e. the edge a company gets by entering a market before any competitors) to the UK in the sector occur on a global scale. The UK's dominance in international carbon trading and advisory services, for example, is in part attributed to London's voluntary carbon market established in 2002[65,66].

An HM Treasury report (2009) identified "critical success factors" for financial services and the broader environment, particularly in the context of a global financial centre, and evaluated UK performance accordingly (see Figure 5.3)[67]. In a qualitative analysis carried out for this project[68], these critical success factors were evaluated to consider the UK's likely performance in the face of a changing climate out to 2050. Potential positive shifts in performance are shown in boxes in Figure 5.3, and include professional services, life quality and an innovative focus.

60 Yeandle, M., Mainelli, M. & Harris, I. (2007; 2008; 2009), The *Global Financial Centres Index*. Z/Yen Group. Reports available at: http://www.longfinance.net/fcf-publications.html (last accessed 21/06/11).

61 HM Treasury (2009), *UK international financial services – the future. A report from UK based financial services leaders to the Government.* Report available at: http://www.hm-treasury.gov.uk/ukinternational_financialservices.htm (last accessed 21/06/11).

62 International Financial Services of London (IFSL) (2009), *Key Facts About The City of London 2H-2009*. Report available at: http://www.thecityuk.com/what-we-do/reports/articles/2009/november/key-facts-about-the-city-of-london-2h87222009.aspx (last accessed 21/06/11).

63 Z/Yen Group (2010), *Global Finance Centres 7*. Available at http://www.zyen.com/long-finance/global-financial-centres-index-gfci.html, last accessed 21/06/11.

64 R:8 (Annex B refers).

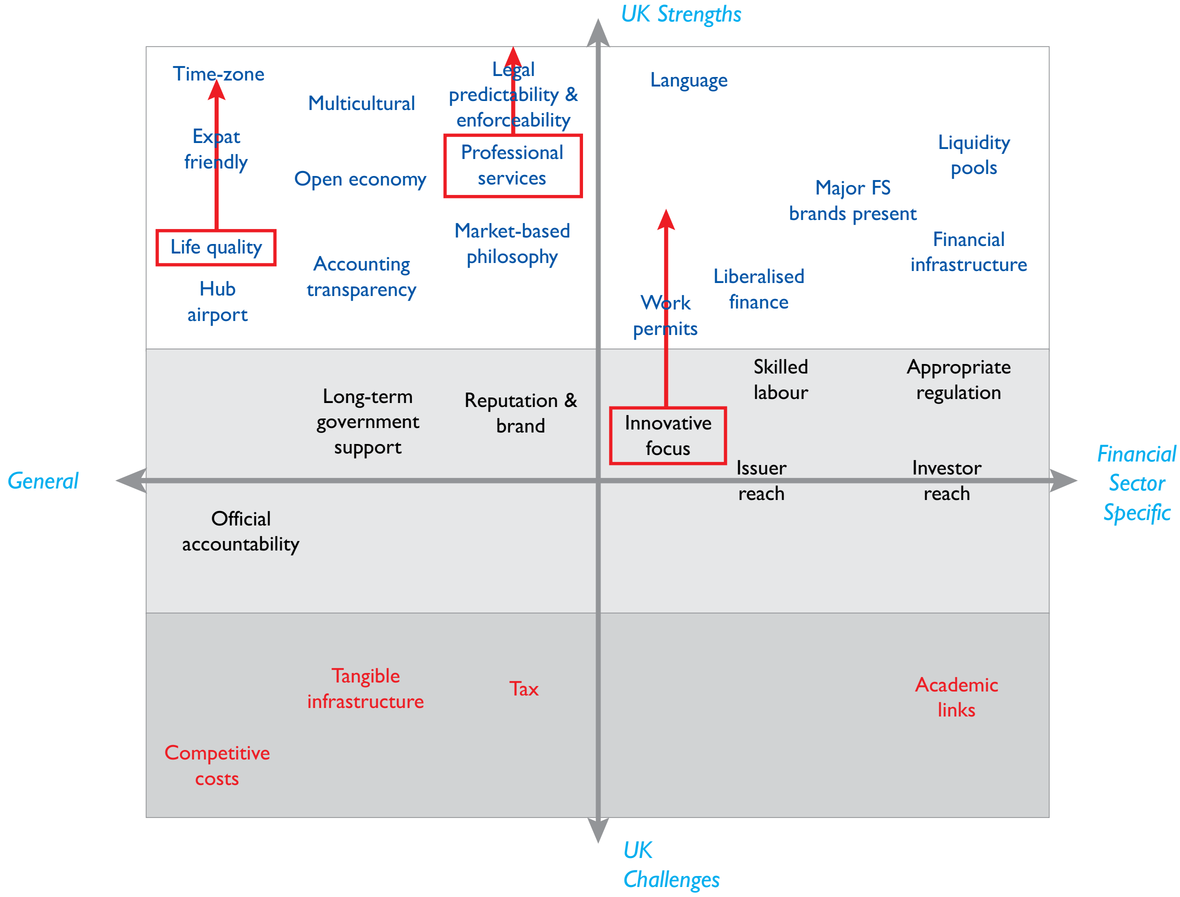
65 *ibid.*

66 NAO (2004), *The UK Emissions Trading Scheme: A New Way to Combat Climate Change.* Report available at: http://www.nao.org.uk/publications/0304/uk_emissions_trading_scheme.aspx (last accessed 21/06/11).

67 HM Treasury (2009), *UK international financial services – the future. A report from UK based financial services leaders to the government*, London. Report available at: http://www.hm-treasury.gov.uk/ukinternational_financialservices.htm (last accessed 21/06/11).

68 R:8 (Annex B refers).

Figure 5.3: Critical financial services success factors and UK performance with potential positive climate change influences[69]. Boxes highlight UK critical success factors of increasing importance in a changing climate out to 2050. This analysis is qualitative and based on expert judgement[70].



Professional services: The UK's pre-eminence in professional services can be attributed to historical factors, the London cluster effect, the presence of the leading professional institutions, and the availability of well-qualified staff[71]. UK firms and professional institutions have taken a proactive role in leading on adaptation and mitigation, and as the importance of climate change grows, the UK's strength in this field is thought likely to prove advantageous[72].

Life quality: Compared with other parts of the world, the UK is expected to retain a relatively benign climate in the first part of the century with generally hotter, drier summers and wetter, milder winters[73]. The UK is taking a proactive approach to adaptation, low-carbon energy generation and risk analysis suggesting that similar levels of life quality could be maintained at least up to the middle of the century. As a consequence, the UK could be relatively more attractive to live in than financial centres located in regions that will experience more severe impacts.

69 Image reproduced from R:8 (Annex B refers) p100.

70 R:8 (Annex B refers).

71 HM Treasury (2009), *UK international financial services – the future. A report from UK based financial services leaders to the government*, London. Report available at: http://www.hm-treasury.gov.uk/ukinternational_financialservices.htm (last accessed 21/06/11).

72 R:8 (Annex B refers).

73 UK Climate Projections 2009 – based on the medium emissions scenario. More information is available at: http://www.ukcip.org.uk/uk-impacts/uk-maps/maps/precipitation/ (last accessed 21/06/11).

Innovative focus: UK institutions and practitioners have shown an appetite for innovative financial solutions to the growth area of low-carbon finance. London has become a leading centre in carbon trading, while the UK is the leading investor in Clean Development Mechanism projects[74,75]. Over 100 clean technology companies are quoted on London's Alternative Investment Market (AIM), and these have raised over £3 billion to fund expansions[76]. New initiatives, such as the Green Investment Bank[77], will also strengthen its position as a leader in financial instruments for a potentially carbon-constrained world.

Greater awareness of climate risks is likely to lead to rising demand for financial products to manage them, which in turn would present opportunities for the UK insurance sector to expand its market, in partnerships with multilateral institutions and governments[78]. One example is that under the UNFCCC process, the Alliance of Small Island States has proposed a multi-window insurance platform, effectively an insurance scheme for governments to manage large climate impacts. In the event of a climate-related crisis, the scheme would provide liquid funds up front to the affected nation(s), which would then have the means available to deal with the catastrophe and day-to-day running of the country. Such a system already exists in the Caribbean[79] and could be extended internationally (see Box 5.5). One area of insurance where the UK has a leading role is in the organisation ClimateWise, which incorporates 40 insurance companies and organisations from across Europe, North America and Southern Africa. It aims to reduce the overall risks of climate change faced by economies and societies by analysing threats, informing public policymaking and increasing climate awareness[80].

74 The CDM was the mechanism created by the Kyoto Protocol by which high-income countries could claim carbon credits in return for funding the reduction in GHG emissions in low-income countries. More information is available at: http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php (last accessed 21/06/11).

75 TheCityUK (2010), Financial Services Report: How financial services make our world go round. Available at: http://www.thecityuk.com/what-we-do/reports/articles/2010/may/why-financial-services-matter.aspx (last accessed 21/06/11).

76 *ibid*.

77 HM Treasury (2010), *Spending Review 2010*. Available at: http://cdn.hm-treasury.gov.uk/sr2010_completereport.pdf (last accessed 21/06/11).

78 Silver, N. & Dlugolecki, A. (2009), *The insurability of the impacts of climate change*. IARU International Scientific Congress on Climate Change Copenhagen, March 2009. Available at: http://www.actuaries.org.uk/research-and-resources/documents/insurability-impacts-climate-change (last accessed 21/06/11).

79 CCRIF – The Caribbean Governments' Insurance Fund for Earthquake and Hurricane Catastrophes. Available at: http://www.ccrif.org/ (last accessed 21/06/11).

80 ClimateWise website available at: http://www.climatewise.org.uk (last accessed 21/06/11).

Box 5.5 Opportunities for the insurance sector[81]

Although climate change has the potential to have major impacts on vulnerable low-income countries, fewer than 5% of poor people across the world have access to insurance[82]. However, novel financial instruments are being introduced to the market to transfer the risk arising from catastrophe to global financial markets. They include[83]:

- **Ethiopian weather derivative** – index-based insurance system using rainfall data from 26 weather stations in Ethiopia designed by the World Food Programme and administered by French reinsurance company AXA Re;
- **Mexican catastrophe bond** – the Mexican Government insured its catastrophe fund against major earthquake events with a mix of reinsurance and catastrophe bonds with a parametric trigger[84] in terms of magnitude and depth of seismicity over a three-year period. The contract was provided by Swiss Re.
- **Caribbean Catastrophe Risk Insurance Facility** – the Caribbean Island States in 2007 formed the world's first multi-country catastrophe insurance pool, reinsured in the capital markets, to provide governments with immediate liquidity in the aftermath of hurricanes or earthquakes.

Micro-insurance (and wider microfinance schemes) for people in low-income countries is also becoming increasingly widespread, providing simplified cover to 90 million families in the developing world, with distribution through informal networks and non-insurance organisations[85].

The high level of adaptability required to ensure resilience to climate change, allowing firms to continue to do business – albeit in a different way or with a different set of actors – and exploit new business areas, has been a strength of the UK financial sector[86]. This is exemplified by innovative products such as interest-rate derivatives, carbon permit trading and Islamic finance[87,88,89].

Where climate change opportunities coincide with general attributes of strength in financial services, the UK is well positioned to increase its competitiveness as a leader across these areas. These include its speciality in carbon market and management services, and its international reach and experience in innovating new products that penetrate emerging overseas markets.

The UK financial sector has the global reach and extensive expertise needed for the development of financial products driven by climate change.

81 R:8 (Annex B refers).

82 Lloyd's (2009), *Insurance in Developing Countries: Exploring opportunities for microinsurance.* Lloyd's 360° Risk Project. Available at: http://www.lloyds.com/News-and-Insight/360-Risk-Insight/Research-and-Reports (last accessed 21/06/11).

83 Mechler, R., Hochrainer, S., Pflug, G., Lotsch, A. & Williges, K. (2010), *Assessing the Financial Vulnerability to Climate-Related Natural Hazards.* Background Paper to the 2010 World Development Report. Available at: http://www-wds.worldbank.org/ (last accessed 21/06/11).

84 Parametric triggers are a mechanism for paying out on catastrophe insurance bonds based on the actual reported physical event, such as the magnitude of an earthquake.

85 Dlugolecki, A. (2009), *The Climate Change Challenge.* Risk Management SC1, The Geneva Association. Available at: http://www.naic.org/documents/committees_ex_climate_climate_change_challenge.pdf (last accessed 21/06/11).

86 R:8 (Annex B refers).

87 HM Treasury (2009), *UK international financial services – the future. A report from UK based financial services leaders to the government*, London. Report available at: http://www.hm-treasury.gov.uk/ukinternational_financialservices.htm (last accessed 21/06/11).

88 Z/Yen Group (2010), *Global Finance Centres 7*. Available at http://www.zyen.com/long-finance/global-financial-centres-index-gfci.html, last accessed 21/06/11.

89 International Financial Services of London (IFSL) (2010), *Banking* 2010. Available at: http://www.thecityuk.com/research/our-work/reports-list/banking-2010/ (last accessed 21/06/11).

5.3.2 Scientific understanding of climate change

The UK has a relatively large number of organisations conducting state-of-the-art research into all aspects of climate change, and playing an active part in international collaborations (such as the IPCC). The UK is at the forefront of research in improving the understanding of the mechanisms and progress of climate change. The Met Office's Hadley Centre has an extensive research programme[90]. Other organisations include the Tyndall Centre for Climate Change Research, which brings together scientists, economists, engineers and social scientists to develop sustainable responses to climate change[91], and the European Centre for Medium-Range Weather Forecasts (ECMWF), which is an independent intergovernmental organisation supported by 34 member states[92]. The Climatic Research Unit (CRU) at the University of East Anglia also provides global academic leadership in the UK. The National Environmental Research Council[93] (NERC) supports fundamental climate research through its strategic research programmes, by supporting national capability – the facilities needed to support fundamental and applied research – and through grants to universities and other eligible organisations. UK universities are home to several world-leading centres on climate change research and policy, such as the Grantham Institutes[94] (Imperial College London/London School of Economics) and the Walker Institute[95] (University of Reading).

The UK is considered a leader in several areas of science-based policy on climate change. The UK Climate Impacts Programme[96] (UKCIP) helps organisations to adapt to inevitable climate change, and has disseminated UK-specific climate projections, most recently UKCP09[97]. This work pre-empted similar activities in the EU, and the UKCIP has been praised as a leading organisation in the promotion of adaptation policy[98]. As noted earlier, the Climate Change Act (2008)[99] set legally-binding emissions limits, provided a legislative framework for five-year carbon budgets, and initiated five-yearly Climate Change Risk Assessments[100]. It also set a reporting requirement for public bodies on actions being taken to address climate change risk and established the independent Committee on Climate Change[101], which advises the UK Government on setting and meeting carbon budgets and on preparing for the impacts of climate change. In 2011, the UK published the Carbon Plan, a government-wide climate change action plan which set out departmental responsibilities and actions for the next five years[102].

The UK is also a leading contributor to many international ventures and organisations, such as the World Climate Programme, the International Council for Science, Intergovernmental Oceanographic Commission, the International Group of Funding Agencies for Global Change Research, and the World Meteorological Organization (WMO), which operates the World Climate Programme[103]. The UK is also heavily involved in the Intergovernmental Panel on Climate Change (IPCC). Around 150 UK scientists (about 9% of the total) acted as lead authors and review editors on the IPCC 4th Assessment Report, and 63 have been named as lead authors and review editors on the 5th Assessment Report.

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90 Met Office Climate Science homepage available at: http://www.metoffice.gov.uk/climate-change(last accessed 21/06/11).

91 Tyndall Centre homepage available at: http://www.tyndall.ac.uk/ (last accessed 21/06/11).

92 ECMWF homepage available at: http://ecmwf.int/ (last accessed 21/06/11).

93 NERC homepage available at: http://www.nerc.ac.uk/ (last accessed 21/06/11).

94 More information on the Imperial College London-based Grantham Institute for Climate Change is available at: http://www3.imperial.ac.uk/climatechange (last accessed 21/06/11), while more information on its sister institute, the London School of Economics-based Grantham Research Institute on Climate Change and the Environment, is available at: http://www2.lse.ac.uk/GranthamInstitute/Home.aspx (last accessed 21/06/11).

95 More information on the Walker Institute for Climate System Research is available at: http://www.walker-institute.ac.uk/ (last accessed 21/06/11).

96 From September 2011, the role of UKCIP will change as the Environment Agency will be responsible for delivering DEFRA's work on adaptation. More information is available at: http://www.ukcip.org.uk/ (last accessed 21/06/11).

97 UKCP09 was delivered in partnership with BADC, MCCIP, Met Office, Newcastle University, POL, Tyndall Centre, UEA and UKCIP.

98 Pfenninger, S. *et al.* (2010), *MEDIATION Report on perceived policy needs and decision contexts*. EU FP7 programme. [Final draft report subject to approval by the European Commission]

99 The Climate Change Act (2008) may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

100 CCRA homepage available at: http://www.defra.gov.uk/environment/climate/adaptation/ccra/index.htm (last accessed 21/06/11).

101 Committee on Climate Change homepage available at: http://www.theccc.org.uk/ (last accessed 21/06/11).

102 UK Government (2011), *Carbon Plan*. London, UK. Available at: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/carbon_plan/carbon_plan.aspx (last accessed 21/06/11).

103 WMO World Climate Programme website, available at: http://www.wmo.int/pages/prog/wcp/index_en.html (last accessed 21/06/11).

Maintaining and developing this world-leading expertise and capability allows UK policy to be well informed on climate change, so that the country can be better positioned to identify and respond to possible threats and opportunities. For example, seasonal and decadal forecasting gives early warning of unfavourable seasons, which can be used to inform responses. Demonstrating scientific leadership on climate change could also present opportunities to export services to other countries, including climate modelling and the promotion of the UK as a scientific centre of excellence, reinforcing its attractiveness for overseas investment.

The UK can act as a global leader in the development of science-led climate change policy, helping to ensure that the implications of climate change impacts are identified and understood.

5.3.3 Engineering and technology

As countries strive to mitigate and adapt to climate change, opportunities will arise for the UK to capitalise on its engineering and technology expertise. As discussed in Section 5.3.1, new markets are opening for 'clean technologies' that can reduce emissions of greenhouse gases. Infrastructure may need to be adapted to be more resilient to the changing climate. There may also be a possible role for geoengineering in the future to augment mitigation and adaptation methods[104].

The Committee on Climate Change's report on building a low-carbon economy states that "*the UK will be better placed to accelerate the development of new technologies where it has a particular advantage – for example where the UK has the full range of manufacturing and business R&D facilities*"[105]. This potential push towards low-carbon energy generation as a result of efforts to mitigate climate change may increase the demand for niche capabilities and technological expertise. However, the level of demand and scale of economic opportunity that emerges over the next 20 years will depend upon national and global policy agreements, intentions and implementations on curbing emissions and incentivising low-carbon energy generation. HSBC's report "*Sizing the Climate Economy*" considers four scenarios of future low-carbon market growth based on policy implementations, with its most likely scenario estimating a $2.2 trillion global low-carbon market by 2020 (moving from 1.3% of global GDP in 2009 to 2.1% in 2020). However, its worst-case scenario, based on a decade in which governments fail to implement their commitments on emissions cuts, still estimates a global market of $1.5 trillion, with a best-case scenario of $2.7 trillion (where governments exceed their existing commitments)[106].

Coastal engineering, wave and tidal power, and the development of low-carbon vehicles are all examples of areas of technology in which the UK could lead through development, engineering, manufacturing, installation and operation over the next few decades to meet the requirements of countries around the world in reducing their emissions.

Coastal engineering: Rising sea levels and increased storm intensity along coastal areas is likely to increase the demand for expertise in civil engineering and construction. The UK (together with the Netherlands) is world leading in long-term strategic planning of coastal areas, as exemplified by the Shoreline Management Planning Approach, which has been adopted more widely in initiatives such as Eurosion[107] and the Thames Estuary 2100 Project[108]. UK firms have also been involved in developing coastal management and engineering in Louisiana since Hurricane Katrina[109].

104 DP:1 (Annex B refers).

105 Committee on Climate Change (2010), *Building a low-carbon economy – the UK's innovation challenge*. Available from: http://www.theccc.org.uk/reports/low-carbon-innovation (last accessed 21/06/11).

106 HSBC (2010), *Sizing the climate economy*. Available at: http://www.research.hsbc.com/midas/Res/RDV?ao=20&key=wU4BbdyRmz&n=276049.PDF (last accessed 21/06/11).

107 Eurosion, (2004), *Living with coastal erosion in Europe: Sediment and Space for Sustainability. Part-1 Major findings and Policy recommendations of the EUROSION project. Guidelines for implementing local information systems dedicated to coastal erosion management. Service contract B4-3301/2001/329175/MAR/B3* "Coastal erosion – Evaluation of the need for action". Directorate General Environment, European Commission, p54. Available from: http://www.eurosion.org/reports-online/reports.html (last accessed 21/06/11).

108 Environment Agency (2009), *TE2100 Plan Consultation Document. Managing flood risk through London and the Thames estuary April 2009*. Available from: http://www.environment-agency.gov.uk/static/documents/Leisure/TE2100_Chapter01-04.pdf (last accessed 21/06/11).

109 R:6.1 (Annex B refers).

Wave and tidal energy: The UK is a world leader in the development of wave and tidal stream technology. It has a strong academic base in this area and leading expertise from oil and gas offshore operations and engineering. It also has testing and demonstration facilities at the European Marine Energy Centre (EMEC) in Orkney, the Wave Hub in Cornwall and the National Renewable Energy Centre (Narec) in the north-east of England[110]. The UK's experience in offshore structures and operations in the gas and oil industry also puts it in a good position to engage in overseas developments in wave and tidal energy[111]. Estimates suggest that by 2035, the UK marine energy sector could employ up to 19,500 people and add £800 million per annum to the UK economy[112]. By 2020, the Carbon Trust estimates that the UK may be able to produce up to 3% of the total national energy demand from its natural abundance of wave and tidal stream sources (Figure 5.4). The experience available to UK companies, as well as the existence of potential generation sites, may enable a large proportion of the European market share to be UK owned[113].

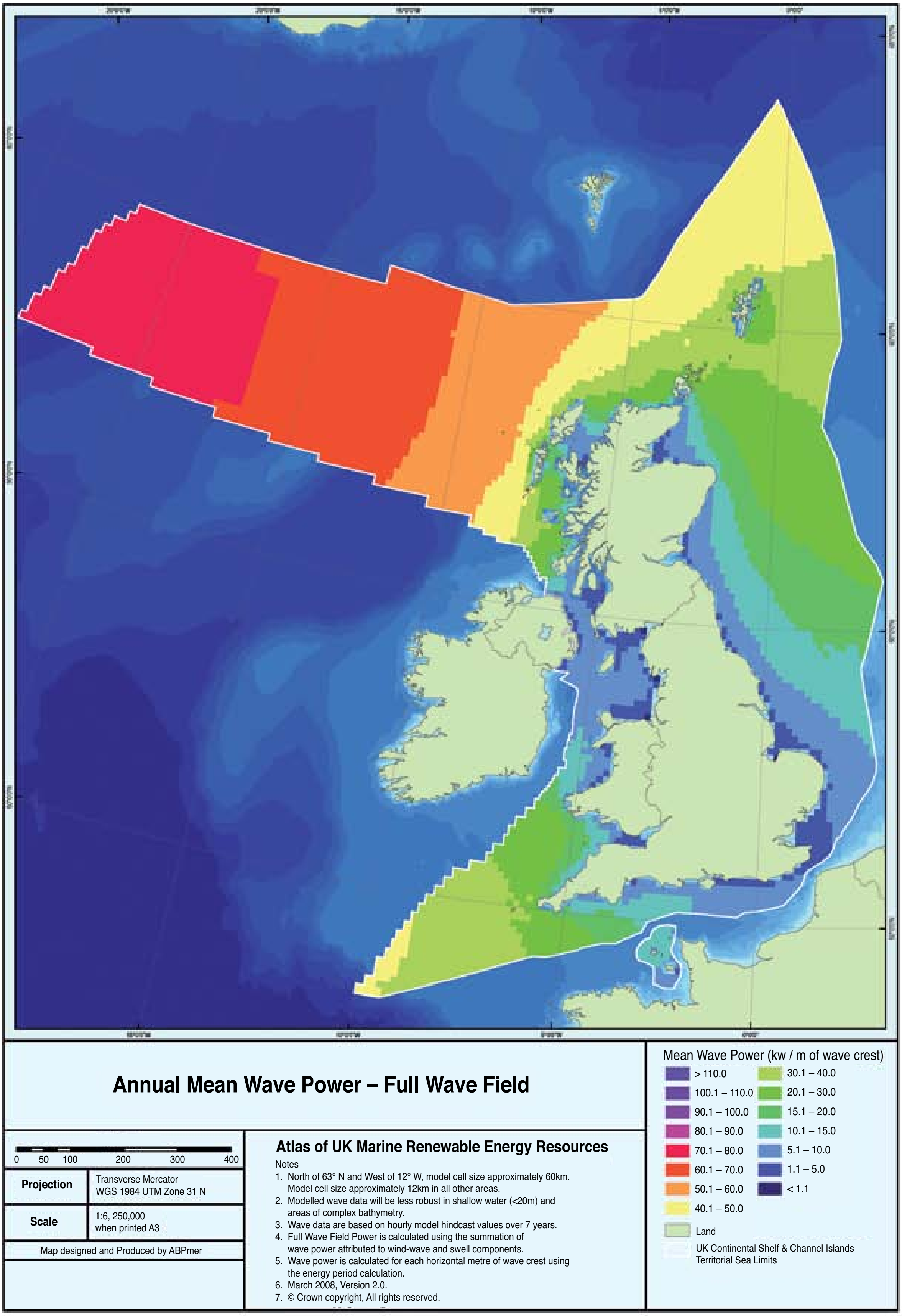
110 Foresight (2010), *Technology Innovation Futures: Technology Annex*. Foresight, UK – p21. Available at: http://www.bis.gov.uk/foresight/our-work/horizon-scanning-centre/technology-and-innovation-futures (last accessed 21/06/11).

111 *ibid.*, p23.

112 RenewableUK (2010), *Channelling the Energy – A Way Forward for the UK Wave and Tidal Industry Towards 2020*. London. Report available at: http://www.bwea.com/ref/reports-and-studies.html (last accessed 21/06/11).

113 Carbon Trust (2006), *Future Marine Energy. Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy*. Report available at: http://www.oceanrenewable.com/wp-content/uploads/2007/03/futuremarineenergy.pdf (last accessed 21/06/11).

Figure 5.4: Mean wave power in the UK[115]



114 BERR/ABPmer (2008), Atlas of UK marine resources: Technical Report. © Crown copyright, all rights reserved. Report available at: http://www.renewables-atlas.info/ (last accessed 21/06/11).

Low-carbon vehicles: The UK's automotive industry is one of the most productive vehicle manufacturing industries in Europe, with particular strengths in engine manufacture[115]. These strengths present opportunities for the UK with the development of low-carbon vehicles and a move away from the conventional internal combustion engine to hybrids and those based on electric or low-carbon fuel. The global market for low-carbon transport (also including trains and coaches) could be worth £440 billion by 2020[116].

Carbon capture and storage (CCS): CCS aims to remove carbon dioxide from energy generation or other industrial processes, preventing its release into the atmosphere before it is transported and stored underground for the long term[117]. The North Sea offers great potential for possible storage sites. The value to the UK from global markets for new advanced coal-fired power generation plants, including those fitted or retrofitted with CCS, could be £2-4 billion per year by 2030[118].

Geoengineering: While reduction of GHG emissions is likely to remain the focus of efforts to mitigate climate change, geoengineering may offer a contribution[119]. Geoengineering can be defined as "*the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming*"[120], and the methods proposed typically fall into two classes: carbon dioxide removal (removing GHGs directly from the atmosphere), and solar radiation management (reflecting solar radiation away from the Earth). Although some forms of geoengineering are likely to be technically possible[131], there are major uncertainties over its effectiveness, cost, and social and environmental impact. Currently, a lack of international governance and treaties affords a large degree of freedom to states to initiate geoengineering activities, and there is a risk of methods being applied by individual nations without concern for negative cross-boundary implications[121]. More research to understand the risks and benefits is required before deployment. The UK could contribute through appropriate observations, the development and use of climate models, and carefully planned and executed experiments[122]. If geoengineering is deemed appropriate, and robust regulation and governance frameworks are put in place, then the UK would have opportunities to build on its research and contribute significantly to the deployment of the technology.

The UK has the opportunity to develop world-leading expertise in many areas of cutting-edge green technology, including wave and tidal energy, coastal engineering, carbon capture and storage, and, in time, perhaps geoengineering.

5.4 Trade and resources

The UK's low exposure to extreme climate change impacts relative to other nations and its large domestic renewable energy resources place it in a relatively good position to capitalise on new market opportunities. The possibility of new trade routes through the Arctic as new sea passages open up also offers potentially significant economic savings in the transportation and trade of goods. This section outlines how these factors may present opportunities for the UK in the areas of trade and resources.

5.4.1 Resources and commodities

Until at least the middle of the century, the UK is less likely to be exposed to the most extreme effects of climate change than the continental land masses and other areas of the world. This is because of its

115 Howleg, M., Davides, P. & Podpolny, D. (2009), *The competitive status of the UK automotive industry*. Report available at: http://www-innovation.jbs.cam.ac.uk/publications/downloads/holweg_competitive.pdf (last accessed 21/06/11).

116 HSBC (2010), *Sizing the climate economy*, p4. Report available at: http://www.research.hsbc.com/midas/Res/RDV?ao=20&key=wU4BbdyRmz&n=276049.PDF (last accessed 21/06/11).

117 Foresight (2010), *Technology Innovation Futures: Technology Annex*. Foresight, UK p39. Available at: http://www.bis.gov.uk/foresight/our-work/horizon-scanning-centre/technology-and-innovation-futures (last accessed 21/06/11).

118 AEA (2009), *Future Value of Coal Carbon Abatement Technologies to UK Industry*. Report to DECC, URN 09/738. Available at: http://www.aeat.co.uk/cms/assets/MediaRelease/PR_190609.pdf (last accessed 21/06/11).

119 DP:1 (Annex B refers) p2.

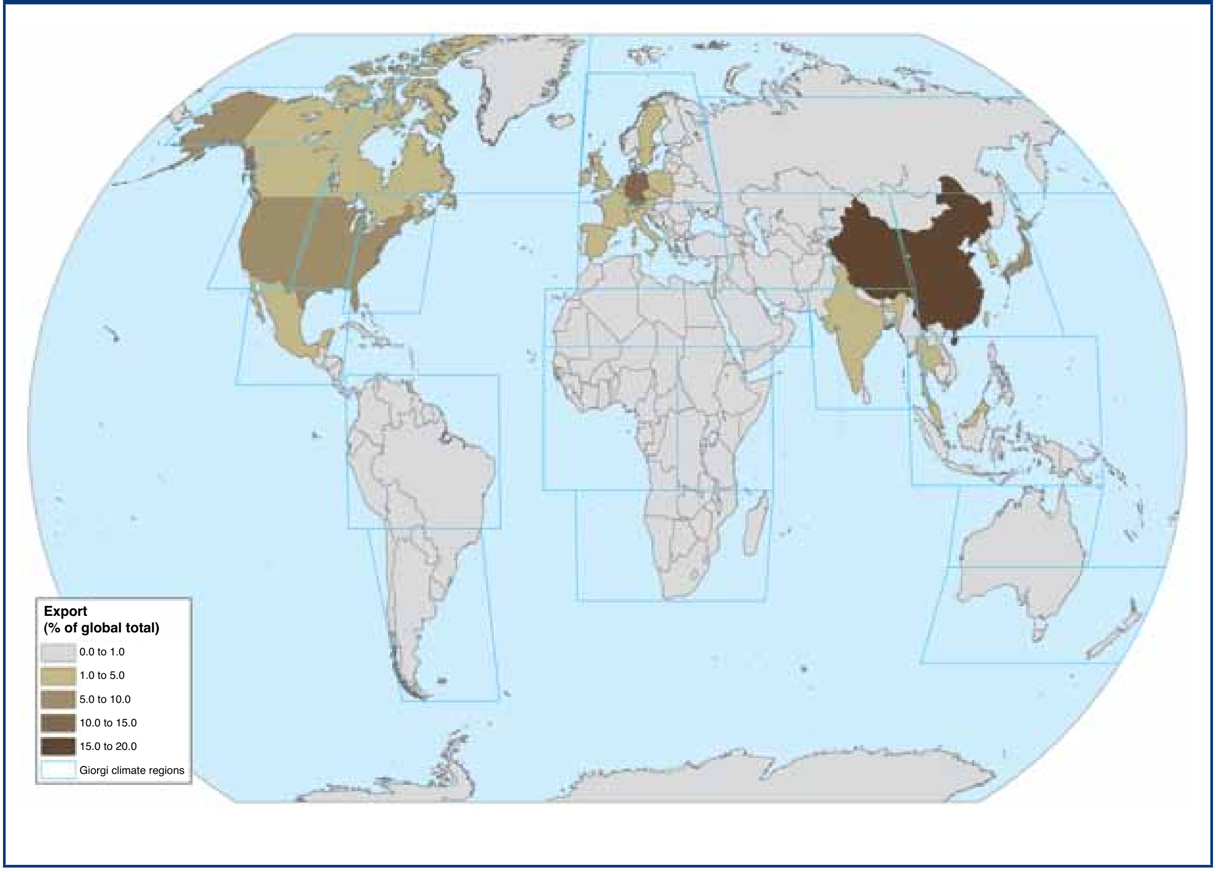
120 Royal Society (2009), *Geoengineering the climate – Science, governance and uncertainty*. Available from: http://royalsociety.org/Geoengineering-the-climate (last accessed 21/06/11).

121 Virgoe, J. (2009), *International governance of a possible geoengineering intervention to combat climate change*. Climatic Change, **95**: 103-119.

122 DP:1 (Annex B refers).

proximity to the North Atlantic Ocean, which moderates the changes in temperature between seasons (by absorbing heat in the summer and releasing it in the winter) and provides moisture to the atmosphere[123]. Furthermore, the UK's temperate climate is in part maintained by the Atlantic Ocean Circulation (the Gulf Stream)[124]. These influences are expected to continue under a range of plausible climate change scenarios[124]. As a consequence, the comparatively low risk of severe, direct climate change impacts may make the UK more attractive as a manufacturing base, provided its infrastructure, skills and manufacturing processes are adapted appropriately.

Figure 5.5: The export value of all manufactured goods and chemicals per country as a percentage of the world export total[126]



If the UK were to become a more attractive manufacturing region, its level of exports could be expected to increase. Currently, the global export of manufactured goods and chemicals is unevenly distributed, with China as the largest exporter, followed by Germany and the USA (see Figure 5.5)[126]. The USA is the largest producer of manufactured goods (valued at US$1.7 trillion in 2008), followed by China (valued at US$1.1 trillion in 2008)[127]. Africa and South America are, by contrast, regions of low export. The impact of climate change on the location of manufacturing processes is extremely complicated and difficult to analyse. However increases in temperature, sea level rise and possible increase in the intensity of storms all have the potential to damage coastal infrastructure, with largely negative consequences for energy production and transportation links (as described in Chapter 2), both vital sectors for manufacturing[128]. The effects of climate change on food, water, health and general regional stability will also affect the

123 Wood, R. & Wallace, C. (2009). *Annex 5: Changes to the Atlantic Ocean Circulation (Gulf Stream)*, annex to the *UK Climate Projections Science Report*, available at: http://ukclimateprojections.defra.gov.uk/content/view/944/500/ (last accessed 21/06/11).

124 Jenkins, G. J., Murphy, J. M., Sexton, D. M. H., Lowe, J. A., Jones, P. and Kilsby, C.G. (2009), *UK Climate Projections: Briefing Report*. Met Office Hadley Centre, Exeter, UK. Report available at: http://ukclimateprojections.defra.gov.uk/content/view/1370/500/ (last accessed 21/06/11).

125 UN Comtrade – International Merchandise Trade Statistics http://comtrade.un.org/ (last accessed 21/06/11).

126 R:3 (Annex B refers).

127 Note that the Chinese valuation also includes mining, quarrying, electricity, water and gas supply, which the US figure does not. Values are in constant 1990 dollar prices, figures from the UN Statistics Division, available at: http://unstats.un.org/unsd/snaama/dnllist.asp (last accessed 21/06/11).

128 R:3 (Annex B refers).

supply of human resource and cost of labour around the world. These combined physical and societal impacts of climate change result in potentially significant negative implications for some regions' ability to maintain or develop their manufacturing base. As a consequence, the UK could grasp potential new opportunities as manufacturing becomes more challenging in some regions, driving a shift in production and bringing the potential for expansion to the UK.

The UK can improve its global position in manufacturing and infrastructure, relative to other countries where risk is higher or more uncertain.

As discussed in Sections 4.1.4 and 4.2.1, the UK's dependency on importing energy does lead to risks in the security and price of supply of fossil fuels, against a backdrop of a need to reduce the UK's GHG emissions. However, as an island nation, the UK has significant opportunities to generate energy from its domestic renewable sources of wind (both onshore and offshore), tidal and (to a lesser extent) wave energy (see Section 5.3.3). This has the potential to not only reduce emissions, but also reduce reliance on imported fossil fuels and increase the security and affordability of the UK's energy supply[129].

As discussed earlier, the Climate Change Act 2008 set a legally binding target of at least an 80% cut to UK GHG emissions by 2050[130], and this will require movement to low-carbon energy generation[131]. The UK Government's *2050 Energy Pathways* report analyses six different pathways between now and 2050 of how energy demands and supplies across sectors could change in the future so that the UK would meet its 2050 goal. A common message from all of the pathways examined is that electricity supply needs to be decarbonised by about 2030, whilst demand might double[153].

Achieving the 2020 and 2050 targets will require substantial contributions from all sectors. The expansion of renewable energy will be a major element, required also by the UK's obligation under the Renewable Energy Directive to source 15% of its energy from renewables by 2020. Economic and technological factors mean that most of this will come from onshore and offshore wind and biomass/biofuels over the next decade, although other renewables such as wave and tidal power have the potential to make greater contributions in the longer term. A 2011 report by the Committee on Climate Change highlighted the significant potential for the UK to generate energy from renewable sources – 45% penetration of renewable energy[132] is considered the maximum possible by 2030, with 30% penetration considered a more likely figure by this date[133].

Once established, marine energy has the potential to generate 15-20% of current UK electricity demand, and 15% of EU demand[134]. However, a study using three scenarios (representing an EU generating 40%, 60% or 80% of its electricity from renewable energy sources) has estimated that, should the EU pursue a greener energy generation infrastructure, capital expenditure increases of between 50% and 110% may be required, and prices per unit of electricity may rise by 10-15% (not accounting for any prices for CO_2 emissions), with much of this rise being realised early on[135]. Such a level of expenditure would require industry and the general population to be convinced of the arguments driving any change to a low-carbon energy-generating infrastructure[136].

The UK also has the largest technical potential for offshore wind generation in Europe (based on available areas and average windspeeds), at around 1939 TWh per year, equivalent to six times the total

129 DECC (2010), *Annual Energy Statement: Departmental Memorandum*. Available at: http://decc.gov.uk/en/content/cms/what_we_do/uk_supply/aes/aes.aspx (last accessed 21/06/11).

130 The Climate Change Act (2008) may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

131 DECC (2010), *2050 Pathways Analysis report*. Available at: http://decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx (last accessed 21/06/11).

132 These estimates include total heating and cooling, electricity and transport requirements.

133 Committee on Climate Change (2011), *The Renewable Energy Review: May 2011*. London, UK. The report is available at: http://www.theccc.org.uk/reports/renewable-energy-review (last accessed 21/06/11).

134 RenewableUK (2010), *Channelling the Energy: A way forward for the UK wave and tidal industry towards 2020*. Report available at: http://www.bwea.com/pdf/publications/RenewableUK_MarineReport_Channelling-the-energy.pdf (last accessed 21/06/11).

135 McKinsey (2010), *Roadmap 2050: A Practical Guide to a Prosperous, Low-Carbon Europe. Volume 1 – Technical and Economic Analysis*. Available at: http://www.roadmap2050.eu/downloads (last accessed 21/06/11).

136 See Section 5.5.

UK electricity requirement in 2009[137]. By 2020 wind power could generate over 20% of the UK's current electricity demand[138]. By 2050, generation may be able to match the current energy production of North Sea oil and gas and provide annual revenues of £62 billion if 29% of the potential resource was used[139], although changes to the national grid would be required[140]. Another estimate considers the potential resource to be somewhat greater, and by 2030, the UK may be able to generate a sixth of the total European wind power potential[141]. It should be noted that there is potential for climate change to affect the UK's wind power resource and conditions throughout this century, through changes to the formation and duration of blocking high pressure systems, and extreme wind activity across the globe. However, the confidence in projections of these activities is low[142].

By increasing the proportion of energy generation from domestic renewable sources to meet emissions targets, the UK has an opportunity to also increase its security of supply and reduce dependency upon energy imports. By building skills, experience, capacity and markets domestically, the UK will be better placed to compete in new markets for renewable technologies overseas. RenewableUK estimates that by 2035 the UK marine energy sector may employ 19,500 people and contribute GVA[143] worth £800 million to the national economy[144].

The UK's renewable energy resources will contribute to meeting emissions targets, reducing its dependency on energy imports and increasing security of supply.

5.4.2 Trade routes

The expected opening of new routes across the Arctic and expansion in their annual availability due to the receding sea ice cover represents an important aspect of climate change for shipping. This would lead to shorter trade routes between North America, Europe and Asia, with the Northwest Passage (see Figure 5.6) in particular having the potential to reduce the shipping routes between Europe and Asia by approximately 4000 miles (30 per cent) from the current alternative via the Panama Canal[145,146,147].

137 The Offshore Valuation Group (2010), *The Offshore Valuation: A valuation of the UK's offshore renewable energy resource*. Report available at: http://www.offshorevaluation.org/ (last accessed 21/06/11).

138 Committee on Climate Change (2008), *Building a low carbon economy – The UK's contribution to tackling climate change: The First Report of the Committee on Climate Change*. Report available at: http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf (last accessed 21/06/11).

139 The Offshore Valuation Group (2010), *The offshore valuation: a valuation of the UK's offshore renewable energy resource – executive summary*. Available at: http://www.offshorevaluation.org/downloads/offshore_valuation_exec.pdf (last accessed 21/06/11).

140 Foresight (2010), *Technology Innovation Futures: Technology Annex*. Foresight, UK. Report available at: http://www.bis.gov.uk/foresight/our-work/horizon-scanning-centre/technology-and-innovation-futures (last accessed 21/06/11).

141 European Environment Agency (2009), *Europe's onshore and offshore wind energy potential: an assessment of environmental and economic constraints*. Report available at: http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential (last accessed 21/06/11).

142 R:3 (Annex B refers).

143 Gross Value Added (GVA) measures the contribution to the economy of each individual producer, industry or sector in the UK. Information on GVA is available at: http://www.statistics.gov.uk/cci/nugget.asp?id=254 (last accessed 21/06/11).

144 RenewableUK (2011), *Wave and Tidal Energy in the UK: State of the industry report*. Report available at: http://www.bwea.com/pdf/publications/WandT_SoI_report.pdf (last accessed 21/06/11).

145 R:3 (Annex B refers).

146 Ministry of Defence/DCDC (2010), *Strategic Trends Programme: Global Strategic Trends – Out to 2040*. 4th Edition, p166. Available from: http://www.mod.uk/NR/rdonlyres/D70F2CC7-5673-43AE-BA73-1F887801266C/0/20100202GST_4_Global_Strategic_Trends_Out_to_2040UDCDCStrat_Trends_4.pdf (last accessed 21/06/11).

147 Berkman, P.A. (2010), *Environmental Security in the Arctic Ocean: Promoting Co-operation and Preventing Conflict*. RUSI, Abingdon. More information available at: http://www.rusi.org/publications/whitehall/ref:I4CA4506CA6EBA/ (last accessed 21/06/11).

Figure 5.6: Route of the Northwest Passage and Northern Sea Route. Canada is the land mass to the left of the image, while Russia makes up the majority of the land mass to the right. The UK is at the bottom of the image.[149]

In September 2009, the first reported commercial ice-free navigation[149] was made of the Northern Sea Route, along the northern coast of Russia[150]. This was estimated to have saved the Beluga shipping company $300,000 per ship and 10 days' transit time compared with the route through the Suez Canal, which is approximately 3500 miles longer[151]. Furthermore, piracy around the Gulf of Aden accounted for 44% of all global piracy incidents in the first nine months of 2010[152] and affects shipping passing through the Suez Canal, often in transit between Europe and Asia. Moving shipping to alternative northern transit routes would be expected to reduce the associated disruptive effects of piracy on global shipping, potentially triggering reductions in insurance premiums and in the protection of routes by maritime forces. As shown in Figure 5.7, Asia represents the most significant market for UK container traffic by tonnage, and the opening up of new, shorter shipping routes would result in considerable savings being made.

However, investment would be needed in Arctic infrastructure if the potential of these shipping routes is to be fully realised. There is currently a shortage of major shipping ports in the region (except those in Norway and Northwest Russia), a need for suitably ice-strengthened vessels, and limitations to radio communication due to a lack of complete satellite coverage of the area[153]. However, if routes were more

148 Ahlenius, H., UNEP/GRID-Arendal (2007), Reproduced with permission from the copyright holder. Available from: http://maps.grida.no/go/graphic/arctic-sea-routes-northern-sea-route-and-northwest-passage (last accessed 21/06/11).

149 Voyages of the 'Fraternity' and 'Foresight' from Ulsan, South Korea, to Rotterdam, the Netherlands.

150 "*Cargo ships navigate the Northeast Passage for the first time*". The Times, 14/09/09. Available from: http://www.timesonline.co.uk/tol/news/world/europe/article6832885.ece (last accessed 21/06/11).

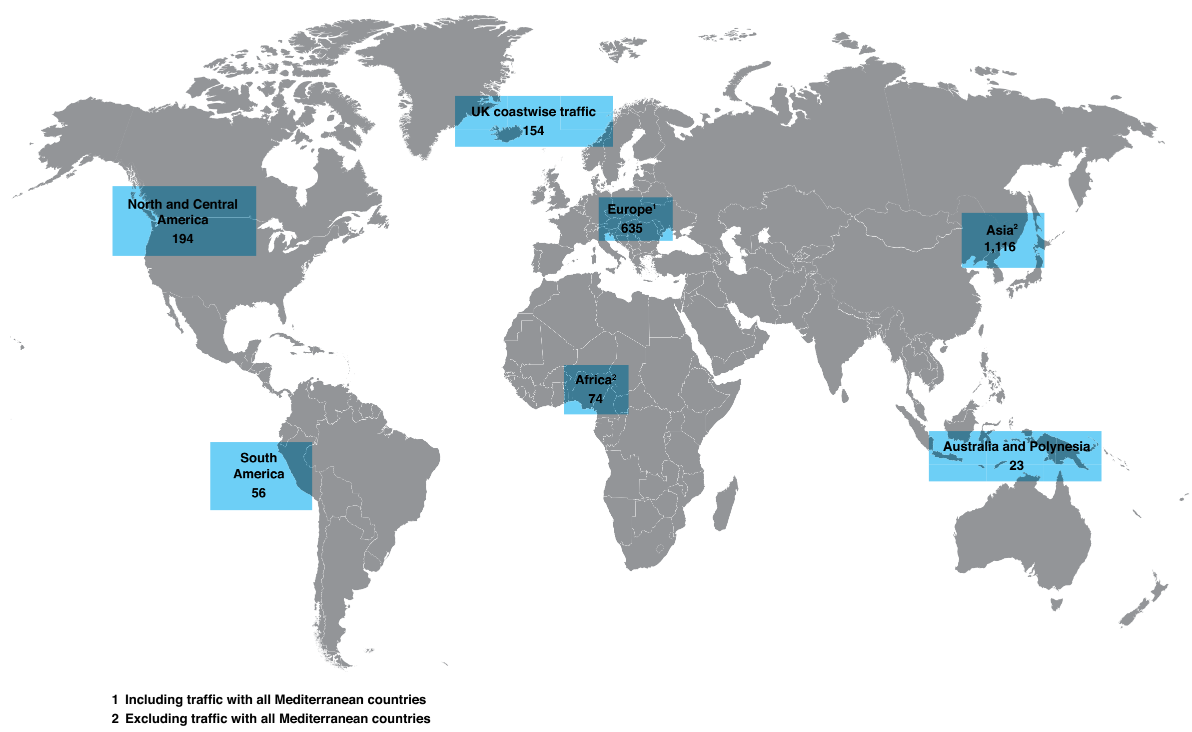
151 Smith, A. (2009), *Global Warming Reopens the Northeast Passage*. TIME magazine, 17/09/09. Available at: http://www.time.com/time/world/article/0,8599,1924410,00.html (last accessed 21/06/11).

152 International Chamber of Commerce Commercial Crime Services, *Pirates intensify attacks in new areas, with first Somali hijacking reported in Red Sea*, 18/10/10. Available at: http://www.icc-ccs.org/ (last accessed 21/06/11).

153 Arctic Council (2009), *Arctic Marine Shipping Assessment 2009 Report*. Available at: http://www.pame.is/amsa/amsa-2009-report (last accessed 21/06/11).

exploited in future, providing satellite coverage could become commercially viable. Access to the routes would also be determined by relevant international agreements and frameworks such as UNCLOS (which provides for rights of navigation, transit passage and innocent passage[154]) and the International Maritime Organization's polar shipping code (currently being developed[155]) as well as any legal requirements of the Arctic coastal states[156]. Co-ordinated regulatory frameworks (e.g. to cover coastguard operations, environmental protection, etc.) would also be required[157].

Figure 5.7: International container traffic to the UK major ports. Figures provided are in thousand units. Data taken from the Department for Transport's Maritime Statistics 2009 report[158]. Blank map used under Creative Commons Attribution-ShareAlike 3.0 Unported (BY-SA 3.0) license from http://gunn.co.nz/map (last accessed 28/04/11).



Modelling[159] carried out for the Arctic Climate Impact Assessment (ACIA) suggests that by 2050 the Northern Sea Route may be navigable for 125 days each year by ice-strengthened cargo ships[160]. Both of the scenarios used by ACIA (the A2 and B2 SRES scenarios) predict approximately 1.5°C warming of the Arctic by 2050 relative to 1990 levels[161]. Given that A2 has global temperature predictions similar to the medium emissions scenario used in this Report[162], and B2's temperature projection is slightly less

154 Full text of the UN Convention on the Law of the Sea is available at: http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm (last accessed 21/06/11).

155 For more information, see: http://www.imo.org/MediaCentre/MeetingSummaries/DE/Pages/DE-54th-Session.aspx (last accessed 21/06/11).

156 Østreng, W. (ed.) (1999), *National Security and International Environmental Cooperation in the Arctic: The case of the Northern Sea Route*. Environment & Policy, Vol. 16. Dordecht, Kluwer Academic Publishers.

157 Berkman, P.A. (2010), Environmental Security in the Arctic Ocean: Promoting Co-operation and Preventing Conflict. RUSI, Abingdon. More information available at: http://www.rusi.org/publications/whitehall/ref:I4CA4506CA6EBA/ (last accessed 21/06/11).

158 DfT (2010), *Maritime Statistics 2009*. Report available at: http://www.dft.gov.uk/pgr/statistics/datatablespublications/maritime/compendium/maritimestatistics2009 (last accessed 21/06/11).

159 Modelling was carried out using the IPCC B2 and A2 emissions scenarios as described in the IPCC Special Report on Emissions Scenarios, published in 2000.

160 Weller, G. *et al.* (2005), *Chapter 18. Summary and Synthesis of the ACIA*. Part of the *Arctic Climate Impact Assessment*, Cambridge University Press. Available at: http://www.acia.uaf.edu/pages/scientific.html (last accessed 21/06/11).

161 Kattsov, V.M. *et al.* (2005), *Chapter 4: Future Climate Change: Modelling and Scenarios for the Arctic*. Part of the *Arctic Climate Impact Assessment*, Cambridge University Press. Available at: http://www.acia.uaf.edu/pages/scientific.html (last accessed 21/06/11).

162 See Section 2.3.

than the high emissions scenario used in this Report[163], this prediction may plausibly occur under either the medium or high emissions scenarios. The complex geography of the Canadian Arctic prevents accurate modelling and hence comparable data are not available on the Northwest Passage[164].

The opening of new sea routes from the middle of the century will have economic benefits through a reduction in Northern Hemisphere shipping costs between Europe, North America and Asia.

5.5 Values and behaviour

As well as the more tangible political and economic effects on the UK arising from climate change impacts overseas, it is also important to consider how international climate change events and trends overseas may affect the structure and functioning of UK society and the behaviour of the population. High-level dialogue on climate change mitigation and adaptation generally focus on elements such as economic and cost–benefit analyses of differing approaches, and, as such, ethical, social and behavioural factors are to some extent downplayed. However, the effects of climate change will no doubt have significant impacts on societies around the world, and the values and behaviours of citizens within them. These areas are therefore considered alongside the more traditional areas of concern to climate change policymakers in this Report.

Adverse climate impacts occurring in more vulnerable locations across the world over the next 40 years (e.g. in Africa or Asia) are, of course, likely to be of a different order to those occurring in the UK. But even the most serious events overseas might serve only to reinforce the notion that climate change is a matter for other countries and peoples[165], and consequently viewed as a distant issue by many people in the UK[166], rather than a problem which is personally threatening or relevant. Major loss of life occurring in distant countries rarely generates the same level of emotional or cognitive engagement as individual, identifiable deaths[167].

A considerable challenge already exists for both governments and communicators in making climate change a salient issue for people in the UK, one which is sufficiently motivating to make mitigation an aspect of everybody's lives and actions. There currently exists a very real gap[168] between people's expressed concerns about the environment and their actions. In nationwide surveys conducted in the UK in 2005 and 2010 only 8% and 10% respectively of respondents stated that the main responsibility for action on climate change lay with individuals and their families[169,170]. Rather, primary responsibility was overwhelmingly ascribed to powerful external actors such as the international community, national governments and businesses. In part, this outcome can be interpreted as people seeking to displace responsibility for major action onto others rather than to themselves as individuals, and in this way avoid what are perceived to be costly or difficult changes to behaviour and lifestyles[171]. When asked whether they are personally prepared to do something about climate change most people will agree, although many will state that it is currently difficult to take appropriate action but that they would respond only if

163 For comparison of temperature projections of the four scenarios, see: IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, p45.

164 Instanes, A. *et al.* (2005), *Chapter 16. Infrastructure: Buildings Support Systems, and Industrial Facilities*. Part of the *Arctic Climate Impact Assessment*, Cambridge University Press. Available at: http://www.acia.uaf.edu/pages/scientific.html (last accessed 21/06/11).

165 R:5 (Annex B refers).

166 *ibid.*

167 Slovic, P. (2007), *'If I look at the mass I will never act': psychic numbing and genocide*. Judgment and Decision Making, **2**: 79-95.

168 The gap between people's stated concerns and their willingness to significantly alter their behaviour to address these. For further discussion see R:5 (Annex B refers).

169 Poortinga, W. & Pidgeon, N.F. (2003), *Public Perceptions of Risk, Science and Governance. Main Findings of a British Survey on Five Risk Cases (Technical Report)*. Norwich: Centre for Environmental Risk. Available at: http://psych.cf.ac.uk/understandingrisk/reports/index.html (last accessed 21/06/11).

170 Spence, A., Venables, D., Pidgeon, N., Poortinga, W. & Demski, C. (2010), *Public Perceptions of Climate Change and Energy Futures in Britain: Summary Findings of a Survey Conducted in January-March 2010.* Technical Report (Understanding Risk Working Paper 10-01). Cardiff: School of Psychology. Available at: http://psych.cf.ac.uk/understandingrisk/reports/index.html (last accessed 21/06/11).

171 R:5 (Annex B refers).

given the right guidance, help or incentives from government[172]. There remains a clear gap between people's expressed concerns and their willingness to make significant changes to their behaviour[173].

Recent polling suggests that scepticism about climate change has increased, alongside diminished concern for its effects. In 2006, 81% of surveyed UK citizens were fairly or very concerned about climate change compared with 76% in 2009 in an identical tracking survey[174]. The same trend has been noted in the EU[175], the US[176] and 10 other countries[177]. Possible explanations for this trend include:

- fatigue with climate change as an issue;
- the global economic recession (people are more concerned over their immediate financial concerns than climate change);
- politicisation of the issue and distrust of sources of communication;
- increasing prominence of climate-sceptic agendas;
- realisation that current lifestyles may require radical change; and
- transfer of uncertainty – a process by which uncertainty over one aspect of climate science or policy (e.g. how best to alleviate climate change effects) spreads to generate scepticism over another area, or the subject as a whole.[178]

Should scepticism continue to increase, democratic governments are likely to find it harder to convince voters to support costly environmental policies aimed at mitigation of, or adaptation to, climate change. Fear of a "backlash at the ballot box" could prevent parties pursuing policies that attempt to force people to accept radical changes in lifestyle, new environmental taxes, or stricter legislation[179]. As a consequence, climate change could slip down the list of policy priorities. Should governments pursue these costly policies in a future where the public are not convinced they are necessary or justified, the electorate will become increasingly distant from their elected representatives.

If people are to be convinced that action is needed in the short term to address these significant long-term risks, concerns about climate change must resonate with people's ethical norms and values[180]. Approaches to public attitudes and action on climate change are likely to be increasingly informed by social science and by opportunities for influencing through social network media, community groups and trusted peer networks. It has often been argued that the public desire bold, visible and demonstrably effective action on climate change from governments and other societal actors, before they are willing to take these steps themselves[181]. If public trust in government messages and authority remains relatively low, it might be necessary to put more effort into indirect influencing via trusted third parties in civil society, through new forms of public engagement and policy dialogues[182].

The onset of more severe climate impacts overseas may also open up temporary opportunities, or 'policy windows'[183]. These would allow legislators the licence to take specific bold actions which they ordinarily believe would not otherwise be possible or politically acceptable[184], such as the introduction of the Clean Air Act after the London smog, and the development of the Thames Flood Barrier after the

172 R:5 (Annex B refers).

173 *ibid*.

174 DfT (2010), *Public Attitudes Towards Climate Change and the Impact of Transport; 2006, 2007, 2008 and 2009*. London: Department for Transport. Report available at: http://www.dft.gov.uk/pgr/statistics/datatablespublications/trsnstatsatt/climatechngeandtranport1 (last accessed 21/06/11).

175 Eurobarometer (2009), *Europeans' Attitudes Towards Climate Change*. Eurobarometer 69. Available from: http://ec.europa.eu/public_opinion/archives/ebs/ebs_322_en.pdf (last accessed 21/06/11).

176 Dunlap, R. E. & McCright, A. M. (2008), *A widening gap: Republican and Democratic views on climate change*. Environment, **50**: 26-35

177 HSBC (2009), *Climate Confidence Monitor 2009*. London: HSBC Climate Partnership, available from: www.hsbc.com/climateconfidencemonitor (last accessed 21/06/11).

178 R:5 (Annex B refers).

179 *ibid*., p21.

180 R:1.3 (Annex B refers).

181 Lorenzoni, I., O'Riordan, T., & Pidgeon, N.F. (2008), *Hot air and cold feet: the UK response to climate change*. In H. Compston and I. Bailey (eds.) *Turning Down the Heat: The Politics of Climate Policy in Affluent Democracies*. Basingstoke: Palgrave Macmillan, pp. 104-124.

182 R:1.3 (Annex B refers).

183 Kingdon, J. W. (1984), *Agendas, Alternatives and Public Policies*. Boston: Little Brown.

184 R:5 (Annex B refers)

flooding of East Anglia in 1953. In effect, envisaged solutions can become rapidly translated into practical options for action following a major disaster or near-miss.

Establishing climate salience (or the equivalent of placing society on a 'war footing' in its climate response[185]) is unlikely to come about in the near-term simply because of a recognition that physical impacts of climate change are occurring directly in the UK. However, by using consistent framing, or narrative, linking climate risk, impacts and extreme weather events overseas, there is an opportunity to influence and prompt behavioural change within the UK[186].

Effective, consistent communication and education linking climate change impacts to events overseas allows the UK government to encourage domestic behavioural change and the adoption of low-carbon technologies.

185 Clayton, H., Pidgeon, N.F. & Whitby, M. (2006), *Is a Cross-party Consensus on Climate Change Possible – or Desirable? First Report of the All Party Parliamentary Climate Change Group*. London: Westminster.

186 Nisbet, M.C. (2009), *Communicating climate change: why frames matter to public engagement*. Environment, **51**: 12-23.


CHINA
THAILAND
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GREECE
SPAIN
INDIA

6 Directions for the UK in a warming world

This final chapter considers the nature of the risks identified in this Report. It sets out how they should be treated by policymakers to help ensure that the UK is well placed to address international impacts of climate change, so that it remains competitive, secure and able to protect the wellbeing of the nation.

6 Directions for the UK in a warming world

This Report shows that the consequences for the UK of climate change occurring in other parts of the world could be as important as climate change directly affecting these shores. The UK will be unable to isolate itself from these global impacts, and will need to give careful consideration to their implications.

At first glance it may appear that the UK has little reason to be concerned about climate change. Northern European nations are projected to be relatively less affected by the most severe climatic changes. Indeed, compared with the continental land masses and lower latitude countries, the UK is fortunate in relation to the geography of climate change impacts. Its proximity to the North Atlantic Ocean moderates temperature changes between the seasons and provides moisture to the atmosphere, as well as the maintenance of its temperate climate through the Gulf Stream[1]. Furthermore, as one of the largest global economies, the UK is better placed than many to be able to afford significant levels of adaptation. Moreover, in 2007, it contributed only 1.84% of global greenhouse gas (GHG) emissions[2].

However, the impact of technology, migration and trade has led to a highly interconnected globalised world and it will be difficult for the UK to isolate itself from the global economic and geopolitical shocks[3] that look certain to be experienced in a warming world. Risks include disruption to the UK's supply of imported energy, natural resources and commodities, impacts on the UK Overseas Territories, threats to national security and shifts in the nation's international role and global influence. Handling of these risks will need to be carefully considered by policymakers and sector experts.

The UK's Climate Change Act (2008)[4] introduced the world's first long-term, legally binding framework to tackle the impacts of climate change. Through this legislation, the UK is committed to taking its share of global responsibility for reducing global GHG emissions by setting a legally binding target to reduce emissions by 80% (from 1990 levels) by 2050. As well as domestic action, the UK government is committed to working "*towards an ambitious global climate deal that will limit emissions and explore the creation of new international sources of funding for the purpose of climate change adaptation and mitigation*"[5]. This includes continued efforts within the UNFCCC process, and its next Conference of Parties meeting in Durban in 2011.

However, as well as supporting efforts to achieve global mitigation of GHG emissions, policymakers should recognise that the UK needs to adapt to the climate change that is locked in and already under way. The UK's first Climate Change Risk Assessment is a statutory obligation under the Climate Change Act (2008) and in 2012 will set out the level of risk to the UK from domestic climate change effects. It is highly likely that the UK will be at relatively low risk from the more severe direct impacts of climate change, in contrast to some of the poorest countries that are expected to be more vulnerable, experience more severe effects, and have a limited capacity to adapt (such as parts of Africa, small low-lying islands and Asian mega-deltas)[6]. **Although direct comparison is difficult, it is clear that the risks described in this Report (i.e. to the UK from climate change effects overseas) could lead to impacts on the UK and its interests that are of comparable or greater magnitude than those resulting from climate change effects on the UK mainland.**

1 See Section 5.4.1.

2 Percentage calculated from the UN Millennium Development Goal series "*Carbon dioxide emissions (CO2), thousand metric tons of CO_2 (CDIAC)*". Available at: http://mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749 (last accessed 21/06/11).

3 HM Government (2010), *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. UK: The Stationery Office.

4 The Act may be viewed in full at: http://www.legislation.gov.uk/ukpga/2008/27/contents (last accessed 21/06/11).

5 HM Government (2010), The Coalition: our programme for government. Cabinet Office: London. Available at: http://www.cabinetoffice.gov.uk/news/coalition-documents (last accessed 21/06/11).

6 IPCC (2007), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

6.1 Implications for policy

This Report has identified and brought together for the first time the threats and opportunities from climate change effects overseas with the potential to affect the UK across the political, economic and social spectrum. Some of these risks are well known and established, others are less so. But all need to be considered by policymakers within government, as well as businesses, charities and other organisations. This Report also provides an additional body of evidence to improve understanding of how the UK may be affected. It has brought together the best available research and advice from a multi-disciplinary team of government policymakers, economists, social scientists, security experts, climate scientists, risk analysts, business leaders and many others. The priority areas of impact for the UK are:

- **International stability:** Social and political instabilities could arise in regions around the world through climate change impacts, creating defence and security problems which will affect many countries. Increased instability could lead to calls for higher levels of UK humanitarian assistance, and more support for peacekeeping operations. It may increase pressure on UK budgets, and necessitate continued assessment of the suitability of military hardware to the changing operational landscape (in 2010, the UK provided nearly £600 million to the UN peacekeeping budget, 8.16% of the total amount[7], and in 2009/10 the UK gave £435 million in humanitarian assistance). The impacts of extreme weather, sea level rise and large-scale changes to precipitation on the infrastructure and governance of already unstable regions may lead to an increase in failed states and ungovernable spaces, acting as a source of growing terrorist and insurgent activity. This may also lead to implications for global transport and trade networks – piracy off the coast of Somalia (top of the Failed States Index) accounted for 92% of all ship seizures in 2010, and maritime piracy worldwide had an estimated cost of between $7 billion and $12 billion. Furthermore, interventions in destabilised regions may risk an increase in domestic protest in the UK, with its consequential impacts on the police and justice system. Finally, the expansion of civil nuclear power as nations attempt to decarbonise their energy generation may lead to greater risk of nuclear proliferation, although work to mitigate this by the UK and others through the IAEA is ongoing.
- **Global influence:** The UK has a significant stake in ensuring that global governance structures have both the legitimacy and the capacity to support those states and regions which are most vulnerable to climate change. Failure to support these nations and regions may precipitate the risks outlined above on international stability. There is a risk that UK international influence may decline if existing institutions through which it engages at a global level (such as the UN and NATO) are weakened by the new geopolitical challenges posed by climate change. But there are also opportunities for the UK to take a leadership role and use its skills and expertise in mitigation and adaptation to support those nations most affected by climate change.
- **Finance, business and trade:** There is a risk that the impacts of a warming world are not being properly evaluated or anticipated in the global financial system, leading to potential losses and instability. The vulnerabilities of the financial services are by no means confined to insurance of overseas assets at risk from the effects of climate change. The UK banking sector originates more cross-border bank lending than any other country (18% of the world total in 2009) and UK fund managers are responsible for worldwide assets of £1.2 trillion[8]. Risks of potential disruption to trade flows (UK imports in 2010 were worth £363 billion[9]); commodity price instability and infrastructure from climate change effects need to be considered by both government and businesses. However, there is the possibility of new Arctic trade routes opening, shortening transit times between Europe and Asia. Further, large-scale global investment opportunities relating to adaptation and mitigation ($243 billion investment was made in sustainable energy around the world in 2010[10]) will give opportunities for the UK to capitalise on areas where the UK has a strong competitive advantage, such as financial services, engineering, biotechnology and technology and climate science.

7 United Nations (2011), *UN Peacekeeping Background Note*. Available at: http://www.un.org/en/peacekeeping/documents/backgroundnote.pdf (last accessed 21/06/11).

8 International Financial Services of London (2009) *Fund Management 2009*. Available at: http://www.thecityuk.com/research/our-work/reports-list/ (last accessed 21/06/11).

9 Bloomberg New Energy Finance (2011), Available from: http://www.bloomberg.com/news/2011-01-11/low-carbon-energy-investment-hit-a-record-243-billion-in-2010-bnef-says.html (last accessed 13/04/2011).

10 Nicholls, R., Brown, S., Hanson, S. & Hinkel, J. (2010), *Economics of Coastal Zone Adaptation to Climate Change.* World Bank report, available at: http://beta.worldbank.org/sites/default/files/documents/DCCDP_10_CoastalZoneAdaptation.pdf (last accessed 21/06/11).

- **Resources and infrastructure:** There are risks of future disruption to international infrastructure upon which the UK is dependent, such as transportation, communication and energy networks, due to changing regional climatic conditions, as well as changes in frequency or intensity of extreme weather events. One estimate for adaptation of global coastal zones to predicted sea level rise by 2030 suggests that between $22 billion and $46 billion per year will be needed. The interconnectivity of national and international infrastructure increases the risk of "cascade failures", and the possibility that the impacts of climate events will be felt far from where they occur. This could affect UK business and trade in a number of ways. The security of supply and cost of imported commodities and resources may also be adversely affected by climate change, particularly in the case of food where potential reductions in water availability for agriculture may compound the impact. However, as a wealthy trading nation, the impact on the food supply of the UK is likely to be in the form of price increases rather than loss of security of supply. Other goods that may be negatively affected include aquacultural commodities, manufactured goods and solid fuel and electricity imports. Conversely, relative to nations more affected by climate change, the UK could become more attractive as a source for manufacturing.
- **Health:** There may be direct impacts upon the UK population through an increased risk of infectious diseases being transmitted to the UK, although the extent and timescale for such expansion will be highly specific to individual diseases. There are also likely to be other negative health effects for UK citizens overseas, for example increased deaths from respiratory and cardiac diseases during heatwaves, and injuries and illness caused by flooding.
- **Values and behaviour:** a rising frequency and severity of disasters overseas attributable to climate change in the future may prove to be the catalyst for bridging the value-action gap in the UK whereby the public sees responsibility for mitigation and adaptation lying solely with the government. This offers the opportunity for policymakers to prompt behavioural change and raise the profile of climate change in the UK by communicating effectively on how the onset of climate change effects overseas are having a direct impact on the UK.

6.2 What does this mean for policymakers?

By considering the impact of climate change outside of the UK's borders, this Report offers a new and important perspective on 'what climate change means for the UK'. Key messages from this Report are:

- **To address the risks to the UK from climate change impacts overseas, it is crucial that government departments work across existing boundaries between domestic and international policy, and between climate change mitigation and adaptation.** This requires a collective understanding and response, and should not be 'owned' by any one group working unilaterally. Failure to do this may lead to these risks not being understood or mitigated until it is too late for action.
- **The long-term nature of climate change combined with the uncertainties that exist in projections (for example, on the pace of change, and regional effects), is acting as a significant barrier to decision-making on climate change policies (and policies affected by climate change) and may lead to inappropriate adaptation or inaction when it is needed most.** In many cases, action taken now or in the near future will address future problems for significantly less resource than action at a later date. Policymakers will need to assess potential risks to identify those which require immediate action, or those which may be concerns over the longer term, as the evidence develops and uncertainty diminishes. Building greater resilience into policymaking will therefore be essential to ensure that it has the necessary flexibility and adaptability to manage the uncertainties in the scientific projections.
- **Climate change risks cannot be assessed or treated in isolation from other global threats. The impacts of climate change will need to be factored in across all areas of government policy which have an international dimension.** Climate change is a risk multiplier, interacting with global trends, and exacerbating existing threats to global systems, stability and security. It is not possible to treat the risks identified in this Report in isolation from non-climate change-driven risks. They need to be put into the context of the wider potential changes to the global system over the next century, and the UK's role and position within it. Neither is it plausible or useful to assess these risks directly against each other. They need to be compared with existing risks across the wider UK policy spectrum, for example, conventional threats to national security and resource scarcity.

- **While policymakers need to recognise the high degree of uncertainty in climate projections and future emissions profiles, the challenges of a warming world will arise in one form or another. The uncertainty is not *whether* the world will experience climate change but *how* its impacts will be felt.** The high levels of uncertainty around climate change effects, their interaction with non-climatic drivers of change, the future socio-economic and political direction of global systems and the UK's position within them mean that the risks identified are uncertain to varying degrees. However, if the UK is to identify and respond effectively to the threats of international climate change, plausible risks that go beyond the bounds of observational data need to be considered.
- **There will inevitably be interactions and interdependencies between the impacts of climate change as they develop and the threats and opportunities associated with them.** Although the risks within this Report are presented separately from each other, there are interdependencies and influences between them. A reduction or realisation of one risk may well exacerbate or reduce another, with cumulative impacts a particular concern (e.g. simultaneous negative impacts across diverse energy infrastructure overseas). Consideration of aggregate effects should be more deeply embedded in strategic thinking and policymaking.
- **Managing the risks associated with climate change will require a high degree of international co-operation. It will be important to strengthen the UK's networks of international influence and to work constructively with business and financial organisations.** Mitigating risks affecting the business and financial community will also require a high degree of co-operation between government and the private sector to ensure that the UK is well placed to manage the risks of climate change across all sectors.

6.3 Conclusion

The UK cannot isolate itself from the significant impacts of climate change on other countries around the world. Up to around the 2040s, the Earth is already committed to some level of warming as the climate system slowly responds to past and current greenhouse gas emissions. The level of warming beyond this will be dependent upon on levels of greenhouse gas emissions in the future, and the implications for the UK from global climate change may become increasingly severe. Besides continuing efforts to minimise further warming, the UK needs to take a proactive approach to minimise and manage the threats whilst building on the opportunities identified in this Report.

The way in which many of the risks to the UK may develop are dependent on the actions of other nations. UK action and leadership on combating climate change can encourage other nations to follow suit and ensure that irreversible climate change and unacceptable levels of global impact are avoided, reducing the risks to the world, other nations, and the UK itself.

Annex A: Acknowledgements

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Annex B: Project publications and studies

The views expressed in these papers are the views of the authors and do not represent the views of the Government Office for Science nor the policy of the UK Government.

Reviews (R)	Ref No.
Health sector-related issues in the UK of the impacts of climate change abroad Grynszpan, D., Murray, V., Kreis, I., Zenner, D., Vardoulakis, S., Caldin, H., Morgan, D., Heaviside, C. & Heyman, D.	R:1.1.1
Ethical, social and behavioural impacts of climate change Christie, I., Jackson, T. & Rawles, K.	R:1.3
Understanding the implications of climate change for global governance and institutions Depledge, D. & Feakin, T.	R:2
Physical resources and commodities and climate change Lewis, K., Witham, C. & McCarthy, R.	R:3
A reflection on the long-term evolution of international climate change law and potential impacts upon key areas that may require a response from the United Kingdom de Cendra de Larragán, J.	R:4
Public understanding of and attitudes towards climate change Pidgeon, N.	R:5
The implications on the UK of the impacts of climate change and sea-level rise on critical coastal infrastructure overseas, 2010 to 2100 Nicholls, R. & Kebede, A.S.	R:6.1
The impacts of climate change on overseas infrastructure McGee, A.	R:6.2
The impact of climate change overseas on the UK financial services sector Silver, N., Cox, M. & Garrett, E.	R:8

Discussion Papers (DP)	
The following reports and papers contain interesting perspectives, views and opinions but are not formal reviews. They do not represent the views of Government or of Foresight.	
Climate change and geoengineering Shepherd, J.	DP:1
How climate change will affect the world's largest companies Dickinson, P.	DP:2
Achieving scale in investment: global risk and opportunity from climate change Jones, A.W. & Hiller, B.T.	DP:3
Proprietary environments: innovation paradox and policy Martin, E.D.	DP:4
Climate change and social capital Pelling, M.	DP:5
The ramifications of climate change – the security perspective Feakin, T.	DP:6
The state of climate change science and technology in the UK Kenward, M.	DP:7

Note: some reference numbers were originally reserved for reports that were subsequently not commissioned.

All of the above can be downloaded from the Foresight website (http://www.bis.gov.uk/foresight)

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