Climate Change Risk Assessment for the Energy Sector

January 2012

McColl, L., Angelini, T. and Betts, R.

Contractors: HR Wallingford
AMEC Environment & Infrastructure UK Ltd (formerly Entec UK Ltd)

1The Met Office
Collingwood Environmental Planning
Alexander Ballard Ltd
Paul Watkiss Associates
Metroeconomica
Statement of Use

This report presents the research completed as part of the UK Climate Change Risk Assessment (CCRA) for a selected group of risks in the Energy sector. Whilst some broader context is provided, it is not intended to be a definitive or comprehensive analysis of the sector.

Before reading this report it is important to understand the process of evidence gathering for the CCRA.

The CCRA methodology is novel in that it has compared over 100 risks (prioritised from an initial list of over 700) from a number of disparate sectors based on the magnitude of the consequences and confidence in the evidence base. A key strength of the analysis is the use of a consistent method and set of climate projections to look at current and future threats and opportunities.

The CCRA methodology has been developed through a number of stages involving expert peer review. The approach developed is a tractable, repeatable methodology that is not dependent on changes in long term plans between the 5 year cycles of the CCRA.

The results, with the exception of population growth where this is relevant, do not include societal change in assessing future risks, either from non-climate related change, for example economic growth, or developments in new technologies; or future responses to climate risks such as future Government policies or private adaptation investment plans.

Excluding these factors from the analysis provides a more robust ‘baseline’ against which the effects of different plans and policies can be more easily assessed. However, when utilising the outputs of the CCRA, it is essential to consider that Government and key organisations are already taking action in many areas to minimise climate change risks and these interventions need to be considered when assessing where further action may be best directed or needed.

Initially, eleven ‘sectors’ were chosen from which to gather evidence: Agriculture; Biodiversity & Ecosystem Services; Built Environment; Business, Industry & Services; Energy; Forestry; Floods & Coastal Erosion; Health; Marine & Fisheries; Transport; and Water.

A review was undertaken to identify the range of climate risks within each sector. The review was followed by a selection process that included sector workshops to identify the most important risks (threats or opportunities) within the sector. Approximately 10% of the total number of risks across all sectors was selected for more detailed consideration and analysis.

The risk assessment used UKCP09 climate projections to assess future changes to sector risks. Impacts were normally analysed using single climate variables, for example temperature.

A final Evidence Report draws together information from the 11 sectors (as well as other evidence streams) to provide an overview of risk from climate change to the UK.

Neither this report nor the Evidence Report aims to provide an in depth, quantitative analysis of risk within any particular ‘sector’. Where detailed analysis is presented using large national or regional datasets, the objective is solely to build a consistent picture of risk for the UK and allow for some comparison between disparate risks and regional/national differences.
This is a UK risk assessment with some national and regional comparisons. The results presented here should not be used by the reader for re-analysis or interpretation at a local or site-specific scale.

In addition, as most impacts were analysed using single climate variables, the analysis may be over-simplified in cases where the consequence of climate change is caused by more than one climate variable (for example, higher summer temperatures combined with reduced summer precipitation).
Sector summary

Introduction

The Climate Change Risk Assessment (CCRA) provides an assessment of the risks to the UK caused by climate change. This report covers the impacts of climate change in the Energy Sector.

The UK Energy Sector plays an important role in the UK economy contributing to 3.7% of Gross Domestic Product (GDP) and employing 150,200 people (5% of industrial employment). It also contributes a large fraction of the UK’s total carbon dioxide (CO₂) emissions, since energy production is largely reliant on fossil fuels (emissions from power stations currently account for just under one-third of total CO₂ emissions). In 2009, 5% of the UK energy mix came from nuclear or renewable generated electricity.

The UK government is committed to action to both mitigate and adapt to climate change. The Climate Change Act 2008 sets a clear and credible long term framework for the UK to reduce its greenhouse gas (GHG) emissions including a legal requirement to reduce emissions by at least 80% below 1990 levels by 2050 and by at least 34% by 2020. There is a 15% target for renewable energy contribution towards total energy demand for 2020; this equates to a 30% contribution towards electricity demand for 2020. The devolved administrations are also committed to their own individual adaptation and mitigation targets and policies. These commitments (both national and devolved) mean that the future energy mix will change, but the exact mix (particularly beyond 2050) remains uncertain. Therefore all climate risk-related decisions in this sector will need to be made in the context of this changing landscape and its associated uncertainties.

Key findings

1. Climate change risks facing the industry, including flooding, reduced water supply and extreme temperatures, could adversely affect the ability of the UK Energy Sector to meet projected energy demand.

2. Power stations, electricity substations and other energy infrastructure located in vulnerable areas are likely to face an increased risk of flooding, potentially disrupting energy supplies.

3. The number of power stations at risk of flooding in England and Wales is projected to rise from 19 today to 26 (21 to 27) in the 2020s to 38 (31 to 41) in the 2080s. The risk of flooding to major substations is projected to rise from 46 today, to 53 (48 to 60) by the 2020s and 68 (57 to 79) by the 2080s.

4. The requirements for cooling are likely to increase in the future due to higher temperatures. Energy demand for cooling in London could rise from approximately 1.6 to between 2.2 TWh (Terawatt-hour) and 2.5 TWh, which could have significant associated costs.

5. The findings for demand for cooling must be considered in context with the impact of climate change on demand for heating (BE9 in the Built Environment Sector), which is projected to reduce by approximately 15% by the 2020s, 25% by the 2050s and 40% by the 2080s (for the p50 medium emissions scenario). These reductions would have associated economic benefits.
6. Increases in temperature are expected to reduce the capacity of the electricity networks since in high temperatures certain types of equipment must be "de-rated" (i.e. the amount of current carried must be reduced). De-rating is part of a wider issue since the network experiences approximately 1.5-2% load growth per year and this may increase substantially if the transport system or heating becomes dependent on electricity.

7. Weather sensitivities are routinely taken into account in the Energy Sector, in order to plan maintenance or ensure sufficient contractors are available during large weather events (for example snow or gales). While this does not always specifically include considerations of the impacts of climate change, it provides a good basis upon which such considerations can now be made.

Overall

The objective of the analysis was to assess the main current and future risks to the Energy Sector posed by the current climate and future climate change for the UK to the year 2100. This was carried out using a tiered assessment of risks with Tier 1 (broad level) identifying a broad range of potential impacts and Tier 2 (detailed level) providing a more detailed analysis including quantification and monetisation of some impacts. In the Tier 2 analysis response functions were developed, which defined how changes in climate related to specific consequences, using either historical data or expert elicitation. These response functions were then used to assess the magnitude of risks the UK could face due to climate change, by making use of the UKCP09 climate projections. Where it was not possible to develop response functions, a narrative approach was taken instead.

Why the Tier 2 risks were chosen

The risks selected for the Tier 2 analysis were as follows:

- EN1: Flooding of infrastructure
- EN1b: Flooding of power stations
- EN2: Demand for cooling
- EN3: Heat related damage / disruption
- EN4: Water abstraction.

These risks were selected because:

1. Their likelihood is assessed as relatively high – we are confident that temperatures will continue to rise, so anything vulnerable to the direct effects of warming is likely to be affected. Clearly demand for cooling and heat-related damage relate to temperature. In addition to temperature-related impacts, the increases in intense precipitation projected by climate models and high likelihood of wetter winters in UKCP09 indicate that an increased occurrence of flooding events is a strong possibility.

2. Their impact was assessed as large, either through being widespread (similar effects across large parts of the system, such as widespread increases in demand for cooling) or through potential impacts at key points (e.g. flooding of certain critical pieces of infrastructure).

3. The urgency of addressing these risks is assessed as relatively high. In all cases this is because addressing the risks may take considerable time
(years to decades) between decision and implementation, since they all involve changes in infrastructure.

In addition to the Tier 2 impacts, five other impacts were assessed as marginal:

- EN5: Demand by water suppliers
- EN6: Electricity turbine efficiency
- EN7: Gas pipeline compressor rating
- EN8: Power station cooling processes
- EN9: Wind damage
- EN10: Transmission capacity.

All of these impacts were candidates for a more detailed analysis, however due to time constraints of the CCRA it was only possible to carry out a detailed assessment of impact EN10: Transmission capacity. Often marginal impact scores were slightly lower than the priority impacts because they affect the efficiency of energy production rather than the ability of producing it altogether. This was reflected in lower societal scores compared to the priority impacts. It may be prudent to revisit the remaining marginal impacts in more detail in future CCRA updates. It is also important to note that not being selected for Tier 2 analysis is not an indication that the risks associated with a particular impact are not important.

Finally, one surprising result is that no impacts related to renewables were chosen for assessment. These impacts have been assigned a lower societal score since the UK’s reliance on renewable energy is currently low and for some (for example solar power and biofuel yields) a low likelihood score. It is clear, however, that in the future reliance on renewable power is likely to increase in order to achieve emissions reductions targets. These possible changes in the future energy mix should be readdressed in the future.

Emerging challenges

- **Understanding the future energy mix** – Prioritising adaptation responses to the impacts of climate change must be considered in the context of a changing energy landscape.

- **Changing requirements on the electricity grid** – The load on the electricity network is likely to increase in the future, due to the measures in place to transition towards a low carbon economy. In addition the patterns of energy demand are also likely to change as a consequence of climate change; the seasonal demands on heating and cooling requirements are likely to alter and this may also be affected by future building regulations.

- **Adaptation of existing flood defences** – The defence systems that protect the floodplains and coastline are well developed across most of the UK and have been built to allow for climate change since the 1990s and before. There is likely to be a need to continue to adapt the existing flood risk management systems for future change. The total length of flood defences is over 40,000 km in England and Wales alone, and adaptation to reduce flood risk is likely to remain a significant policy challenge for Government.

- **Balancing water availability** – Any reductions in summer river flows, coupled with unsustainable abstraction, would present a serious challenge for future water and environmental policies. Balancing water availability for
different uses will be a challenge throughout the UK and not just in the South East of England. Due to the uncertainty in climate projections, decisions made now will need to be robust to the full spread of future scenarios and, in due course, be adapted to changing patterns of water availability.

- **Decision-making in the absence of certainty** – Decisions need to be made taking into consideration key uncertainties in future climate change and the consequences of this. For example, some climate variables can be projected with greater confidence than others e.g. mean temperature changes is much better constrained than changes in wind.

**Risk descriptions**

**EN1 and EN1b: Flooding of infrastructure and power stations**

The main risk that flooding poses to the energy sector concerns power stations, electricity transmission and major distribution substations, as overhead lines, underground cables and gas pipelines appear to be less vulnerable to both fluvial and short-term coastal/tidal flooding. Data are not available to assess the vulnerability of gas infrastructure to permanent inundation by sea level rise.

Major fluvial and pluvial flooding events have occurred in the UK in recent years, with electricity supplies being affected. These flooding events have been mostly associated with either, or both, intense rainfall or periods of prolonged rainfall (although one particular major flood also had a significant contribution from rapid and widespread snow melt). Climate projections indicate that a greater proportion of precipitation is expected to fall in intense events, and hence this would increase the risk of flooding events. Moreover, mean winter precipitation is projected to increase, which again would be expected to increase the risk of flooding since soil saturation and filling of stream and river channels would be more common. While climate studies agree on a projected increase in heavy rainfall events in winter over the UK, there is uncertainty in summertime heavy rainfall changes.

There is already an increasing hazard of coastal flooding due to existing sea level rise, and this hazard is confidently expected to increase as further sea level rise is already inevitable. Moreover, even if global warming itself is stabilised, sea level could continue to rise for decades or possibly centuries. However the rate of rise is uncertain.

The Tier 2 analysis of EN1 and EN1b found that substations are at greater risk of fluvial flooding and more power stations are at greater risk of tidal flooding. The number of power stations at risk of flooding in England and Wales is projected to rise from 19 today to 26 (21 to 27) in the 2020s to 38 (31 to 41) in the 2080s. The consequence of flooding on power stations is estimated by the capacity of energy generated by those at significant risk. For tidal flooding this could be 16GW (14.7 to 18.6GW) by the 2080s which is between 18% and 22% of the total capacity of the UK energy network (of course this capacity will increase in the future).

Flooding risk also depends on the vulnerability of the infrastructure. Steps have been taken in recent years to reduce this by assessing the vulnerability of major electricity substations. There may be further opportunities to reduce this still further as current infrastructure reaches the end of its lifetime (power stations, for example, have a lifecycle of approximately 40 years). However, a major component of vulnerability to flooding arises from the siting of infrastructure, and in many cases there are reasons to site new infrastructure at existing sites. Hence flooding risk may also depend strongly on the design of new infrastructure as well as its siting.
The flooding of energy infrastructure seems unlikely to be of major significance for the environment, but would be of very great significance for society and the economy. Loss of power can have severe consequences for communities, ranging from general disruption to everyday life, to implications for health and wellbeing through being able to provide adequate heating and food. In some cases, loss of power can be life-threatening if, for example, critical services such as hospitals are affected. Economic impacts can be very large if businesses are unable to operate and products and services cannot be provided due to loss of power.

**EN2: Cooling demand**

Cooling of buildings accounts for around 4% of the total electricity demand in the UK (approximately 15 TWh) and this demand is increasing with the growth of air-conditioning sales by 5% per year (Day et al., 2009). There have been many changes in Building Regulations to reduce the amount of heating required by new and refurbished buildings (since heating accounts for a far larger proportion of total energy demand), which has led to changes in cooling requirements that include both positive and negative effects.

Temperatures are confidently expected to rise and hence the demand for cooling (for air conditioning, IT infrastructure and refrigeration) can be expected to also rise as an autonomous adaptation response. Increased cooling requirements would have an impact on the Energy Sector since it must be able to meet any changes in energy demand. The impact may be two-fold: first they need to ensure that any increase in summer demand can be met (when historically any maintenance has been carried out during the summer months) and, secondly an increase in demand could affect emissions.

Day et al. (2009) estimate that energy demand for cooling in London could rise from approximately 1.6 TWh, to between 2.2 TWh and 2.5 TWh under a low or high climate change scenario respectively. The cost of an increase in cooling demand is estimated to be high; between £100 and £1000 million in the 2050s and in excess of £1000 million in the 2080s.

One risk to the environment posed by increased demand for cooling would be the potential for increased GHG emissions if the increased demand is met by increased fossil fuel consumption. A further risk to the environment is the potential for increased contribution of waste heat to urban heat islands.

Impacts on society could be significant if demand for cooling is not met. The European heat wave of 2003 claimed several thousand lives, largely due to vulnerable people being unable to keep cool.

Impacts on the economy could be negative or positive. Failure to meet cooling demand could reduce workplace productivity. However meeting the demand could provide opportunities for those responsible for cooling infrastructure and electricity supply.

**EN3: Heat-related damage**

The high temperatures observed in both 2003 and 2006 resulted in power cuts due to cumulative stresses of pre-existing faults compounded by extreme heat. Such evidence combined with the likelihood of higher average temperatures in the future meant that this metric scored highly in the Tier 1 impacts list. However, further exploration of the fault data at a national level and consultation with industry representatives found that any risks from rising temperatures appear to be within the level of planned adaptation for this sector. This is because equipment currently used in the UK is built to resist average temperatures that are much higher than peak temperatures reported in the hottest year. For example, the design standards for
power transformers in the UK state that they must sustain peak ambient air temperature not greater than \(30^\circ\text{C}\) average in one day or more than \(20^\circ\text{C}\) average in any one year.

An important assumption in these conclusions is that old and faulty equipment will be maintained and/or replaced; however there are not data available to explore this assumption analytically.

**EN4: Water abstraction**

The risk of water abstraction for power generation is measured by the volume abstracted from sustainable sources. The Tier 2 analysis shows that there are regulatory risks which may result in the loss of abstraction licences for the power generation sector. This could affect the availability of cooling water for power stations, in turn potentially affecting energy supply. The analysis for this metric was completed for England and Wales only as data were unavailable for Scotland and Northern Ireland.

**EN10: Transmission capacity**

The risk of climate change to transmission capacity, relates to the losses that occur due to temperature increases to overhead line conductors, underground cables and power transformers. In all these cases, the amount of current passing through the equipment must be reduced (or “de-rated”) as air temperature increases, to ensure it does not exceed its maximum permissible operating temperature. This maximum temperature varies depending on the piece of equipment and the impact of increased temperatures also varies (for overhead lines it increase their sag, but for power transformers it can cause electrical faults).

The risk of de-rating the electricity networks (both transmission and distribution) is estimated to increase in the future to increasing temperatures by up to 12% by the 2080s depending on the type of equipment considered. Lower voltage systems are more susceptible to de-rating. It is important to consider this result in conjunction with current changes to load on the network, which have been subject to a load growth of approximately 1.5% to 2% per annum. Therefore, the impact of de-rating is not dissimilar to recent demand. Additionally the future use of smart network technology, although its primary function is mitigation through the transition to a low carbon economy, may provide an adaptation measure to de-rating.

The significance of this risk for the environment is not clear. Impacts on society and economy could be significant if electricity supplies are interrupted more frequently.

**Current vulnerability**

Currently the Energy Sector is most vulnerable to extreme weather events that have an immediate impact on energy supply. Examples include flooding of infrastructure (such as the Carlisle floods in 2005), wind storms or snow and ice accretion causing the failure of overhead lines (the latter being particularly relevant in the 2009 and 2010 winters). The Energy Sector is able to react quickly to events such as wind and snow storms and will usually restore customer supplies within a few days. There is ongoing work within the Energy Sector to address their vulnerability to flooding and to protect substations to 1 in 100, 200 or 1000 year events (depending on the type of flooding and equipment).

In the longer term, climate change impacts are likely to have a greater impact on the vulnerability of the Energy Sector.
• Increases in the requirements of cooling are likely to affect the pattern of energy demand, particularly during periods that are historically used for maintenance.

• De-rating is likely to become more widespread affecting the capacity of the networks. This must be taken into consideration as well as other changing demands (such as increased load due to the electrification of the transport network).

• The efficiency of power generation is likely to be affected in multiple ways due to hotter temperatures; for example reducing turbine efficiency. Additionally, the number of sustainable sources of water abstraction is likely to reduce, affecting the cooling process.

Since energy infrastructure generally has a long life-cycle, reducing vulnerability through decisions to replace infrastructure is not likely to happen quickly. However, when infrastructure must be replaced reducing the risks of climate change can be built into new designs such as improved flood defences.

Adaptive capacity/Awareness in sector

Engagement with industry representatives and the regulator, and the existence of several industry-sponsored analyses of climate change risks, suggests that the energy sector has a relatively high awareness of the risks posed to the sector by climate change. However it is recognised that this varies within individual stakeholders (e.g. different energy companies, and even different sub-sections of the sector).

Adaptive capacity exists to the extent that weather sensitivities and influences are already routinely taken into account in planning in the energy sector. However, since there are often long lead times in implementing decisions (as they often require major changes such as in infrastructure), the response time of the sector may be slow in many cases, simply for practical reasons relating to the nature of the sector. Also, adaptive capacity may be constrained by other factors affecting decisions.

A specific example is reducing the risk of coastal flooding of power stations. A power station typically has a lifetime of around 40 years. If the likelihood of the flooding hazard exceeding vulnerability thresholds is acceptably low within this lifetime, then adaptation may not have to be taken into consideration until planning its predecessor. In this case adaptation can occur by either siting the new power station in a less exposed location, and/or by incorporating flood management within the design of the new power station. The level of acceptability may need to include consideration of the consequences of a flooding event, which may change with time due to factors such as the size of population dependent on the power station and the existence/resilience of other power stations. A more rapid increase in risk (considering changes in both hazard and vulnerability) may require retro-fitting of an existing power station.

Adaptive capacity may also depend to some extent on the specific details of sensitivities to weather and climate, and the ability with which the relevant changes can be forecast. For example, adaptation decisions concerning sea level rise can probably be made with greater confidence than those concerning changes in wind, since changes in the former can be projected with relatively greater confidence. Hence adaptation of coastal power stations (through coastal flood defences) may be easier to assess than the planning of wind farm sites.
Interdependencies

Key links to other CCRA risks and sector reports

There are links to other CCRA sector reports, both through energy sector impacts depending on impacts in other sectors and through risks to energy supply leading to consequences in other sectors. Furthermore, adaptation needs in other sectors could have implications for the energy sector.

The three sectors which energy has the greatest links to are the Floods and Coastal Erosion, Water and Built Environment sectors. For the first, changes in flooding risks could potentially have major implications for energy infrastructure and the security of supply (as a consequence of flooded infrastructure). The generation of energy is highly dependent upon water abstraction (from both rivers and sea water) for use as cooling water in power station processes. This may be affected if temperatures increase in the future, potentially causing river water to be too warm to meet the cooling requirements necessary. The demand for water may also become more competitive if changes in seasonal precipitation patterns result in a decline in water availability. Finally changes in energy demand for both heating and cooling are conditional on the built environment. The pattern of energy demand does not only depend upon temperature, but other factors such as the future uptake of air conditioning or the energy efficiency of future housing stock. Information from all three sectors has been included in this report to highlight these links and dependencies.

In addition to the Floods and Coastal Erosion, Water and Built Environment sectors, there are links to other sectors which are less fundamental, but still remain important. For example, the productivity of biofuels may be affected by climate change providing interdependency between the Energy and Agriculture sectors. Potential impacts in the Marine and Fisheries sector such as a reduction in Arctic sea ice could have positive impacts on the Energy Sector as it may open up Arctic shipping routes, but conversely ocean acidification could damage offshore structures through corrosion.

There are clearly consequences of energy sector impacts for other sectors; since many depend critically on a secure energy supply – indeed it could be argued that most if not all sectors have some dependency. In particular, risks to human health, business and transport may arise from risks to the energy supply.

Finally adaptation needs in other sectors could have consequences on energy, for example reducing heat stress in the Health sector or changes in building design and urban planning in the Built Environment could both have effects on energy demand.

Other drivers

The major socio-economic driver affecting the energy sector is energy policy. This is influenced by the climate change agenda, and the indications are that this influence will probably increase over time as unilateral and international policy moves more towards establishing clear policies relating to GHG emissions reductions.

Similarly, consumer demand may affect the energy sector, especially if there is a consumer requirement to move away from fossil fuels. This is also influenced to some extent by policy, such as the Feed-In Tariff affecting domestic take-up of renewables (particularly solar photovoltaic electricity).

Changes in energy demand, driven by factors such as increasing use of technology, are also a key factor.

Political and societal attitudes to different energy supply sources may be important and may change over time. For example there has been a continuing debate about the
need to increase nuclear capacity. In addition, some renewables – for example, onshore wind – are affected by planning processes.

About the analysis

Data quality and modelling issues

The aspiration to develop response functions relating recent impacts data to weather/climate data, which can be then applied to the UKCP09 probabilistic projections, was ambitious and difficult to do with confidence. In some cases the lack of available datasets and the time available to perform the analysis, was insufficient. In some cases the analysis relied on response functions or results that were derived by previous studies (such as EN10: transmission efficiency or EN2: cooling demand). In future updates of the CCRA it is important that these response functions are checked to ensure that they remain true.

For some analyses it was not possible to carry out a full UK assessment due to a lack of data for Northern Ireland and Scotland; for both the flooding metrics (EN1 and EN1b) and water abstraction (EN4) results are available for only England and Wales.

Daily data were required to carry out cooling degree days (CDD). In this instance the UKCP09 probabilistic projections could not be used since they represent thirty year means. Alternatively daily data from the Met Office regional climate model (RCM) were used. Therefore the results do not sample the same range of uncertainty as the UKCP09 probabilistic projections and only consider the medium emissions scenario. CDD is also available through the Weather Generator and given more time a comparison using the RCM and Weather Generator derived CDD data would be useful.

Many impacts on the Energy Sector depend on extreme events, and only limited information on these is available with the UKCP09 probabilistic projections. Seasonal thirty year means of the change in temperature of the hottest day and the change in precipitation on the wettest day are available. However, these seasonal averages will not capture statistics of extreme events such as prolonged spells of hot weather that occur during heat waves. Alternatively the Weather Generator can be used to generate time series of random weather statistically consistent with the mean climate state in the projections, allowing users to explore how weather may change on a daily basis. However, it is important to note that these data are generated using empirical relationships derived from current weather, which assumes that these relationships will remain constant with climate change. Additionally, since an observed record of 30 years of rainfall data was used to train the Weather Generator, investigating extreme statistics for return periods longer than 10 years should be undertaken with caution.

What is certain and what is uncertain

Many of the impacts in this sector can, in principle, be represented quantitatively, and relationships with weather and other environmental conditions are in many cases already established (either through specific analysis or through hands-on experience of members of the industry). Also, it is a sector where a lot of data is collected in order to monitor performance, and this can be used to analyse relationships with weather and climate variables which are outputs from climate models. Therefore this sector is one in which some degrees of analytical evidence for future impacts can be provided – even if this is still just a quantification of a wide range of possible outcomes.

Clearly a large part of the certainty/uncertainty depends on the uncertainty in the climate projections and uncertainty in the regional climate response to global warming is key. There is greater certainty in some climate variables than others (e.g. mean temperature rise is confidently expected, changes in summer precipitation are less well-constrained, and there is no clear signal in changes in windspeed). These
uncertainties feed through into the uncertainties in the sector-specific impacts; therefore those impacts depending on poorly-constrained variables such as wind can only be assessed by looking at a range of possible outcomes.

Long-term impacts are also contingent on emissions scenarios. Near-term impacts (within the next decade) depend more on natural variability of the climate system than on ongoing warming due to anthropogenic effects. Forecasting of this near-term climate variability has not been included in UKCP09 as this relies on new model techniques (initialised forecasting). Some work has been done outside of the CCRA on applying these near-term climate forecasts to enable improved demand forecasting. There could be scope to build on this.

Very major uncertainties also arise from changes in vulnerability, which depends on a large number of factors, such as the extent to which particular assets are key to supply to a large population, and the resilience of infrastructure to different weather events. Another key aspect of this is the mix of different energy sources. Fossil fuels, nuclear and renewables all have different vulnerabilities to climate change; the future energy mix in the UK is uncertain at present and dependent on UK energy policy.
Acknowledgements

This report incorporates inputs from a number of individuals who provided information and guidance to the project team. We wish to acknowledge the author of the costs assessment (Chapter 7), Paul Watkiss. In addition the project team would like to thank the following organisations for their contribution to this analysis.

Association of Independent Gas Transporters
E.ON
EDF Energy
Energy Networks Association
Energy North West
Environment Agency
National Grid
Natural England
Northern Gas
Ofgem
RWEnpower
Scotia Gas Networks
Scottish Government
Scottish Power Energy Networks
Wales and West Utilities
Western Power Distribution
Key Term Glossary

The key terms are defined below.

**Adaptation** (IPCC AR4, 2007)

- **Autonomous adaptation** – Adaptation that does not constitute a conscious\(^1\) response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.

- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

**Adaptive Capacity** - The ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (modified from the IPCC to support project focus on management of future risks) (Ballard, 2009). As such this does not include the adaptive capacity of biophysical systems.

**Adaptation costs and benefits**

- The costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs.

- The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures.

**Consequence** - The end result or effect on society, the economy or environment caused by some event or action (e.g. economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected etc).

**Impact** - An effect of climate change on the socio-bio-physical system (e.g. flooding, rails buckling).

**Response function** – Function showing how climate impacts or consequences vary with key climate variables; can be based on observations, sensitivity analysis, impacts modelling and/or expert elicitation.

**Risk** - Combines the likelihood an event will occur with the magnitude of its outcome.

**Sensitivity** - The degree to which a system is affected, either adversely or beneficially, by climate variability or change.

**Uncertainty** - A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known.

**Vulnerability** - The extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. It depends not only on a system’s sensitivity but also on its adaptive capacity.

\(^1\) The inclusion of the word ‘conscious’ in this IPCC definition is a problem for the CCRA and we treat this as anticipated adaptation that is not part of a planned adaptation programme. It may include behavioural changes by people who are fully aware of climate change issues.
Contents

Statement of Use v

Sector summary vii

Acknowledgements xvii

Key Term Glossary xix

Contents xxii

1 Introduction 1
  1.1 Background 1
  1.2 Scope and structure of this report 3
  1.3 Overview of the UK Energy sector 4
  1.4 Policy context 7

2 Methodology 12
  2.1 Introduction: CCRA Framework 12
  2.2 Outline of the method used to assess impacts, consequences and risks 13
  2.3 Identify and characterise the impacts 15
  2.4 Assess vulnerability 15
  2.5 Identify the main risks 16
  2.6 Assess current and future risk 16
  2.7 Report on risks 18

3 Impacts and Risk Metrics 19
  3.1 Scoping of impacts 19
  3.2 Selection of impacts 24
  3.3 Narrative summary of impacts 28
  3.4 Risk metrics 31

4 Response Functions 34
  4.1 EN1: Flooding of infrastructure 34
  4.2 EN1b: Flooding of power stations 35
  4.3 EN2: Cooling demand 36
  4.4 EN3: Heat related damage 38
  4.5 EN4: Water abstraction 38
  4.6 EN10: Transmission capacity 41

5 Changes with Climate 43
  5.1 EN1: Flooding of infrastructure 43
  5.2 EN1b: Flooding of power stations 47
Appendix 1 Workshop Outputs 107
Appendix 2 Social Vulnerability Checklist 109
Appendix 3 Scored Tier 1 Impacts 115
Appendix 4 Magnitude, Confidence and Presentation of Results 119
Appendix 5 Water Quality and Environmental Metrics 123
Appendix 6 Future Flood Sector Scenarios 127
Appendix 7 Risk Matrix 133

Tables
Table 1.1 The Government’s framework to ensure the delivery of the Carbon Plan (Source: DECC) 7
Table 1.2 Present devolution arrangements 10
Table 3.1 Energy Tier 1 impacts list 20
Table 3.2 Tier 1 impacts that have been identified as cross-sector 26
Table 4.1 Types of electricity substations and customers supplied 34
Table 4.2 Response function for overhead line conductors, underground cables and power transformers relating the reduced current capacity with an increase of 1°C in temperature 42
Table 5.1 Number of electricity substations at significant risk (1:75) of fluvial and tidal flooding in England and Wales 46
Table 5.2 Number of power stations in England and Wales at significant risk (1:75) of fluvial and tidal flooding and the sum of their capacity (MW) 48
Table 5.3 The number of proposed new nuclear power stations, radioactive waste stores and decommissioning sites at risk of flooding or erosion 49
Table 5.4 Power generation abstractions (Ml/d) coming from sustainable sources (i.e. catchments classed green/grey), considering local catchment water availability 57
Table 5.5 Projected percentage change in power generation abstractions coming from sustainable sources (i.e. catchments classed green/grey), considering local catchment water availability 58
Table 5.6 Projected percentage capacity losses for different UKCP09 climate scenarios and electricity infrastructure (rounded to 1 significant figure) 62
Table 5.7 Projected percentage capacity losses for different UKCP09 climate scenarios and each administration region for overhead line conductors on the distribution network 63
Table 7.1 Summary of results in £million per annum 68
Table 7.2 Monetisation of energy impacts 70
Table 7.3 Future Energy Price Projections (Variable) 71
Table 7.4 Future GHG Emissions from the Electricity Generation Mix 72
Table 7.5 Future GHG Values. Central values and Sensitivity for carbon prices 2008-2100, 2009 £/tCO2e (2009 prices) 73
Table 7.6 Air quality damage costs for electricity generation, 2009 p/kWh 73
Table 7.7 Indicative analysis of Future Cooling Cost and Ancillary GHG and AQ Costs for the marginal increase 10TWh by the 2080s 78
Table 7.8 Indicative analysis of Future Cooling Cost and Ancillary GHG and AQ Costs for the marginal increase of 10 TWh over low emission scenario, by the 2080s 79
Table 7.9 Future Energy Cooling Cost (marginal increase due to climate change) for the UK for UKCIP02 projections [* = increase in energy use] - original prices and reported estimates 79

Figures
Figure 1.1 Summary flow chart of UK energy in 2009 6
Figure 2.1 Stages of the CCRA (yellow) and other actions for Government (grey) 12
Figure 2.2 Steps of the CCRA Method (that cover Stage 3 of the CCRA Framework: Assess risks) 14
Figure 3.1 Impact clusters for the Energy Sector 23
Figure 4.1 Power generation sector (local): reduction in volume abstracted from sustainable sources against reduction in Q95 by UKCP09 river basin region (where data were available) 39
Figure 4.2 Power generation abstractions from sustainable and unsustainable sources by UKCP09 river basin region (baseline flows) 40
Figure 5.1 Cooling Degree Days (CDD) from the 11 member RCM climate projections 53
Figure 5.2 Trajectories for domestic (top) and non-domestic (bottom) cooling demand 55
Figure 5.3 Total water use (Ml/d) of Nuclear Decommissioning Authority sites by UKCP09 river basin region in financial year 2009/2010 59
1 Introduction

1.1 Background

It is widely accepted that the world's climate is being affected by the increasing anthropogenic emissions of greenhouse gases into the atmosphere. Even if efforts to mitigate these emissions are successful, the Earth is already committed to significant climatic change (IPCC, 2007).

Over the past century, the Earth has warmed by approximately $0.7^\circ$C. Since the mid-1970s, global average temperature increased at an average of around $0.17^\circ$C per decade. UK average temperature increased by $1^\circ$C since the mid-1970s (Jenkins et al., 2009), however recent years have been below the long-term trend highlighting the significant year-to-year variability. Due to the time lag between emissions and temperature rise, past emissions are expected to contribute an estimated further $0.2^\circ$C increase per decade in global temperatures for the next two to three decades (IPCC, 2007), irrespective of mitigation efforts during that time period.

The types of impacts expected later in the century are already being felt in some cases, for example:

- Global sea levels rose by 3.3 mm per year ($\pm 0.4$ mm) between 1993 and 2007; approximately 30% was due to ocean thermal expansion due to ocean warming and 55% due to melting of land ice. The rise in sea level is slightly faster since the early 1990s than previous decades (Cazenave and Llovel, 2010).

- The increasing acidity of the oceans caused by increasing atmospheric carbon dioxide (CO$_2$) concentrations is likely to have a negative impact on the many marine organisms and there are already signs that this is occurring, e.g. reported loss of shell weight of Antarctic plankton, and a decrease in growth of Great Barrier coral reefs (ISCCC, 2009).

- Sea ice is already reducing in extent and coverage. Annual average Arctic sea ice extent has decreased by 3.7% per decade since 1978 (Comiso et al., 2008).

- There is evidence that human activity has doubled the risk of a very hot summer occurring in Europe, akin to the 2003 heat wave (Stott et al., 2004).

The main greenhouse gas responsible for recent climate change is CO$_2$ and CO$_2$ emissions from burning fossil fuels have increased by 41% between 1990 and 2008. The rate of increase in emissions has increased between 2000 and 2007 (3.4% per year) compared to the 1990s (1.0% per year) (Le Quéré et al., 2009). At the end of 2009 the global atmospheric concentration of CO$_2$ was 387.2 ppm (Friedlingstein et al., 2010); this high level has not been experienced on earth for at least 650,000 years (IPCC, 2007).

---

2 Global temperature trends 1911-2010 were: HadCRUT3 0.8°C/century, NCDC 0.7°C/century, GISS 0.7°C/century. Similar values are obtained if we difference the decadal averages 2000-2009 and 1910-1919, or 2000-2009 and 1920-1929.

3 Global temperature trends 1975-2010 were: HadCRUT3 0.16°C/decade, NCDC 0.17°C/decade, GISS 0.18°C/decade.
The UK government is committed to action to both mitigate and adapt to climate change⁴ and the Climate Change Act 2008⁵ makes the UK the first country in the world to have a legally binding long-term framework to cut carbon emissions, as well as setting a framework for building the nation’s adaptive capacity.

The Act sets a clear and credible long term framework for the UK to reduce its greenhouse gas (GHG) emissions including:

- A legal requirement to reduce emissions by at least 80% below 1990 levels by 2050 and by at least 34% by 2020.
- Compliance with a system of five-year carbon budgets set up to 15 years in advance, to deliver the emissions reductions required to achieve the 2020 and 2050 targets.

In addition it requires the Government to create a framework for building the UK's ability to adapt to climate change and requires Government to:

- Carry out a UK wide Climate Change Risk Assessment (CCRA) every five years.
- Put in place a National Adaptation Programme for England and reserved matters to address the most pressing climate change risks as soon as possible after every CCRA.

The purpose of this first CCRA is to provide underpinning evidence, assessing the key risks and opportunities to the UK from climate change, and so enable Government to prioritise climate adaptation policies for current and future policy development as part of the statutory National Adaptation Programme which will begin from 2012. The CCRA will also inform devolved Governments’ policy on climate change mitigation and adaptation.

**Climate Change Act: First five year cycle**

The Scope of the CCRA covers an assessment of the risks and opportunities to those elements which have social, environmental and economic value in the UK, from the current climate and future climate change, in order to help the UK and devolved governments identify priorities for action and implement necessary adaptation measures. The Government requires the CCRA to identify, assess, and where possible estimate economic costs of the key climate change risks and opportunities at UK and national (England, Wales, Scotland, Northern Ireland) level. The outputs from the CCRA will also be of value to other public and private sector organisations that have a stake in the sectors covered by the assessment.

The CCRA will be accompanied (in 2012) with a study on the Economics of Climate Resilience⁶ (ECR) that will identify options for addressing some of the priority risks identified by the CCRA, and will analyse their costs and benefits. This analysis will provide an overall indication of the scale of the challenge and potential benefits; and, given the wide-ranging nature of possible interventions, will help to identify priority areas for action by Government on a consistent basis.

This will be followed by the first National Adaptation Programme (NAP). The NAP will set out:

- objectives in relation to adaptation
- proposals and policies for meeting those objectives

⁴ http://www.defra.gov.uk/environment/climate/government/
⁵ http://www.legislation.gov.uk/ukpga/2008/27/contents
⁶ http://www.defra.gov.uk/environment/climate/government/
timescales
an explanation about how those proposals and policies contribute to sustainable development.

The CCRA analysis has been split into 11 sectors to mirror the general sectoral split of climate impacts research; agriculture, biodiversity and ecosystem services, business, industry and services, built environment, energy, floods and coastal erosion, forestry, health, marine and fisheries, transport and water.

1.2 Scope and structure of this report

This Energy sector report is one of the 11 sector reports commissioned as part of the CCRA contract with HR Wallingford, and is a key step in the process of developing the evidence base necessary to deliver the UK CCRA to Parliament, as required by the Climate Change Act, by January 2012. The objective of this report is to provide a comprehensive overview of the risks (and opportunities) presented by climate change on the Energy sector. A tiered methodology has been undertaken to identify and, where possible, quantify these risks, where the level of detail has increased with each tier. This report summarises the results and information obtained during each tier of the methodology.

In Chapter 2 the CCRA methodology that has been applied to each of the 11 sectors is summarised. The first step (known as Tier 1) in the risk assessment was to identify all possible climate impacts on the UK Energy Sector and what is known about them. This work was based on literature reviews, stakeholder participation through workshops, correspondence with wider stakeholders and soliciting expert opinion and was summarised in the Energy Sector Early Issues Report (Met Office, 2010). The impacts and evidence gathered at this stage (including the climate driver and consequences) are summarised in Section 3.1. Since over 30 impacts related to the Energy sector were identified, it was not possible to carry out a full risk assessment on them all. Alternatively, a subset was selected to be analysed in greater detail (the Tier 2 analysis) using a simple multi-criteria assessment; the results of this selection are provided in Section 3.2 and further information on this assessment is provided in Appendix 4. For each impact that has been prioritised for detailed assessment, one or more risk metric was defined and these are described in Section 3.4. The objective of these metrics is to create qualitative or quantitative “response functions” that relate the risk of an impact to climate variables. In addition to the work that is specific to the Energy Sector, Chapter 3 (and where relevant the remainder of this report) draws on information and analysis carried out by other sectors that also affects Energy (for example the Floods and Coastal Erosion Sector analysed the risk of flooding on power stations).

The Tier 2 analysis is undertaken and detailed in Chapters 4-7. The first step in a climate change risk assessment is to understand current sensitivity to climate. This was achieved in Chapter 4 by developing response functions that established how the risk metrics varied with one or more climate variables. In Chapter 5, projections of future climate were then applied to the response functions to assess the magnitude of risk the UK could face due to climate change. The impacts of possible socio-economic changes that are not fully explored by the climate projections are considered in Chapter 6. Examples include population needs or demands, distribution of wealth and level of Government decision making. The final step in the risk assessment was to monetise the risks of the climate change impacts analysed in Tier 2 (Chapter 7). Where sufficiently detailed information from the analysis in Chapter 5 was available a quantitative monetisation was undertaken, otherwise a qualitative assessment has been provided.
All of the information gathered during the tiers of the methodology and the results from the Tier 2 analysis are summarised in the remaining chapters. This includes a discussion of the adaptive capacity of the Energy Sector (Chapter 8), a summary of the results and their implications including any strengths, weaknesses and limitations (Chapter 9) and finally the key conclusions (Chapter 10).

The remainder of this chapter introduces the UK Energy Sector including details of the current UK energy mix, how the sector impacts the national economy and any international dependencies. Section 1.4 focuses on current policy (both national and for the devolved administrations) that affects the Energy Sector, future policy plans and how these may change the future shape and mix of this sector.

1.3 Overview of the UK Energy sector

The majority of the UK’s energy originates from fossil fuels; most power stations are fuelled by coal and gas, the majority of homes have gas central heating and the transport system is dependent on oil. The 2009 UK energy mix (in terms of source and supply) is illustrated in the flow chart in Figure 1.1. This chart is from DECC’s Digest of United Kingdom Energy Statistics (DECC, 2010c) and illustrates the flow of primary fuels from the point at which they become available from home production or imports (on the left) to their eventual final uses (on the right). They are shown in their original state and after being converted into different kinds of energy by the secondary fuel producers. The flows are measured in million tonnes of oil equivalent, with the widths of the bands approximately proportional to the size of the flow they represent.

Key messages from Figure 1.1 are:

- The 2009 UK energy mix consisted of approximately 50% petroleum, 31% natural gas, 11% coal and 5% nuclear or renewable generated electricity.

- In 2009, indigenous production and imports totalled 316.5 million tonnes of oil equivalent. Just over 29% of this energy was exported or used in marine bunkers. A further 16% was lost in converting primary energy into electricity and other energy products, with 6% taken up by energy industry own use through distribution losses. The remaining 48% (152.7 million tonnes of oil equivalent) was final consumption of energy.

- Approximately 69% of UK coal supplies, 40% of oil supplies and 53% of petroleum supplies were imported. Overall the UK imported more coal, manufactured fuels, crude oil, electricity and gas than it exported; but remained a net exporter of petroleum products (DECC, 2010a).

- The majority of energy generated from natural gas is used domestically. All coal supplies are used in coal-fired power stations to produce electricity for domestic and other consumption. A large fraction of petroleum is exported or used in marine bunkers and the remainder is consumed by the transport sector.

In this report we refer to the Energy Sector as consisting of those industries engaged in the production and sales of energy products. The stakeholders in this industry can be divided according to the function that they provide: producing or extracting the primary sources, generation, transmission and distribution, and supply and customer services. Many of the larger companies within the industry perform several of these functions. Organisations such as the Energy Networks Association and the Association of Energy Producers represent groups of companies working within the industry on these specific function areas. These can provide a useful insight into how the industry is responding to climate change and a forum for discussion and developing best practice. The Office
of the Gas and Electricity Markets (Ofgem) regulates the industry, including setting the policy to ensure that the industry adapts to a changing climate, ensuring security of supply, whilst maintaining the best interests of customers.

The Energy Sector plays an important role in the UK economy contributing to 3.7% of Gross Domestic Product (GDP) and employing 150,200 people (5% of industrial employment) in 2009 (DECC, 2010c). As a sector it also contributes a large fraction of the UK’s total CO₂ emissions. Carbon dioxide emissions from power stations currently account for just under one-third of total CO₂ emissions. Since 1990 emissions from power stations have reduced by 26.5% (despite an increase in electricity demand) as a result of greater nuclear and less coal power generation. Emissions from power stations can be split into sectors calculated using their electricity consumption. Fifty-four MtCO₂ (million tonnes of CO₂) from a total of 151 MtCO₂ emitted by power stations in 2009 was attributable to the domestic sector, 48 MtCO₂ to the industrial sector, 45 MtCO₂ to the commercial and public service sector, and 4 MtCO₂ to the transport sector (DECC, 2010b).

Due to the amount of primary energy that is imported into the UK, the Energy Sector is dependent on the international market. Currently, energy import is set to rise from 27% in 2009 to 46-58% in 2020 (DECC, 2010a). The biggest issue associated with this dependency is energy security. Although many countries have established international trade links, climate change could disrupt existing agreements by changing energy requirements and therefore affecting how much energy is available to trade. Additionally, climate change could result in non energy-related political tensions between countries that could then spill over the energy domain.

The UK’s current dependence on fossil fuels is not sustainable in the long term for two reasons: its commitment to reduce GHG emissions and to improve the security availability and affordability of energy through diversification (DECC, 2010a). In the following section, energy policy implemented to achieve this goal is summarised and the potential effects on the future UK energy mix are discussed.
Figure 1.1 Summary flow chart of UK energy in 2009

Source: DECC, 2010c
1.4 Policy context

Mitigation: UK and non-devolved matters

The way in which the landscape of the Energy Sector may change in the future to achieve the UK’s emission reduction targets is a key uncertainty in this report. Any changes in this industry are likely to be dependent upon government policy and strategy.

A comprehensive national strategy to deliver emissions cuts of 18% on 2008 levels by 2020 was delivered in the UK Carbon Plan, published in March 2011. This document sets out actions and deadlines for each government department for the next five years to tackle climate change. The key steps, set out by the UK Government, to a low carbon transition include:

1. A 15% target for renewable energy contribution towards total energy demand for 2020; this equates to a 30% contribution towards electricity demand for 2020.

2. Ensuring the energy efficiency of our housing stock, with a move to zero-carbon new homes by 2016.

3. Transforming transport by cutting average CO₂ emissions from new cars across the EU by 40% on 2007 levels and sourcing 10% of UK transport energy from sustainable renewable sources by 2020.

Whilst the latter two steps will affect the energy sector (for example increased demand due to the electrification of the transport sector), it is the first step that will have the greatest impact on its future landscape. The investment necessary to provide the changes to achieve production of energy through low carbon sources will be realised through a mixture of public and private sector investment, using public money, regulatory change and new incentives, which are detailed in the UK National Infrastructure Plan for England. The policy framework for transforming the sector is summarised in Table 1.1.

Table 1.1 The Government’s framework to ensure the delivery of the Carbon Plan (Source: DECC)

<table>
<thead>
<tr>
<th>Framework to ensure the delivery of the UK Low Carbon Transition</th>
<th>Policy and Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incentivising the power sector to reduce emissions</td>
<td>European Union Emission Trading Scheme (EU ETS). The EU ETS places a cap on total emissions or ‘allowances’, divides the cap into rights to emit and allows participants to trade their allowances. The EU ETS is expected to account for over 65% of the emissions savings in the EU by the 2020s. <strong>Electricity Market Reform White Paper 2011.</strong> Proposing a framework to incentivise low carbon generation and maintenance of secure supplies, whilst keeping bills affordable. This includes:</td>
</tr>
<tr>
<td></td>
<td>• A carbon price floor to reduce investor uncertainty and a fair price on carbon.</td>
</tr>
<tr>
<td></td>
<td>• Feed-in tariffs with contracts for difference to provide stable financial incentives.</td>
</tr>
<tr>
<td></td>
<td>• Emissions performance standard to ensure no new coal-fired power stations are built without</td>
</tr>
</tbody>
</table>
### Framework to ensure the delivery of the UK Low Carbon Transition

<table>
<thead>
<tr>
<th>Taking action to bring forward renewables, nuclear and carbon capture and storage</th>
<th>CCS and to ensure necessary short-term investment in gas.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taking action to create a bigger, smarter grid</td>
<td>Renewables Obligation. Electricity suppliers must source a certain proportion of electricity from renewable sources. Feed-in Tariffs. A financial incentive for the generation of small-scale (less than 5MW) low carbon electricity. Renewable Heat Incentive. Incentivise the generation of renewable heat (to start in 2011). White Paper on Nuclear Power &amp; Energy Act 2008. Facilitating nuclear power new builds and ensuring new nuclear power plants will have secure waste and decommissioning financing. Planning Reform. Ensure planning supports the deployment of electricity technologies. The Government proposes to create a Major Infrastructure Planning Unit, which will take the decisions on larger renewable projects.</td>
</tr>
</tbody>
</table>

The Energy Sector will also have a role in ensuring energy efficiency in the UK’s housing stock as set out in the Green Deal. This deal establishes a framework to allow private companies within the sector to offer consumers energy efficiency improvements at no upfront costs, and recoup payments through a charge in instalments on the energy bill. The additional charge on their bills will be tempered by the reductions that occur due to the amount of savings made by the efficiency improvements. An important aspect of the Green Deal charge is that it is only payable by the bill-payer; i.e. the financial obligation does not move with the individual, but moves to the next bill-payer.

There is much greater uncertainty associated with how the energy sector may change beyond 2020. This depends on many factors including technology costs, physical constraints (including how fast infrastructure can be built), global energy prices, global emission targets, decisions made by individuals and businesses and future policy.
choices. DECC’s 2050 Pathways Analysis has been created to help policymakers, businesses and the public understand the different choices that could be taken to achieve the target of reducing GHG emissions by 80% in 2050 (DECC, 2010d). Originally published in July 2010 and updated earlier this year following a Call for Evidence, the two reports have described a series of illustrative pathways to show some different routes to 2050. None of these pathways are a preferred option. However, they have shown it is possible to meet the target even if some key technologies fail, but that a real challenge to decarbonise major sectors of the economy lies ahead. Although successful to 2050 pathways differ in the technology and lifestyle choices taken, a series of common themes emerge:

- Ambitious reduction in energy demand
- Substantial electrification of the heating, transport and industry sectors
- Electricity supply which is decarbonised and may need to increase significantly on current levels
- A greater variety of renewable energy generation increases the challenge of balancing the grid
- Where electrification is not possible (for example in the aviation sector) sustainable bioenergy supplies are very important
- Demand for fossil fuels will continue
- Emissions from agriculture, waste, industrial processes and international travel, whilst currently a small proportion of today’s emissions, will exceed the maximum level of emissions set by the 2050 target if no action is taken.

The pathways analysis highlights that there are different options available to achieve the 2050 target. However, there is still much uncertainty associated with the shape of future energy infrastructures since this depends upon which sources of energy are prioritised. It is clear, however, that the electricity transmission and distribution networks will have to cope with increased electricity demand. The UK energy mix by 2050 is likely to come from a range of sources including wind, nuclear and fossil fuels with Carbon Capture and Storage (CCS), but the precise mix remains uncertain since the capacity of some generation options is still unclear, due to technological or economic uncertainties.

Mitigation: Devolved Administrations

In addition to the UK strategy, the devolved administrations are also committed not only to achieving the emissions target set out in the UK Climate Change Act 2008, but also to their own individual targets via Northern Ireland’s Programme for Government 2008-2011, Scotland’s Climate Change (Scotland) Act 2009 and the Climate Change Strategy for Wales. In each case the administrations are putting in place strategies and incentives to source a greater proportion of energy from renewables.

---

8 http://www.dhsspsni.gov.uk/index/hss/pfg.htm
9 http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact
10 http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/?lang=en
Table 1.2 shows present devolution arrangements:

<table>
<thead>
<tr>
<th>Devolution in electricity generation and transmission</th>
<th>Wales</th>
<th>England</th>
<th>Scotland</th>
<th>N Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onshore ≤ 50MW</td>
<td>Devolved</td>
<td>LPA</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
<tr>
<td>Onshore &gt; 50MW</td>
<td>IPC</td>
<td>IPC</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
<tr>
<td>Offshore ≤ 1MW</td>
<td>Devolved</td>
<td>LPA</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
<tr>
<td>Offshore &gt; 1MW ≥ 100MW</td>
<td>MMO</td>
<td>MMO</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
<tr>
<td>Offshore &gt; 100 MW</td>
<td>IPC</td>
<td>IPC</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
<tr>
<td>Transmission ≥ 132 KV</td>
<td>IPC</td>
<td>IPC</td>
<td>Devolved</td>
<td>Devolved</td>
</tr>
</tbody>
</table>

Scotland
Scotland’s Energy Sector Plan\(^{11}\) sets out how to ensure that a diverse range of energy sources, robust and resilient transmission systems and prudent energy efficiency measures are in place so that as a country it is well placed to maximise the opportunities presented by climate change and minimise the resulting negative impacts. It includes actions on renewables including marine and offshore wind, development of carbon capture and storage and energy efficiencies.

Wales
The Welsh Government has significant powers relating to delivering wider aspects of a low carbon economy including responsibilities for environmental permitting, marine licensing, general planning (including marine planning), transport, economic development, skills and education, regeneration and local government. The Welsh Government’s Energy Policy Statement, *A Low Carbon Revolution*\(^{12}\), emphasises its determination that Wales should be in the forefront of the global transition to a low carbon economy.

The Welsh Government recognises that energy policy is largely non-devolved, however, within the broad framework of UK energy policy the Welsh Government believes there is considerable scope for greater devolution, especially in relation to consenting individual developments.

The Climate Change Strategy for Wales\(^{13}\) outlines the Welsh Government’s commitment to deliver a 3% reduction in GHG emissions per year in areas of devolved responsibility from 2011. The energy sector has an important contribution to make in delivering this target through reducing energy consumption, improving energy efficiency and maximising renewable and low carbon energy generation. In this context the Welsh Government is committed to delivering a clear framework to encourage behavioural change, working with private and public sector partners to enable the development of larger scale renewable energy generation and supporting transport investment which encourages a shift to low carbon modes of transport. In addition Technical Advice Note (TAN) 8 relates to the provision of wind energy in Strategic Search Areas\(^{14}\).

---


\(^{13}\) [http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/](http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/)

Northern Ireland

In Northern Ireland targets are set in the Northern Ireland Greenhouse Gas Emissions Plan\(^{15}\) and policy to reduce emissions is given in the CRC Scheme\(^{16}\) (Carbon Reduction Commitment Energy Efficiency Scheme). The CRC Scheme aims at improving energy efficiency and cutting CO\(_2\) emissions in large public and private sector organisations.

Adaptation

Whilst the majority of current policy related to the Energy Sector focuses on reducing emissions to meet the targets set by the UK Climate Change Act, there are also policies and strategies in place to consider adaptation measures. Although this sector is traditionally seen as a driver of climate change through its GHG emissions, the sensitivity of key aspects of the Energy Sector to weather reveals that it is likely to be impacted by climate change. Adaptation measures are considered in DECC’s Departmental Adaptation Plan (DAP), the Cabinet Office’s Sector Resilience Plan for Critical Infrastructure 2010 and Climate Resilience Infrastructure: Preparing for a Changing Climate. Since the 2007 UK floods there has been considerable work by the energy companies and Ofgem, supported by DECC, to review the vulnerability of the sector to flooding and to secure funding to increase flood defences. One of DECC’s primary DAP objectives is to work with the Cabinet Office, the energy companies and Ofgem to extend the Sector Resilience Plans beyond flooding risk to an “all hazards” approach (for example considering other extreme weather such as storms, gales, heavy snow, heat waves and drought). The effects of this type of extreme weather were highlighted in the past two winters (2009 and 2010) where snow and exceptionally low temperatures froze pipelines, caused ice accretion on power lines and problems for thermal plants. Finally, the Energy Sector (electricity generators, electricity distributors, electricity transmitters and gas transporters and Ofgem) will all be reporting to Government on the risks they face from climate change and their plans to adapt under the Adaptation Reporting Power\(^{17}\).

Overall it is not certain what the future landscape of the energy sector will be since it depends on many factors both national and international. Nevertheless there are a number of clear commitments incorporated into the current Government strategies to achieve emission reduction targets. In the future there will be a greater reliance on renewable energies. Nuclear power is another low carbon source of energy that may be exploited as an alternative to fossil fuels. There will, however, continue to be a reliance on fossil fuels and consequently there is a continued investment into technologies such as carbon capture and storage. Finally increased energy efficiency is a priority via improvements of the electricity grid. These key messages will be taken into consideration in the remainder of the report.

\(^{15}\) [http://www.doeni.gov.uk/index/protect_the_environment/climate_change.htm](http://www.doeni.gov.uk/index/protect_the_environment/climate_change.htm)

\(^{16}\) [http://www.doeni.gov.uk/index/protect_the_environment/climate_change/crc.htm](http://www.doeni.gov.uk/index/protect_the_environment/climate_change/crc.htm)

2 Methodology

2.1 Introduction: CCRA Framework

The overall aim of the CCRA is to inform UK adaptation policy, by assessing the main current and future risks (threats and opportunities) posed by the current climate and future climate change for the UK, to the year 2100. The overall approach to the risk assessment and subsequent adaptation plan is based on the UK Climate Impacts Programme (UKCIP) Risk and Uncertainty Framework (UKCIP, 2003). The framework comprises eight stages as shown in Figure 2.1. The CCRA has undertaken the Stages 1, 2 and 3 as outlined below. Stages 4 and 5 will be addressed as part of a separate economic assessment, entitled the 'Economics of Climate Resilience', and the remaining stages will be implemented by the UK Government and Devolved Administrations. The framework presents a continual process that can adapt as new evidence and policy emerges; in the case of the CCRA the process will be revisited every five years.

Figure 2.1 Stages of the CCRA (yellow) and other actions for Government (grey)

Adapted from UKCIP (2003).

- Stage 1 is defined by the aim of the CCRA project, to undertake an assessment of the main risks (including both threats and opportunities) posed by climate change that will have social, environmental and economic consequences for the UK.

- Stage 2 established decision-making criteria for the study, which were used to inform the selection of impacts for analysis in Stage 3. These criteria are the social, environmental and economic magnitude of consequences and the urgency of taking adaptation action for UK society as a whole.

- Stage 3 covers the risk assessment process. This involved a tiered assessment of risks with Tier 1 (broad level) identifying a broad range of potential impacts and Tier 2 (detailed level) providing a more detailed analysis including quantification and monetisation of some impacts. A list of climate change impacts was developed based on 11 sectors with further impacts added to cover cross-cutting issues and impacts which fell
between sectors. This list of climate change impacts is referred to as the ‘Tier 1 list of impacts’. This list contained over 700 impacts, which was too many to analyse in detail as part of this first CCRA. Therefore a consolidated list of the highest priority climate change impacts for analysis was developed and referred to as the ‘Tier 2 list of impacts’. This report presents the risk assessment for the Tier 2 impacts.

The background to the framework and the approach used for each of the first three stages is set out in more detail in the CCRA Method Report (Defra, 2010). This chapter aims to summarise the CCRA method for the risk assessment stage (Stage 3 in the framework above) because this includes the specific steps for which results are presented in this report.

2.2 Outline of the method used to assess impacts, consequences and risks

The risk assessment presented in this report is the focus of Stage 3 in the CCRA Framework (see Figure 2.1). This was undertaken through a series of steps as set out in Figure 2.2. These steps are explained in Sections 2.3 - 2.7 below and are discussed in more detail in the CCRA Method report (Defra, 2010).

The components of the assessment sought to:

- **Identify and characterise the impacts** of climate change

  This was achieved by developing the Tier 1 list of impacts, which included impacts across 11 sectors as well as impacts not covered by the sectors and arising from cross-sector links (see Chapter 3 of this report for the Energy Sector Tier 1 list of impacts).

- **Identify the main risks** for closer analysis

  This involved the selection of Tier 2 impacts for further analysis from the long list of impacts in Tier 1. Higher priority impacts were selected by stakeholder groups based on the social, environmental and economic magnitude of impacts and the urgency of taking action (see Chapter 3 of this report and Section 2.5 below).

- **Assess current and future risk**, using climate projections and considering socio-economic factors

  The risk assessment was undertaken by developing ‘response functions’ that provide a relationship between changes in climate with specific consequences based on analysis of historic data, the use of models or expert elicitation. In some cases this was not possible, and a narrative approach was taken instead. The UKCP09 climate projections and other climate models were then applied to assess future risks. The potential impact of changes in future society and the economy was also considered, to understand the combined effects for future scenarios (see Chapters 3 to 7 of this report and Section 2.6 below).

- **Assess vulnerability** of the UK as a whole. This involved:
  
  i. a high level review of Government policy on climate change in the 11 sectors (see Chapter 1 of this report)
  
  ii. a high level assessment of the social vulnerability to the climate change impacts (see Appendix 2 of this report)
iii. a high level assessment of the adaptive capacity of the sectors (see Chapter 8 of this report and Section 2.4 for an overview of the approach, below).

- **Report on risks** to inform action

This report presents the results of the risk assessment for the Energy sector. The results for the other 10 sectors are presented in similar reports and the CCRA Evidence Report (CCRA, 2012) draws together the main findings from the whole project, including consideration of cross-linkages between sectors, and outlines the risks to the UK as a whole.

---

**Figure 2.2 Steps of the CCRA Method (that cover Stage 3 of the CCRA Framework: Assess risks)**
2.3 Identify and characterise the impacts

**Step 1 – Literature review and Tier 1 analysis**

This step scoped the potential impacts of climate change on the UK based on existing evidence and collating the findings from literature reviews, stakeholder participation through workshops, correspondence with wider stakeholders and soliciting expert opinion. This work developed the Tier 1 list of impacts (see Table 3.1). The Tier 1 impacts have not been analysed in detail; high level discussion of these impacts is provided in Chapter 3 of this report.

**Step 2 – Cross-sectoral and indirect impacts**

The Tier 1 lists for the 11 sectors in the CCRA were compared and developed further to include cross-sectoral and indirect impacts. This was undertaken through ‘Systematic Mapping’, which sets out a flow chart to link causes and effects in a logical process. The impacts that were identified in this step were added to the Tier 1 list of impacts.

2.4 Assess vulnerability

**Step 3 – Review of Policy**

Government policy on climate change develops and changes rapidly to keep pace with emerging science and understanding of how to respond through mitigation and adaptation. This report includes an overview of selected relevant policy in Chapter 1 as this provides important context for understanding how risks that are influenced by climate relate to existing policies. This information will be expanded in the Economics of Climate Resilience project and the National Adaptation Programme.

**Step 4 – Social Vulnerability**

The vulnerability of different groups in society to the climate change risks for each sector was considered at a high level through a check list. The completed check list for the Energy sector is provided in Appendix 2. This information is provided for context; it is not a detailed assessment of social vulnerability to specific risks. It should be noted that this step is different from Step 10, which considers how future changes in society may affect the risks.

**Step 5 – Adaptive Capacity**

The adaptive capacity of a sector is the ability of the sector as a whole, including the organisations involved in working in the sector, to devise and implement effective adaptation strategies in response to information about potential future climate impacts. A high level overview of the adaptive capacity of the Energy sector has been carried out through literature review and is presented in Chapter 8. This information is provided for context.
2.5 Identify the main risks

Step 6 – Selection of Tier 2 impacts

The Tier 1 list of impacts for each sector that resulted from Step 2 (see above) was consolidated to select the higher priority impacts for analysis in Tier 2. Firstly, similar or overlapping impacts were grouped where possible in a simple cluster analysis, which is provided in Section 3.1. Secondly, the Tier 2 impacts were selected using a simple multi-criteria assessment based on the following criteria:

- the social, economic and environmental magnitude of impacts
- overall confidence in the available evidence
- the urgency with which adaptation decisions needs to be taken.

Each of these criteria were allocated a score of 1 (low), 2 (medium) or 3 (high) and the impacts with the highest scores over all of the criteria were selected for Tier 2 analysis. The scoring for each sector was carried out based on expert judgement and feedback from expert consultation workshops (or telephone interviews). Checks were carried out to ensure that a consistent approach was taken across all the sectors. The results of the scoring process are provided in Appendix 3.

Step 7 – Identifying risk metrics

For each impact in the Tier 2 list, one or more risk metrics were identified. Risk metrics provide a measure of the consequences of climate change, related to specific climate variables or biophysical impacts. For example, in the Energy sector report, one of the impacts identified is cooling energy demand due to an increase in temperatures. The risk metrics that were identified to measure the consequences of this impact included changes in energy demand (in kWh), peak energy demand in summer (kWh) and cooling degree days (CDD). The risk metrics were developed to provide a spread of information about economic, environmental and social consequences. The metrics have been referenced using the sector acronym and a number; the Energy sector metrics are referenced as EN1 to EN10.

2.6 Assess current and future risk

Step 8 – Response functions

This step established how each risk metric varied with one or more climate variables using available data or previous modelling work. This step was only possible where evidence existed to relate metrics to specific climate drivers, and has not been possible for all of the tier 2 impacts. This step was carried out by developing a ‘response function’, which is a relationship to show how the risk metric varies with change in climate variables. Some of the response functions were qualitative, based on expert elicitation, whereas others were quantitative.

Step 9 – Estimates of changes in selected climate change scenarios

The response functions were used to assess the magnitude of consequences the UK could face due to climate change by making use of the UKCP09 climate projections. This step used the response functions to provide estimates of future risk under three different emissions scenarios (high carbon emissions, A1FI; medium emissions, A1B; low emissions, B1; see http://ukclimateprojections.defra.gov.uk/content/view/1367/687/
for further details), three future 30-year time periods (centred on the 2020s, 2050s and 2080s) and for three probability levels (10, 50 and 90 percent, see http://ukclimateprojections.defra.gov.uk/content/view/1277/500/ for further details), associated with single or combined climate variables. The probability levels are cumulative and denote the degree of confidence in the change given; for example 90% suggests that it is thought very unlikely that the change will be higher than this; 50% suggests that it is thought equally likely that the change will be higher or lower than this; and 10% suggests that it is thought very unlikely that the change will be lower than this. 90% does not mean that the change is 90% likely to occur, for example.

All of the changes given in the UKCP09 projections are derived from a 1961-1990 baseline.

The purpose of this step is to provide the estimates for the level of future risk (threat or opportunity), as measured by each risk metric.

**Step 10 – Socio-economic change**

It is recognised that many of the risk metrics in the CCRA are influenced by a wide range of drivers, not just by climate change. The way in which the social and economic future of the UK develops will influence the risk metrics. Growth in population is one of the major drivers in influencing risk metrics and may result in much larger changes than if the present day population is assumed. For some of the sectors where this driver is particularly important, future projections for change in population have been considered to adjust the magnitude of the estimated risks derived in Step 9.

For all of the sectors, a broad consideration has been made of how different changes in our society and economy may influence future risks and opportunities. The dimensions of socio-economic change that were considered are:

- Population needs/demands (high/low)
- Global stability (high/low)
- Distribution of wealth (even/uneven)
- Consumer driven values and wealth (sustainable/unsustainable)
- Level of Government decision making (local/national)
- Land use change/management (high/low Government input).

The full details of these dimensions and the assessment of the influence they have on the Energy sector is provided in Chapter 6. It should be noted that this step is different from Step 4, which considers how the risks may affect society; whereas this step considers how changes in society may affect the risks.

**Step 11 – Economic impacts**

Based on standard investment appraisal approaches (H.M. Treasury, 2003) and existing evidence, some of the risks were expressed as monetary values. This provides a broad estimate of the costs associated with the risks and is presented in Chapter 7 of this report. A more detailed analysis of the costs of climate change will be carried out in a study on the Economics of Climate Resilience

---

18 http://www.defra.gov.uk/environment/climate/government/
2.7 Report on risks

Step 12 – Report outputs

The main report outputs from the work carried out for the CCRA are:

- The 11 sector reports (this is the sector report for the Energy Sector), which present the overview of impacts developed from Tier 1 and the detailed risk analysis carried out in Tier 2.

- The Evidence Report, which draws together the main findings from all the sectors into a smaller number of overarching themes.

- Reports for the Devolved Administrations for Scotland, Wales and Northern Ireland to provide conclusions that are relevant to each country.
3 Impacts and Risk Metrics

3.1 Scoping of impacts

The initial scoping work in the Energy Sector Early Issues Report (Met Office, 2010) demonstrated that the energy industry has a key role to play in adaptation to, and mitigation of, climate change. The sector is traditionally seen as a driver of climate change, through its greenhouse gas emissions; in the UK, the Government’s commitments, both domestic and international, to abate emissions will have an effect on the industry and the way in which it operates (see Section 1.4 for more details). The sensitivity of key aspects of the energy industry to weather also reveals that all aspects of this industry (producing or extracting primary sources, generation, transmission and distribution, and supply and customer services) are likely to be impacted by climate change.

Using the Early Issues Report (Met Office, 2010) as a starting point, a list of Energy Sector impacts was collated. Impacts were also extracted from the CCRA scoping study (Watkins et al., 2009) and additional grey and research literature (for more details on this process see Section 2.3). The list was collated by considering all energy assets that are sensitive to climate, the climate driver and its consequence. In total, 34 impacts were identified using the methodology outlined in Chapter 2, and a further three were added after comments and suggestions from energy representatives at the energy workshop (see Appendix 1). Table 3.1 lists the Energy Sector impacts including details of their climate driver and consequence. Each impact has been assigned an ID to ensure traceability throughout the CCRA documentation. The table also highlights the impacts that have and have not been selected for the Tier 2 analysis; the scoring system and its implications are discussed in Section 3.2. Finally, the impacts have been grouped into rationalised impacts, highlighting where there are multiple climate drivers that impact on the same type of asset (for example, both reduced days of snow and winter temperatures affect the amount of cold related damage that occurs on energy infrastructure). It is the rationalised impacts that are scored and selected for the Tier 2 analysis.

A cognitive map illustrating how the Tier 1 rationalised impacts cluster is given in Figure 3.1. This map was devised to aid the understanding and interpretation of the impacts during the Tier 1 and 2 scoping and selection process. The impacts were found to divide into the following four clusters: power generation (coal, gas and nuclear), renewables, energy demand and infrastructure and supply.
<table>
<thead>
<tr>
<th>Climate effects</th>
<th>Impacts</th>
<th>T/O/N</th>
<th>Consequences</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main climate driver: Precipitation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Decrease in summer rainfall</td>
<td>Drier summers heighten the risk of subsidence and heave, leaving structures vulnerable to damage or collapse</td>
<td>Red</td>
<td>Power supply disruption – power generation</td>
<td>Rationalised impact: subsidence &amp; heave Not take forward (low score)</td>
</tr>
<tr>
<td>2. Reduced frequency of snowfall and frost (ice storms)</td>
<td>Cold related damage to infrastructure</td>
<td>Green</td>
<td>Reduction in asset deterioration</td>
<td>Rationalised impact: Cold-related damage/disruption Not take forward (low score)</td>
</tr>
<tr>
<td>3. Decreased summer rainfall</td>
<td>Increased demand for water supply (pumping, desalination, recycling and water transfers) and increased competition from other major consumers</td>
<td>Green</td>
<td>Changes to security of supply</td>
<td>Rationalised impact: Demand by water suppliers (ENS) Scored as a marginal impact</td>
</tr>
<tr>
<td>4. Increased frequency and intensity of extreme precipitation</td>
<td>Increased flood risk to infrastructure (power plants, substations and underground transmission infrastructure)</td>
<td>Red</td>
<td>Asset deterioration</td>
<td>Rationalised impact: Flooding of infrastructure (EN1) Selected as a Tier 2 impact (analysis carried out by the Flood Sector)</td>
</tr>
<tr>
<td>5. Changes to seasonal rainfall patterns</td>
<td>Changes to heating demand (time spent indoors)</td>
<td>Yellow</td>
<td>Changes in demand for heating resources (e.g. peaks) - power generation</td>
<td>Rationalised impact: Demand for heating Not taken forward (low score)</td>
</tr>
<tr>
<td>6. Decreased average rainfall</td>
<td>Decreased summer river flow reducing hydro (run of river) or affecting water abstraction for large power stations</td>
<td>Red</td>
<td>Reduced hydropower production and abstraction for power stations.</td>
<td>Rationalised impact: Water abstraction (EN4) and Hydroelectricity production Water abstraction Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>7. Increase in frequency of heavy rainfall events</td>
<td>Increased frequency of dam spills</td>
<td>Yellow</td>
<td>Asset, social and economic deterioration</td>
<td>Rationalised impact: Dam spills Not taken forward (low score)</td>
</tr>
<tr>
<td>8. Changes to cloud cover</td>
<td>Changes to lighting/time spent indoors</td>
<td>Yellow</td>
<td>Changes in energy demand patterns - power generation</td>
<td>Rationalised impact: Demand for heating not taken forward (low score)</td>
</tr>
<tr>
<td>9. Changes to average rainfall</td>
<td>Hydroelectricity availability</td>
<td>Yellow</td>
<td>Water supply - security of supply</td>
<td>Rationalised impact: Hydroelectricity production Not taken forward (low score)</td>
</tr>
<tr>
<td>10. Changes in cloud cover and solar radiation</td>
<td>Changes in resource available for solar power and PV</td>
<td>Yellow</td>
<td>Variations in energy resource - power generation</td>
<td>Rationalised impact: Solar Power Not taken forward (low score)</td>
</tr>
<tr>
<td><strong>Main climate driver: Temperature (gradual changes and extremes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Increased average winter temperature (heating degree days)</td>
<td>Decreased winter heating demand / reduced fuel poverty</td>
<td>Green</td>
<td>Reduced energy demand - power generation</td>
<td>Rationalised impact: Demand for heating Not taken forward (low score)</td>
</tr>
<tr>
<td>Climate effects</td>
<td>Impacts</td>
<td>T/O/N</td>
<td>Consequences</td>
<td>Comments</td>
</tr>
<tr>
<td>------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------</td>
<td>---------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>12. Increased average temperature</td>
<td>Reduction in cold weather related disruption for transmission and distribution infrastructure</td>
<td></td>
<td>Reduction in asset/social/economic deterioration</td>
<td>Rationalised impact: Cold-related damage/disruption Not taken forward (low score)</td>
</tr>
<tr>
<td>13. Increase in temperature (average and extremes)</td>
<td>Overheating of equipment (transformers and transmission lines)</td>
<td></td>
<td>Asset deterioration</td>
<td>Rationalised impact: Heat related- damage/disruption (EN3) Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>14. Higher average summer temperature (cooling degree days)</td>
<td>Increased summer cooling demand (including air conditioning refrigeration)</td>
<td></td>
<td>Increase in installation of mechanical cooling systems (RR); inability of national grid to cope with demand for cooling; evolution of design principles to more passive, less energy intensive, systems (CF) - power generation</td>
<td>Rationalised impact: Demand for cooling (EN2) Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>15. Increase in average summer temperature</td>
<td>Loss of efficiency in power station cooling process</td>
<td></td>
<td>Decrease in power station output - power generation</td>
<td>Rationalised impact: Power stations cooling processes (EN8) Scored as a marginal impact</td>
</tr>
<tr>
<td>16. Increased frequency of high or extreme temperature episodes</td>
<td>Increased summer peak demand (reducing reserve margins)</td>
<td></td>
<td>Greater demand on energy resources at peak times - power generation</td>
<td>Rationalised impact: Demand for cooling (EN2) Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>17. Changes in temperature/soil moisture content</td>
<td>Decrease in efficiency of underground power cables</td>
<td></td>
<td>Potentially reducing the capacity of underground cables - power generation</td>
<td>Rationalised impact: Transmission capacity - underground Low score but incorporated into EN10 in the Tier 2 analysis</td>
</tr>
<tr>
<td>18. Seasonal changes to temperature</td>
<td>Variations in vegetation growing season / vegetation patterns</td>
<td></td>
<td>This affects the resilience of the transmission and distribution network - security of supply</td>
<td>Rationalised impact: Vegetation management Not taken forward (low score)</td>
</tr>
<tr>
<td>19. Increase in temperature</td>
<td>Decrease in efficacy of generation where cooling relies on either sea or river water</td>
<td></td>
<td>Lower cooling efficiency of warmer water - power generation</td>
<td>Rationalised impact: Power stations cooling processes (EN8) Not taken forward (low score)</td>
</tr>
<tr>
<td>20. Increase in average summer temperature</td>
<td>Less air can be drawn into turbines resulting in less fuel burnt.</td>
<td></td>
<td>Decrease in turbine-based power generation – power generation</td>
<td>Rationalised impact: Electricity turbine efficiency (EN6) Scored as a marginal impact</td>
</tr>
<tr>
<td>21. Increase in average summer temperature</td>
<td>Lifestyle changes such as working patterns</td>
<td></td>
<td>Changes in the daily pattern of energy demand - social consequence</td>
<td>Rationalised impact: Diurnal energy demands Not taken forward (low score)</td>
</tr>
<tr>
<td>22. Increased average temperature</td>
<td>Transmission efficiency - lower capacity of electrical transmission as they are de-rated in order to maintain appropriate operating conditions</td>
<td></td>
<td>Reduction in energy supply - power generation</td>
<td>Rationalised impact: Transmission capacity - overhead (EN10) Scored as a marginal impact and selected as a Tier 2 impact</td>
</tr>
<tr>
<td>Climate effects</td>
<td>Impacts</td>
<td>T/O/N</td>
<td>Consequences</td>
<td>Comments</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>-------</td>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td>23. Increased average temperature</td>
<td>Higher work for compressors on gas pipelines</td>
<td></td>
<td>Reduction in energy supply - power generation</td>
<td>Rationalised impact: Gas pipeline compressor rating (EN7) Scored as a marginal impact</td>
</tr>
<tr>
<td>24. Increased frequency of high or extreme temperature episodes</td>
<td>Increased incidence of infrastructure problems to electrical transmission grid</td>
<td></td>
<td>Disruption to energy supply - power generation</td>
<td>Rationalised impact: Heat-related damage/disruption (EN3) Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>25. Increased frequency of high or extreme temperature episodes</td>
<td>Increased inequality for summer cooling availability ('cooling' poverty)</td>
<td></td>
<td>Reduction in energy supply for some - power generation</td>
<td>Rationalised impact: Demand for cooling (EN2) Selected as a Tier 2 impact</td>
</tr>
<tr>
<td>26. Temperature patterns; sea-level rise</td>
<td>Changes in geographic distribution of UK population</td>
<td></td>
<td>Changes to the electricity distribution and transmission networks to account changes in spatial demand – may affect the security of supply</td>
<td>Rationalised impact: Regional energy demands Not taken forward (low score)</td>
</tr>
<tr>
<td>27. Multiple (CO₂, temperature, precipitation extremes, indirect)</td>
<td>Changes in biofuels yields, mainly positive (CO₂ fertilisation, extended growing season) although some negative effects</td>
<td></td>
<td>General increase in biofuels production - power generation</td>
<td>Rationalised impact: Biofuel yields Not taken forward (low score)</td>
</tr>
<tr>
<td></td>
<td>Changes in demand for heating</td>
<td></td>
<td>Changes in demand for heating</td>
<td>Rationalised impact: Taken forward.</td>
</tr>
<tr>
<td></td>
<td>Increased fire hazard due to changes in fuel moisture</td>
<td></td>
<td>Increased fire hazard due to changes in fuel moisture</td>
<td>Not taken forward (low score)</td>
</tr>
<tr>
<td></td>
<td>Increased overheating of energy industry buildings affecting service provision</td>
<td></td>
<td>Increased overheating of energy industry buildings affecting service provision</td>
<td>Not taken forward (low score)</td>
</tr>
</tbody>
</table>

**Main climate driver: Sea level rise**

| 28. Sea level rise and storm surge | Increased rate of inundation in vulnerable areas, increased area considered vulnerable e.g. UK coastal power station sites |  | Asset / Social / Economic Deterioration | Rationalised impact: Flooding of power stations (EN1b) Selected as a Tier 2 impact (analysis carried out by the Flood Sector) |
| 29. Sea level rise and storm surges | Flooding of transport links |  | Restriction of access to (e.g.) power station sites. Potential disruption of fuel deliveries etc - infrastructure failure | Rationalised impact: Flooding of infrastructure (EN1) Selected as a Tier 2 impact (analysis carried out by the Flood Sector) |
| 30. Sea level rise (and storm surge) | Requires consideration in planning and project lifetime of marine renewables installations |  | May change design specifications of marine renewables installations | Rationalised impact: Marine renewables Not taken forward (low score) |

**Main climate driver: Wind speed**

<p>| 31. Change in average wind | Changes in wind generation |  | Changes in wind power production | Rationalised impact: Wind power |</p>
<table>
<thead>
<tr>
<th>Climate effects</th>
<th>Impacts</th>
<th>T/O/N</th>
<th>Consequences</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed</td>
<td></td>
<td></td>
<td>(both on and off shore)</td>
<td>Not taken forward (low score)</td>
</tr>
<tr>
<td>32. Changes in frequency and intensity of storms</td>
<td>Changes to wind load factor</td>
<td></td>
<td>Changes in wind power production (both on and off shore)</td>
<td>Rationalised impact: Wind power Not taken forward (low score)</td>
</tr>
<tr>
<td>33. Changes to frequency and intensity of storms</td>
<td>Changes to storm damage to infrastructure (particularly overhead lines) from fallen trees and wind damage</td>
<td></td>
<td>Disruption to energy supply and asset deterioration</td>
<td>Rationalised impact: Wind damage (EN9) Scored as a marginal impact</td>
</tr>
<tr>
<td>34. Changes to frequency and intensity of storms</td>
<td>Changes in storm damage on wind turbines</td>
<td></td>
<td>Disruption to energy supply and asset deterioration</td>
<td>Rationalised impact: Wind damage (EN9) Scored as a marginal impact</td>
</tr>
</tbody>
</table>

**Additions from workshop and review comments**

| 35. Changes in seasonal patterns of precipitation | Changes to when maintenance schedules can be undertaken | Maintenance of excavation, cable repairs and pipe work may be more difficult | Rationalised impact: Maintenance schedule Not taken forward (low score) |
| 36. Increases in the incidences of lightning strikes | Increases in lightning could decrease the resilience of the electricity networks. | Disruption to energy supply and asset deterioration | Rationalised impact: Lightning Not taken forward (low score) |
| 37. Increased sea level rise, frequency and intensity of extreme precipitation | Increased coastal and river bed erosion exposing energy infrastructure | Disruption to energy supply and asset deterioration | Rationalised impact: Coastal and river bed erosion Not taken forward (low score) |

Figure 3.1 Impact clusters for the Energy Sector

Note: The rationalised impacts and their ID numbers correspond with those in Table 3.1 and those impacts highlighted in bold were selected for Tier 2 analysis.
This schematic illustrates that:

- Those impacts that only affect coal, gas or nuclear power generation are all associated with measures that affect the efficiency of the process. For example, warmer ambient temperatures reduce the amount of air drawn into electricity turbines (warmer air is less dense) and decrease its efficiency (impact 20).

- The majority of impacts in the renewables cluster are directly associated with the amount of energy generated; this is because their energy source is highly correlated with a weather variable such as solar radiation or wind.

- There is very little overlap between those impacts that are clustered in energy demand and the other impact clusters.

- Impacts that belong to multiple clusters are primarily those that are related to infrastructure and, in particular, the delivery of energy (irrespective of how it was generated). For example, cold related damage or disruption belongs to all the clusters with the exception of energy demand.

### 3.2 Selection of impacts

#### 3.2.1 Scoring of impacts

With over 600 impacts identified in the Tier 1 assessment for all 11 sectors and 37 in the Energy Sector, it was outside the scope of the analysis to complete a full assessment of these impacts as part of this CCRA. Alternatively, a subset was selected using a multi-criteria assessment discussed in Section 2.5. The criteria take into consideration three factors: the magnitude of consequences, the likelihood of the consequences occurring and the urgency with which a decision needs to be made. This means that the impacts chosen for the Tier 2 analysis are of the highest priority; in that the consequences of the impacts are large, the certainty associated with them is high and a policy decision to deal with their consequences is needed by 2020. The result of the score for each rationalised impact is given in Table 3.1 and the detailed breakdown in Appendix 3.

The following thresholds were used to divide the impacts into those that would and would not be prioritised for Tier 2 analysis:

1. Priority impacts: 35 or more
2. Marginal impacts: 30 – 35
3. Excluded impacts: less than 30.

These thresholds were selected so that approximately 60% of the impacts that scored the lowest were excluded and the top 20% were included. The remainder of impacts were defined as marginal and to be assessed if there was sufficient time to do so.

Using these thresholds, the priority impacts selected for a more detailed risk assessment for the Energy sector were:

- EN1: Flooding of infrastructure
- EN1b: Flooding of power stations
- EN2: Cooling demand
• EN3: Heat related damage/disruption
• EN4: Water abstraction.

Although identified as a priority impact in the Energy Sector the analysis for impact EN1b was undertaken by the Floods and Coastal Erosion Sector team (FL11a - Power stations at significant likelihood of flooding (number and capacity). However, due to its importance to this sector, the details of the analysis and results of these impacts are included in this report.

Impacts with scores that were assessed as marginal were:

• EN5: Demand by water suppliers
• EN6: Electricity turbine efficiency
• EN7: Gas pipeline compressor rating
• EN8: Power station cooling processes
• EN9: Wind damage
• EN10: Transmission capacity.

All of these impacts were candidates for a more detailed analysis, however due to the time constraints of the CCRA it was only possible to carry out a detailed assessment of impact EN10 (transmission capacity). Often these impact scores were slightly lower than the priority impacts because they affect the efficiency of energy production rather than the overall ability to produce it. This was reflected in lower societal scores compared to the priority impacts. However, due to the importance of the remainder of the marginal impacts a narrative discussing their future risks and consequences is provided in Section 3.3. Although only overhead transmission capacity on the electricity networks scored as a marginal impact and not underground, both are considered in EN10 since the information for both is available.

The remaining impacts have been excluded from any further analysis. One surprising result is that (with the exception of wind damage) all of the impacts that are in the renewables cluster have been excluded (see Figure 3.1). This includes impacts relating to wind power, hydroelectricity production, marine renewables and solar power. In these cases, the impacts have relatively low societal (and in some cases low likelihood) scores compared to the marginal and priority impacts. It is likely that the renewable impacts have been assigned a lower societal score since the Energy Sector’s reliance on renewable energy is currently low. However, it is clear that in the future this reliance is likely to increase due to the UK Government’s policy that has been set in place to achieve their emissions reduction targets (see Section 1.4 for more details). It seems that this policy has not been fully considered when scoring these impacts and may be a limitation in the impacts selection process. To address this, wind power is considered in the narrative on marginal impacts in Section 3.3 and in future updates to the CCRA it is recommended that renewable impacts be considered in conjunction with Government policy.

It is important to note that, although there are many impacts that have not been selected for Tier 2 analysis, this is not an indication that the risks associated with these impacts are not important. For practical purposes the list of impacts had to be narrowed down, but all impacts identified should be considered by the Government.
3.2.2 Cross-sector impacts

To supplement the Energy Sector impacts identified, the process of systematic mapping was undertaken by the Sector Champion to identify any relevant cross-sector impacts (see Section 2.3 for more details). This analysis identified a large number of potential links between impacts in the Energy Sector and those in other sectors. This was either through impacts from one sector affecting another, or through biophysical impacts leading to concurrent consequences in more than one sector. Details of impacts that have cross-sector consequences are provided in Table 3.2.

Table 3.2 Tier 1 impacts that have been identified as cross-sector

<table>
<thead>
<tr>
<th>Impact</th>
<th>Sectors</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding of power stations or infrastructure</td>
<td>Floods and Coastal Erosion, Energy, Built Environment, Agriculture, Business Industry and Services, Transport, Health</td>
<td>Flooding events (of all kinds) often affect a wide geographic area, with consequences for a number of sectors simultaneously. This means that dealing with these events, especially in emergency response, can be affected by a complex cascade of consequences. Flooding can directly affect homes and infrastructure, croplands, businesses and road and rail networks, and create immediate danger to people as well as introducing risks of hypothermia and disease and adverse affects on mental health. Concurrent interruptions or risk to the energy supply (or increases in demand) can compound the overall consequences for all sectors.</td>
</tr>
<tr>
<td>Cooling demand</td>
<td>Energy, Built Environment, Business Industry and Services, Transport, Health</td>
<td>Increased temperatures may result in an increased demand for cooling and would influence building design or retrofitting and urban planning. At the same time, the consequences of high temperatures for electricity supply and transmission (e.g. de-rating of equipment) may potentially affect the ability to meet cooling demand. Failure to meet demand has implications on heat stress and workforce productivity.</td>
</tr>
<tr>
<td>Demand for heating</td>
<td>Energy, Built Environment, Transport</td>
<td>Warmer winters lead to reduced demand for energy for heating and thus reduced energy bills. This is also a design opportunity for new build, as reduced heating capacity/plant would be required.</td>
</tr>
<tr>
<td>Demand for water</td>
<td>Energy, Agriculture, Water, Business Industry and Services, Built Environment, Biodiversity and Ecosystem Services</td>
<td>Changes in seasonal patterns for precipitation may result in a decline of water availability and as a consequence increased competition for water between various sectors. For example, water abstraction for crops may compete with water abstraction for power stations, and both may compete with abstraction for drinking and industrial uses.</td>
</tr>
<tr>
<td>Drought</td>
<td>Energy, Agriculture, Water, Biodiversity and Ecosystem Services</td>
<td>The frequent correlations of drought with high temperatures means that the consequences of drought for the Energy Sector (e.g. availability of cooling water for non-coastal power stations) could coincide with other sectors (similar to demand for water), again leading to compounding consequences across sectors.</td>
</tr>
<tr>
<td>Wind damage</td>
<td>Energy, Business Industry and Services, Health, Transport</td>
<td>Wind damage affecting the Energy Sector (for example loss of overhead lines) affects other CCRA sectors through loss of power to business, homes and hospitals, and these sectors may also be directly affected by wind damage themselves. Dealing with multiple consequences, especially as emergency response, therefore becomes complex.</td>
</tr>
<tr>
<td>Biofuel yields</td>
<td>Energy, Agriculture, Biodiversity and Ecosystem Services</td>
<td>Impacts of climate change and CO₂ rise (through CO₂ fertilisation) on crop productivity may affect the Energy Sector via the supply of biofuels. This may be a positive or negative effect depending on both the climate signal and the strength of CO₂ fertilisation (currently poorly known).</td>
</tr>
<tr>
<td>Disruption to port activities</td>
<td>Energy, Marine and Fisheries, Business Industry and Services, Floods and Coastal Erosion</td>
<td>Increases in sea level rise and storm surges could result in delays or closure of ports and prevention of port activities, damage to infrastructure and cargo and increased costs of maintaining navigation channels. All of these consequences could in turn affect energy through disruption to fuel imports.</td>
</tr>
<tr>
<td>Impact</td>
<td>Sectors</td>
<td>Consequences</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Arctic shipping routes</td>
<td>Energy, Marine and Fisheries, Biodiversity and Ecosystem Services, Business Industry and Services</td>
<td>Arctic sea ice is an important part of the global climate system and is also key to socioeconomic activities in the Arctic and its surroundings. Changes in Arctic sea ice may have both environmental and socioeconomic consequences such as endangering habitats for both animals and indigenous people or opening up shipping routes. Whilst new shipping routes may potentially benefit fuel imports they could also increase the risk of oil spills and the invasion of new alien species to the Arctic.</td>
</tr>
<tr>
<td>Fire risk</td>
<td>Energy, Biodiversity and Ecosystem Services, Forestry, Agriculture, Built Environment</td>
<td>Increased risk of wildfire may have a profound effect on the habitats and species in fire prone areas. Wildfires can also increase rates of erosion and have a detrimental effect on water quality, and hence on aquatic ecosystems. Finally wildfires can have significant threats to large infrastructure.</td>
</tr>
<tr>
<td>Marine renewables</td>
<td>Energy, Marine and Fisheries, Biodiversity and Ecosystem Services</td>
<td>Changes in storm intensity, tidal patterns and wind intensity may all impact on the potential for main renewables such as tidal stream, waves, barrages and offshore wind farms.</td>
</tr>
<tr>
<td>Offshore infrastructure</td>
<td>Energy, Marine and Fisheries</td>
<td>Changes in storm intensity and increases in sea levels may impact on a variety of offshore energy infrastructure including oil and gas platforms, offshore cabling and the structural stability of offshore wind and wave farms. Changes in ocean circulation may also increase the scour around legs and supports of offshore installations.</td>
</tr>
<tr>
<td>Ocean acidification</td>
<td>Energy, Marine and Fisheries</td>
<td>The impact of climate change on increased ocean acidification may have negative consequences on marine species and ecosystems. It is also possible that increased acidification could increase corrosion on offshore structures.</td>
</tr>
</tbody>
</table>

The following cross-sector impacts detailed in Table 3.2 were selected for the Tier 2 analysis in other sector reports: demand for heating, demand for water, Arctic shipping routes and ocean acidification. A discussion and overview of these Tier 2 analyses are provided in Section 3.3.

### 3.2.3 Gaps

Since completing the selection process it has been identified that there are certain impacts that have either not been included on the initial Tier 1 impacts list or have been given a surprisingly low score. Where possible these gaps (detailed in the bullet points below) have been addressed in the report or alternatively are discussed within summaries.

- **Impacts related to nuclear energy infrastructure.** With current Government policy considering the future use of nuclear power as a low carbon energy source (see Section 1.4 for more policy details), consideration of these impacts may be increasingly important. The Floods and Coastal Erosion Sector analysis of power stations includes existing and decommissioned nuclear sites. A separate analysis has been carried out for sites for proposed nuclear power stations, radioactive waste stores and 16 decommissioned sites. This analysis is detailed in Chapter 5.

- **Impacts related to wind power.** As discussed in Section 3.2.1 this impact did not score highly during the selection process. However, with the Government’s commitment to increasing renewables in the coming years (see Section 1.4 for more policy details) impacts relating to wind power may become increasingly important. In hindsight this should have been taken...
into consideration during the scoring and an alternative qualitative assessment is provided in Section 3.3.

- Impacts related to international dependencies. In the systematic mapping process it was identified that the impact of climate change overseas may affect the UK energy sector, for example through the supply of fuel. Although this has not been considered in detail in this report, potential international dependencies are discussed in Section 3.3.

### 3.3 Narrative summary of impacts

Narratives of the potential risks and consequences of the climate change impacts that were categorised as marginal, Tier 2 cross-sector, or identified as gaps are provided below. These impacts have not been included in the Tier 2 analysis due to time constraints and should still be considered as important climate change impacts that may require action.

**EN5: Demand by water suppliers**

A decrease in summer rainfall could increase the demand for water supply (necessary for pumping, desalination, recycling and water transfer) and the competition between the energy industry and other major water consumers. Although this impact has been scored as marginal in this sector, the Water Sector team considered water demand and the amount of water available for public supply, industry and agriculture in its Tier 2 analysis. Metrics to measure this impact were primarily based on water service provider assessments of the amount of water available (Deployable Outputs), the rising demand for water and the balance between these two measures. They also considered the percentage of population affected by a supply-demand deficit (when water resource zones fall into deficit and require demand or supply-side measures).

The analysis found that there are pressures on water availability in the UK that could increase due to drier conditions and rising demands. These pressures affect the north and west as well as the south-east of England, north and south Wales, parts of Scotland and Northern Ireland. In the near term (2020s), the current water resources framework is likely to maintain water supplies but in the longer term (2050s, 2080s), further measures and potentially a change in approach will be required to manage water sustainably.

**EN6: Electricity turbine efficiency**

The efficiency of thermal power stations may be affected by increases in temperature. High temperatures result in lower air density, which may reduce the amount of air drawn into a turbine and consequently the amount of fuel burnt. How much this may affect thermal power station outputs is currently unknown and further research would have to be undertaken to assess this.

**EN7: Gas pipeline compressor ratings**

Offshore gas is processed and brought to shore by gas processing companies and fed into the gas transmission system. The transmission system operates at high pressure (70-94 units of gauge pressure), which in Great Britain is maintained by 26 compressor stations that ensure that gas delivered to coastal terminals is available at the point of demand (National Grid, 2011). Compressor stations are not designed to run at elevated temperatures and consequently in high temperatures the pressure may have to be reduced. The operation of some stations is already an issue in the summer and this could be exacerbated by climate change. Of course this should be considered in combination with pressures of changing patterns of demand. Currently National Grid
Energy Sector Report

(2011) are monitoring this issue to understand whether parts of compressor stations may need to be modified or replaced in the future.

**EN8: Power station cooling process**

The efficiency of thermal power stations depends upon the temperature interval of the steam/gas upstream and downstream. Water is the most effective cooling medium and therefore either river or sea water is extracted in this process. Both increased air and river or sea water temperatures would result in a decrease in the efficiency of a thermal power station. Additionally, water can only be extracted and discharged at or below regulated threshold temperature values. Increased temperatures may result in these thresholds being met more frequently. This could be reduced by changing the cooling system used or reducing the total electricity production (Greis et al., 2009). It is likely that a site-specific analysis would be necessary to carry out a quantitative analysis on this risk since it is likely to depend on many local factors. The ability to provide quantitative information is also dependent on the ability for climate projections to capture climatic conditions such as droughts and hot spells, which is a limitation of the UKCP09 projections.

**EN9: Wind damage**

High wind speeds and gusts can have a large impact on energy infrastructure in particular causing faults on overhead electricity lines. Wind and gale faults are the primary cause of weather-related faults on the network and can cause many customer interruptions. For example, approximately 18,000 wind and gale faults were recorded during the Burns Day storm on 25th January 1990. A recent study by McColl et al. (2011) derived an empirical relationship between daily wind and gale faults and wind gusts. Using future projections of wind gusts from the Met Office Regional Climate Model to drive this empirical relationship, it was found that due to the uncertainty associated with wind projections there is no clear signal associated with the future frequency of wind and gale faults. It is also important to note that whilst the short-term consequences of these types of disruptions are large, repairs can normally be carried out relatively quickly and most customers’ supplies are usually restored within a few days (ENA, 2011).

**BE9: Demand for heating**

Impact BE9 in the Built Environment Sector (Reduction in the number of heating days, Capon and Oakley, 2012) was selected by this sector for Tier 2 analysis as a potential opportunity. Warmer winters in future years are likely to see reduced space heating demand from end users and a reduction in overall fuel bills, increasing the opportunity to lift people out of fuel poverty. There would also be an opportunity for new build design to incorporate lower heating capacity loads. The analysis considered how household space heating energy demand varies with changes in heating degree days. It was found that there is a clear reduction in the projected levels of energy demand to heat homes across all regions in future decades. These figures reinforce the discussion around overheating in buildings, namely that too intent a focus on winter thermal comfort performance in buildings could overlook increasing issues of summer comfort. In the case of domestic properties, a continued focus on improvements to roof and cavity wall insulation in existing stock would provide benefits, both in reducing space heating demand, but also in stabilising internal temperatures during warmer periods. The introduction of shallow geothermal heating-cooling systems could also be used to help mitigate the effect of the potential problem of overheating in buildings.

**MA5: Arctic shipping routes**

Impact MA5 (changes to sea ice) was selected by the Marine and Fisheries Sector for Tier 2 analysis (Pinnegar et al., 2012). In addition to being an important part of the
global climate system, sea ice extent is also key to socioeconomic activities in the Arctic and its surroundings and any changes to sea ice would have huge environmental and socioeconomic consequences (EEA, 2004). For the Energy Sector it could represent an opportunity through the opening of the Arctic passages for shipping and transportation. Using future projections of sea ice extent, the Marine and Fisheries Sector found a projected increase in navigable days in the Arctic particularly for the North East Passage which is key for the UK economy. Although this may have positive impacts on the UK economy it is important to note that there may also be negative consequences such as endangering habitats for indigenous people and animals that rely on the frozen environment to survive, increasing the risk of oil spills and providing a new mechanism for transport of invasive non-native species.

MA3: Ocean acidification

The Marine Sector also considered the impact of climate change on ocean acidification and its consequences on marine species and ecosystems (Pinnegar et al., 2012). This analysis quantified how ocean acidification may change in the future, but the impacts on marine economies and resources remain unknown. It was also identified that ocean acidification may have consequences on the Energy Sector by increasing the corrosion of offshore structures. The Royal Society (2005) report ‘Ocean acidification due to increasing carbon dioxide’ stated that projected changes in acidification up to 2100 are unlikely to cause a large direct increase in the rate of corrosion, but this is a relatively unknown consequence and may be an area worthy of further research.

Gap: Wind power

Changes to wind speed would have an effect on the amount of energy generated by wind power. A particular concern is low wind speeds, since wind turbines will not rotate and generate electricity if the wind speed is too low (below 2 and 5 ms\(^{-1}\)). This is especially problematic during periods of peak energy demand such as during freezing or heat wave conditions. This area of research is a challenging one since climate models are not always able to capture important features such as the storm track or blocking (anticyclonic) conditions (Scaife et al., 2010). A recent study by Thornton (2010) found that mean wind speed over the UK is correlated with the large-scale circulation patterns. Studying future projections of large-scale circulation, an increase in summer anticyclonic conditions over the UK was found which is linked with a reduction in average winds. These results remain uncertain due to climate modelling uncertainty, but with further research this technique may provide useful information to engineers.

Gap: International dependencies

Energy infrastructure by its very nature frequently crosses international boundaries. Notable examples are oil and gas pipelines, and energy network interconnectors between countries. Some of the most strategically-important oil and gas pipelines are located in areas with extreme climates in the present-day. Many pipelines in Russia are built on permafrost, and any melting of the permafrost arising from increasing temperatures could threaten the integrity of the pipeline infrastructures. Extreme weather events in other parts of the world, such as hurricanes in the Gulf of Mexico, can have a dramatic effect on the global energy market, causing price volatility. Extreme conditions with a regional extent large enough to span political boundaries – such as the unusually cold conditions in January 2010 – have the potential to cause international tensions, if demand for energy increases across large regions and the
energy available for trading between countries is reduced. The Foresight International Dimensions of Climate Change\textsuperscript{19} report provides more information on these issues.

3.4 Risk metrics

For each of the priority impacts selected for the Tier 2 analysis, risk metrics have been developed. The objective of these metrics is to create either quantitative or qualitative “response functions” that relate the consequences of an impact to climate variables. More details on risk metrics are provided in Section 2.5.

EN1: Flooding of infrastructure

There are a number of ways to measure the impacts of flooding on energy infrastructure. Discussions with stakeholders identified that under Ofgem’s ongoing Price Control Review, both the electricity (transmission\textsuperscript{20} and distribution\textsuperscript{21}) and the gas (distribution\textsuperscript{22}) sectors have to report the number of faults that have occurred as a result of weather; the length of the disruption; the type of equipment affected; and the number of customers affected. From these last two indicators the total customer minutes lost can be derived (or customer days lost in the case of gas). Since flooding is a fault category that is recorded, these data (in particular the number of flooding faults to have occurred, the number of customer interruptions and the number of customer minutes lost) provide quantitative metrics for the flooding of electricity and gas infrastructure. In addition to these, other metrics proposed included lost load (kWh) or number of physical units being affected by the climate, e.g. cabling, substations, transformers, power stations, pipelines etc. However historical records of these metrics are not available since they are not part of the required data submitted to Ofgem and for this reason the industry finds such quantities more difficult to estimate.

EN1b: Flooding of power stations

This analysis was undertaken by the Floods and Coastal Erosion Sector team, but due to its importance, the results are also detailed in this report. The risk metric for this analysis is defined as the number of power stations at significant risk of flooding (considering both fluvial and coastal/tidal flooding) and their total capacity (in MW). The power stations considered included coal, gas, nuclear and renewable as well as decommissioned nuclear sites. An additional, qualitative assessment has been carried out for proposed new nuclear power stations, radioactive waste stores and decommissioned sites.

EN2: Cooling demand

With increased temperatures, it is likely that energy demand for cooling may also increase due to an increased uptake of air-conditioning systems in both residential and non-residential buildings (this would be an autonomous adaptation response to warmer conditions). Greater cooling demand may also result in additional stress on the energy system at a period during the year that is historically characterised by lower demand and an opportunity for planned maintenance. This may be exacerbated in cities for equipment such as transformers which have a significant thermal inertia that is

\textsuperscript{19} http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change
\textsuperscript{20} More information on the Transmission Price Control Review 5 is available: http://www.ofgem.gov.uk/Networks/Trans/PriceControls/TPCR5/Pages/TPCR5.aspx
\textsuperscript{21} More information on the Electricity Distribution Price Control Review 5 is available: http://www.ofgem.gov.uk/Networks/ElecDist/PriceCntrls/DPCR5/Pages/DPCR5.aspx
\textsuperscript{22} More information on the Gas Distribution Price Control Review 5 is available: http://www.ofgem.gov.uk/Networks/GasDistr/GDPCR2/Pages/GDPCR2.aspx
exploited by allowing them to heat up during the day since they have the opportunity to cool overnight. The urban heat island effect may mean that there is less opportunity to cool overnight in densely populated areas and additional cooling may be required.

The risk metrics identified to measure this impact are energy demand (in kWh), peak energy demand in summer (kWh) and cooling degree days\(^{23}\). However, none of these alone can fully quantify the impact of climate change on the energy system and it is recommended that a combination of metrics would be more appropriate.

**EN3: Heat related damage/disruptions**

This impact relates to damage/disruption on electricity and gas infrastructure. The data that are reported to Ofgem (described for EN1) can be used to develop quantitative risk metrics since solar heat is a specific fault category that is recorded. The metrics for EN3 are therefore the number of solar heat faults to occur and the subsequent number of customer interruptions/customer minutes lost.

**EN4: Water abstraction**

The risk metric used in this analysis are the change in power generation abstractions coming from sustainable sources. The analysis is similar to that undertaken by the Water Sector team for agricultural and industrial abstractions. It looks at all water bodies (lakes, rivers and estuaries) and provides an insight into how the amount of water available for the power generation sector might vary with climate change, through consideration of abstractions from sustainable sources. This is an important issue because of the need for cooling water for power stations, both nuclear and conventional, as well as for other supporting facilities, and could have implications for the maintenance of electricity supplies. Details on abstraction catchments and how their sustainability is assessed are provided in Section 4.5.

**EN10: Transmission capacity**

The capacity of the electricity networks (both transmission and distribution) refers to the amount of electricity that is transferred through the networks. This depends on a number of factors including demand. Network design takes account of normal load growth, which has historically been around 1.5 to 2% per annum. Although this historical level may reduce due to economic and energy efficiency pressures, load on the network is expected to double over the next forty years due to the electrification of the transport and heating systems (ENA, 2011).

The capacity is also affected by climate factors; specifically the effects of temperature. Equipment is heated by the electrical current which passes through it. The total amount of current that can be passed through (or the total current rating) is defined by the equipment’s maximum permissible operating temperature (which varies depending on the materials used in the equipment’s conductor/insulation material). The three types of equipment considered in this impact are:

1. **Overhead line conductors**: as temperature increases, thermal expansion results in increasing sag of overhead line conductors (there is a statutory ground clearance for sag).
2. **Underground cables**: soil temperature and air temperature are directly related; any increases in soil temperature reduce the soil’s ability to conduct heat away from the cables.
3. **Power transformers**: the load capability of a transformer depends on a maximum temperature above which there is the potential for damage and

\(^{23}\) Cooling degree days (CDD) is a measurement of the extent to which temperatures suggest that building may require some form of cooling, based on the daily temperature being above a certain threshold.
an electrical fault. If temperature increases then the amount of current passed through the transformer must be reduced.

A possible risk metric for these impacts is the capacity losses in percentage terms. Another useful metric would be lost load (kWh), however the calculations require multiple assumptions in terms of power line voltage, length of time under de-rated conditions, extent of normal losses for that time of year, etc. and it was considered that this analysis was too detailed to carry out in the scope of this Tier 2 analysis.

**Limitations of risk metrics**

The above risk metrics (with the exception of EN1b which was analysed by the Floods and Coastal Erosion Sector) were collated during the Energy Sector Workshop (see Appendix 1 for details). The representatives at this workshop were mainly energy distribution and transmission stakeholders and consequently the metrics are primarily focussed on the gas and electricity networks. This may present a limitation in the metric selection; in that it is biased towards industry focus rather than policy focus.

The majority of the risk metrics selected provide a means to analyse the sensitivity of the impacts to the climate and can be spatially aggregated to analyse regional effects. Monetisation has been possible for certain impacts, but not all (see Section 2.6 for more details). However, all of the metrics are limited in their informative value in terms of social and environmental consequences. One reason for this may be due to the industry bias discussed above. Where possible a narrative on any clear environmental consequences (for example decommissioning of nuclear reactors) will be provided as an alternative to a quantitative risk metric. The biggest social consequence is likely to be in terms of the price of energy, but since this will also depend on factors external to the UK energy industry (such as international energy prices) it has not been possible to quantify.
4 Response Functions

The purpose of this step in the methodology is to use the risk metrics derived in Section 3.4 to understand the sensitivity (according to the available evidence) of the selected impacts to climate. The result is a response function that is used in conjunction with future climate projections, in Chapter 5, to assess future risks. Understanding current climate sensitivities is essential, not only to develop the response functions, but also to provide a baseline understanding that can be applied to the future assessment.

4.1 EN1: Flooding of infrastructure

To assess the response function between energy disruptions due to flooding and the climate, data were supplied by the Energy Network Association (ENA) and National Grid. Previous work by the ENA (ENA, 2009) and the Construction Industry Research and Information Association (McBain et al., 2010) on the resilience of critical infrastructure shows that flooding poses a low risk to some elements of the network, for example, electricity overhead lines and underground cables. Similarly, communication with Ofgem and industry representatives revealed that there is a low risk to gas networks as these are mostly underground. For this reason the risk metric assessed here is flooding of major electricity substations (i.e. National Grid supply points that transform 400kV to 132kV, see Table 4.1) only (although the impact of flooding on power stations is explored in impact EN1b; see Section 4.2 for more details).

Electricity is transmitted from power stations by high voltage lines and needs to be transformed to lower voltages to be distributed at a local level. This transformation takes place using four main types of substations: the first converts electricity from the transmission lines delivered by National Grid (400kV) into 132kV, the second converts electricity from 132kV into 33kV, the third from 33kV into 11kV and finally the fourth from 11kV into 400V or 230V. The lower the voltage of the substation, the smaller the area that the network supplies and consequently the fewer the number of customers affected in the case of a disruption. Some substation compounds site several substations of different transformation levels. Details of each substation are provided in Table 4.1.

<table>
<thead>
<tr>
<th>Substation type</th>
<th>Typical voltage transformation levels</th>
<th>Number of substations in the UK</th>
<th>Typical size</th>
<th>Typical number of customers supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td>400kV to 132kV</td>
<td>377</td>
<td>250m x 250m</td>
<td>200,000 to 500,000</td>
</tr>
<tr>
<td></td>
<td>132kV to 33kV</td>
<td>1,000</td>
<td>75m x 75m</td>
<td>50,000 to 125,000</td>
</tr>
<tr>
<td>Primary</td>
<td>33kV to 11kV</td>
<td>4,800</td>
<td>25m x 25m</td>
<td>5,000 to 30,000</td>
</tr>
<tr>
<td>Secondary/ domestic</td>
<td>11kV to 400/230V</td>
<td>230,000</td>
<td>4m x 5m</td>
<td>50 to 500</td>
</tr>
</tbody>
</table>

Secondary/domestic distribution substations generally serve a relatively small and localised area. If flooded, the customers they supply are often also flooded and are
unable to be supplied with electricity (ENA, 2009). Primary substations and transmission substations, however, supply a much larger customer base and when flooded can take longer to restore and for this reason are considered more vulnerable. Loss of supply may affect areas not impacted by flood water. In some cases, electricity may be re-routed to minimise disruption to supplies and to optimise network security.

In Section 3.4, the risk metrics for this impact were identified as the number of faults that are caused by flooding and the corresponding number of customer minutes lost or customer interruptions. These data are useful to quantify the consequences of large flooding events. For example, in 2007, serious floods affected large parts of the country including the South East of England, Shropshire and Yorkshire causing disruption to electricity supplies. During this event 329 flooding faults and 59,443 customer interruptions were recorded in Yorkshire. In 2005, severe flooding affected Carlisle including Carlisle grid substations. In this incident power outages occurred in Carlisle for approximately 36 hours; 44 flooding faults and 63,114 customer interruptions were reported.

Although the flooding faults are useful to examine individual events, a recent study by McColl et al. (2011) found that it is difficult to use these data to define empirical relationships between low probability high consequence events and the climate. This is because these events are rare and consequently there are not enough records to develop a statistically robust relationship. It is also important to note that the vulnerability of sites is also dependent on non-climate, site specific factors such as topography and geology; about which detailed information is not available.

Due to the above limitations, it was considered more appropriate to assess the risk of flooding based on the Floods and Coastal Erosion Sector analysis (FL11b - Electricity substations at significant likelihood of flooding) in the Floods and Coastal Erosion sector report (Ramsbottom et al., 2012). In this work, the risk metric was identified to be the number of major electricity substations at significant risk of flooding (considering both fluvial and tidal/coastal flooding) where significant risk was defined as having a 1.3% annual probability of flooding (or 1 in 75 year return period). The locations of major electricity substations in England and Wales were obtained from National Grid data. There are a total of 271 major substations in England and Wales. These locations were then used with the National Flood Risk Assessment 2008 (NaFRA08) to identify which are currently at significant risk. The result provides counts of installations that have been disaggregated into fluvial and tidal flooding. The response function simply applies projections of future flood frequencies (both fluvial and tidal) to these counts to estimate the future number of installations at risk from flooding. More details on this analysis and any limitations and assumptions are provided when the impacts of changes in future climate are investigated (Section 5.1). The analysis was not carried out for Scotland and Northern Ireland since there were insufficient data.

4.2 EN1b: Flooding of power stations

Whilst the flooding of a substation has a relatively localised consequence, the consequence of a power plant failure due to flooding could affect the national availability of energy. It does, however, depend upon the current generation margin; if this is sufficient then there may be no consequence of a power station failure in terms of energy security. Of course, even if it did not affect security of supply, the flooding of a power station is still likely to have large environmental and social consequences.

Like EN1, flooding to power stations is considered in the Floods and Coastal Erosion sector report (Ramsbottom et al., 2012), risk metric FL11a (Power stations at

significant likelihood of flooding), but due to its importance to this sector, the results for the Energy sector are discussed in Section 5.2. The risk metric is the number of power stations at significant risk and this is calculated in the same way as the electricity and gas installations in EN1, but the locations of power stations in England and Wales are obtained from Environment IPCC licences and the UK TOT Power Station Listing. Coal, gas, nuclear and renewable power stations are all included in this count including decommissioned nuclear power stations. These counts will be used as part of the response function with projections of future flood frequencies to quantify future climate risk. Since the capacity of each power station is also known, the sum of the capacities for all power stations at significant risk during the baseline and in the future time periods is also given. This provides an indication of how energy security could be affected during extreme flooding events. Like EN1, the analysis was not carried out for Scotland and Northern Ireland since there were insufficient data.

A separate analysis has been undertaken for proposed new nuclear power stations, radioactive waste stores and decommissioning sites. There are eight proposed new stations, twelve waste stores and sixteen decommissioning sites at a total of nineteen locations. As there is less quantitative information on these sites a response function has not been derived for these sites. Alternatively a qualitative assessment has been carried out indicating how many may be at no, low, medium or high risk to flooding or erosion. More details are provided in Section 5.2.

4.3 EN2: Cooling demand

Cooling of buildings accounts for around 4% of the total electricity demand in the UK (approximately 15TWh (Terawatt-hour)) and this demand is increasing with the growth of air-conditioning sales by 5% per year (Day et al., 2009). There have been many changes in Building Regulations to reduce the amount of heating required by new and refurbished buildings (since heating accounts for a far larger proportion of total energy demand), which has led to changes in cooling requirements that include both positive and negative effects.

Increased cooling requirements would have an impact on the Energy Sector since it must be able to meet any changes in energy demand. The impact may be two-fold: first, the sector needs to ensure that any increase in summer demand can be met (when historically any maintenance has been carried out during the summer months) and secondly, an increase in demand could affect emissions.

There are studies that have defined relationships between total energy demand and variables such as temperature, humidity, wind speed, geographic location, hours of sunshine and GDP (De Cian et al., 2007 and Hor, 2006). Hor et al. (2006) investigated this relationship in the UK. Their analysis shows that there is a strong inverse relationship between demand and temperature. In the winter time, there is a significant lighting and heating load that coincides with lower temperatures. Conversely, in the summer, demand tends to be lower; however, above a critical temperature (approximately 18°C) consumption tends to rise again due to an increase in cooling and air-conditioning loads.

The Hor et al. (2006) analysis is useful to provide a summary of how energy demand varies with changes in climate, but is not appropriate to analyse future cooling demand. The UK has not experienced temperatures that have led to an increased requirement of cooling and as such, the cooling systems are not in place. This means that historical relationships are not a good measure of future demand; it is possible that more relevant experience could be gained from other warmer countries. Future changes in cooling demand are likely to depend upon many factors including changes in building
stock, changes in the uptake of cooling systems, population size and behavioural change as well as changes in climate.

To create a response function for cooling demand, the risk metric Cooling Degree Days (CDD) is used. CDD is the most common climatic indicator of the demand for cooling services and is a measure of the average temperature's departure from a certain base temperature (Isaac and van Vuuren, 2009). It is assumed that if air temperatures are below the base temperature, no energy for cooling is required. In this UK analysis, CDD is defined as the day-by-day sum of the mean number of degrees by which the air temperature is more than a value of 22°C and calculated using the method set out by Jenkins et al. (2009). Analysing future projections of CDD therefore provides a means to assess how cooling demand may change in the future based on climatic factors alone.

To include non-climate factors in the analysis requires a more in depth study such as Day et al. (2009) who have forecasted future cooling demand in London; Isaac and van Vuuren (2009) who have modelled global residential sector energy demand for heating and air conditioning in the context of climate change; and Eskeland and Mideksa (2010) who have estimated European electricity demand in a changing climate. Day et al. (2009) used a CDD approach where energy demand is calculated as a function of the area in London of a particular type of building stock, the cooling system considered, CDD and a coefficient of system performance (this relationship is detailed in CIBSE, 2006). In this study projections of future cooling demand were calculated for various scenarios. These scenarios included:

- different projections of the market share of air-conditioning
- both changes and no changes to climate.

Isaac and van Vuuren (2009) use a similar approach, but also include factors such as population, income level and efficiency of heating/cooling when calculating energy demand. They apply this analysis to a number of regions throughout the globe. In their analysis they are not only able to examine future projections of cooling demand, but the changes to specific drivers. This means they can examine the mechanisms of cooling demand; for example they found that besides climate change, cooling demand increase is mainly due to income growth in regions with a high potential cooling demand.

Eskeland and Mideksa (2010) estimate electricity demand based on assumptions related to consumption and comfort. Comfort is dependent on climate, building insulation, adaptive equipment (for example heaters or fans) and electricity use. It is assumed that comfort increases when there is an increase in low temperatures and decreases when high temperatures increase. Therefore the relationship between electricity usage and temperature is U-shaped. This study also measures the effects of temperature by using CDD and HDD (heating degree days). The empirical relationship that Eskeland and Mideksa (2010) use to estimate demand is a function of price, HDD, CDD, income and the characteristics of housing and appliances. They measure the effect of climate change by keeping the non-climate factors uniform but applying future projections of HDD and CDD to the empirical relationship. This does not, however, take into consideration how housing stock and changes in the use of heating and cooling appliances may change in the future.

Ideally the response function for EN2 would be similar to the functional relationships developed by Day et al. (2009) and Isaac and van Vuuren (2009) by relating CDD to energy demand taking into consideration factors such as different future projections of building stock and uptake of air-conditioning. However, this type of detailed information is not readily available. Alternatively, projections of future energy demand from Day et al. (2009) are reported. It is also possible to make use of information from DECC's
2050 Pathway Analysis, which has been generated to help policymakers, businesses and the public understand the different choices that could be taken to achieve the emission targets (see Section 1.4 for further discussion). This includes future projections of cooling demand for both domestic and non-domestic and four different scenarios that account for climate change and changes in the uptake of air-conditioning (as well as other factors). These projections are also analysed.

4.4 EN3: Heat related damage

The heat related damage risk metric measures the level of energy interruptions due to solar heat stress on the electricity and gas networks (see Section 3.4 for more details on the metric). The high temperatures observed in both 2003 and 2006 resulted in power cuts due to cumulative stresses of pre-existing faults topped by heat damage (145 solar heat faults were recorded in 2003 and 105 in 2006). Such evidence combined with the likelihood of higher average temperatures in the future meant that this metric scored highly in the Tier 1 impacts list. However, further exploration of the fault data at a national level and consultation with industry representatives has shown that any risks from rising temperatures appear to be within the level of planned adaptation for this sector.

Analysing historical data submitted to Ofgem between 2005 and 2009 by industry, the Energy sector team found that the number of interruptions due to heat damage is marginal when compared with the total (less than 1% of all weather-related faults were caused by solar heat). This result is also confirmed by McColl et al. (2011) who carried out a similar analysis, but on a longer historical record. This low failure rate is explained by the fact that equipment currently used in the UK is built to resist average temperatures that are much higher than peak temperatures reported in the hottest year. For example, the design standards for power transformers in the UK state that they must sustain peak ambient air temperature not greater than 30°C average in one day or more than 20°C average in any one year (Standard BS171; see ENA (2011) Appendix 6 for more design standards).

Power interruptions during the heat waves in 2003 and 2006 demonstrated that heat-related damage does affect energy infrastructure, but that this is rare. However, it is equipment that is already faulty that is particularly at risk from heat damage and the impacts of heat on normally operating equipment are not significant. Therefore to ensure the risk of heat-related damage remains within the planned adaptation level, maintenance operations must be carried out effectively and in a timely fashion with particular attention paid to older infrastructure. This is an example of autonomous adaptation since the industry is well prepared for the impacts of climate change due to current high network resilience to heat assuming that the design standard used is kept under review to maintain this level of resilience. The assumption that old and faulty equipment will be maintained and/or replaced is an important caveat, however there are no data on maintenance schedules available and therefore this assumption cannot be explored analytically. Due to the rare occurrence of solar heat faults, it is not possible to derive a response function for heat-related damage due to insufficient data.

4.5 EN4: Water abstraction

The risk of water abstraction for the power generation sector can be measured by looking at the change in abstractions coming from sustainable sources (Section 3.4). In England and Wales, abstraction licensing is assessed at a catchment scale through the Catchment Abstraction Management Strategies (CAMS) system. Calculations on whether abstraction is sustainable are carried out by the Environment Agency and use
Environmental Flow Indicators (EFIs). EFIs relate flow to the ecological quality of water bodies, providing a good estimate of the physical habitat required to meet good ecological status. They are used as thresholds below which it is likely that good ecological status is not supported in a water body and are assessed for individual water bodies, providing a nationally consistent indicator. The results are presented in a map, an example of which is provided in Appendix 5.

The response function for EN4 relates changes in Q95 with percentage change in the volume abstracted from CAMS water bodies with sustainable abstraction. Q95 is the amount of flow exceeded 95 percent of the time (percentile). This response function is derived using available data on the sensitivity of sites to changing Q95, CAMS abstraction figures (MI/day) and the effects of climate change on Q95 (Entec, 2010). A site is deemed to have unsustainable abstraction if a change in Q95 resulted in a CAMS colour that is not grey or green (see Appendix 5 for a CAMS map and the colour definitions). The response function is illustrated in Figure 4.1. Note that the graph illustrates a percentage reduction and therefore the larger the percentage change the bigger the reduction in volume abstracted sustainably.

![Figure 4.1 Power generation sector (local): reduction in volume abstracted from sustainable sources against reduction in Q95 by UKCP09 river basin region (where data were available)](image)

Figure 4.1 shows that the two river basin regions most affected in terms of changes in sustainable abstractions are the Severn and the Thames. For the Severn, there is a 20% decrease in volume abstracted from sustainable sources, for a 10% reduction in Q95. For further reductions in Q95 there are no additional changes. There is a similar pattern for the Thames, with an 18% reduction in volume abstracted from sustainable sources for a 10% reduction in Q95 and no subsequent changes. There is only one other river basin region which shows notable changes, and this is the Humber. The other regions either show no changes in abstractions coming from sustainable sources (Anglian and North West England), very minor reductions in abstractions coming from sustainable sources (of approximately 0.1%, South West England and Western Wales), or the analysis does not apply as all abstractions for the power generation sector already come from unsustainable sources (Dee and Northumbria), or there are no
abstractions for the power generation sector in the region (South East England). Figure 4.2 shows abstractions for the power generation sector from both sustainable and unsustainable sources for baseline flows, by river basin region.

![Power generation abstractions from sustainable and unsustainable sources by UKCP09 river basin region (baseline flows)](image)

**Figure 4.2 Power generation abstractions from sustainable and unsustainable sources by UKCP09 river basin region (baseline flows)**

Although Q95 is regularly used as a key indicator it is known to be a poor indicator of ecological stress on river ecosystems on its own. Hydro-ecological understanding of stress from flow modifications is based on the importance of the flow regime as a whole, including low flows, mid-range flows and high flows. Therefore the analysis only provides a partial view and more work is needed on this risk in future.

Changing low flow patterns can affect the natural world in a number of ways. Firstly they determine how much water is available for different ecosystems and could therefore affect a number of species to varying extents. For example, summer low flows may provide an inadequate physical habitat for certain fish species. Secondly, low flows can also have implications for water quality. One of the main consequences is the effect on the dilution and dispersion of contaminants. There could also be indirect consequences due to changing river velocities, in-stream processes and enhanced sedimentation and erosion (Whitehead *et al.*, 2009a; Whitehead *et al.*, 2009b; Hammond and Pryce, 2007). These changes in water quality may have detrimental consequences for aquatic ecosystems.

For Scotland and Northern Ireland, enquires were made to the Scottish Environment Protection Agency (SEPA), and the Department of the Environment and Northern Ireland Environment Agency to see if any data existed to create a similar response function. However, neither organisation currently holds data showing a possible change in rivers or water bodies complying with the same standards.
4.6 EN10: Transmission capacity

The transmission capacity risk metric is the capacity losses (%) that occur due to temperature increases and relates to overhead line conductors, underground cables and power transformers (see Section 3.4). In all these cases, the amount of current passing through the equipment must be reduced (“de-rated”) as air temperature increases to ensure it does not exceed its maximum permissible operating temperature. This maximum temperature varies depending on the piece of equipment and the impact of increased temperatures also varies (for overhead lines it increase their sag, but for power transformers it can cause electrical faults).

The response function for transmission capacity must therefore quantitatively relate capacity losses to temperature changes. Response functions are available for all three types of equipment from the Energy Networks Climate Change Adaptation Report (ENA, 2011) and the Met Office Energy Phase 2 project (Met Office, 2008). Details of each response function are provided in the list below and collated in Table 4.2.

1. **Overhead line conductors:** The rating of an overhead line conductor can be calculated using the steady-state heat balance equation defined in IEEE STD 738. Ratings must be reduced the most in conditions of high temperatures, high solar radiation and low wind speeds. The Met Office (2008) and ENA (2011) studies found that it is highest daily average ambient temperatures that have the largest effect (this assumption is discussed further in Section 5.6.3). Therefore, for a given change in temperature, the corresponding approximate change in rating is calculated for each type of conductor.

2. **Underground cables:** The equations that are used to derive cable ratings are well understood and incorporated into a suite of cable rating tools called CRATER (ENA, 2011). Using CRATER the ENA (2011) report has calculated the percentage reduction in rating per 1°C of air temperature for a range of cable types and installation methods. Note that there are 16 different types of underground cable considered by ENA (2011). To reduce the number that are analysed in the risk assessment, the equipment with the largest de-rating is chosen for each voltage category to represent the ‘worst case scenario’.

3. **Power transformers:** The transformer design standard BS CP 1010 provides a means for assessing the rating reduction impacts from increased ambient temperature. The ENA (2011) report has used these standards to calculate the capacity losses experienced with a change in temperature.
Table 4.2  Response function for overhead line conductors, underground cables and power transformers relating the reduced current capacity with an increase of 1°C in temperature

The response functions have been derived in work by Met Office (2008) and ENA (2011)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Type</th>
<th>Season</th>
<th>Existing Current Rating</th>
<th>Maximum Temperature (°C)</th>
<th>Current Reduction (per 1°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead line</td>
<td>Distribution: 25mm² Cu</td>
<td>Summer</td>
<td>126 Amps</td>
<td>50</td>
<td>1.6%</td>
</tr>
<tr>
<td></td>
<td>100mm² Cu</td>
<td></td>
<td>316 Amps</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>175mm² Lynx</td>
<td></td>
<td>342 Amps</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transmission: 400mm² Zebra</td>
<td>Winter</td>
<td>1,230 Amps</td>
<td>75</td>
<td>0.81%</td>
</tr>
<tr>
<td></td>
<td>Transmission: 500mm² Zebra</td>
<td>Winter</td>
<td>1,600 Amps</td>
<td>90</td>
<td>0.63%</td>
</tr>
<tr>
<td>Underground cables</td>
<td>LV</td>
<td>Summer</td>
<td>335 Amps</td>
<td>80</td>
<td>0.60%</td>
</tr>
<tr>
<td></td>
<td>11kV</td>
<td>Summer</td>
<td>270 Amps</td>
<td>65</td>
<td>0.79%</td>
</tr>
<tr>
<td></td>
<td>33kV</td>
<td>Summer</td>
<td>355 Amps</td>
<td>65</td>
<td>0.76%</td>
</tr>
<tr>
<td></td>
<td>132kV</td>
<td>Summer</td>
<td>755 Amps</td>
<td>85</td>
<td>0.56%</td>
</tr>
<tr>
<td></td>
<td>400kV</td>
<td>Summer</td>
<td>1,052 Amps</td>
<td>85</td>
<td>0.99%</td>
</tr>
<tr>
<td>Power transformers</td>
<td>11kV</td>
<td>Summer</td>
<td>-</td>
<td>-</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>33 – 132kV</td>
<td>Summer</td>
<td>-</td>
<td>-</td>
<td>0.7%</td>
</tr>
</tbody>
</table>
5 Changes with Climate

In this chapter, the response functions developed in Chapter 4 will be scaled using the UKCP09 future climate scenarios to assess how the risk of each impact may change due to future climate (step 9 in Section 2.6). Before providing the results for each impact, details of the methodology, the data, baseline information and any assumptions or limitations of the analysis are provided. Note that the results presented in this section represent the impacts of climate change, i.e. they consider the impacts of climate change relative to the current socio-economic baseline. Social and economic drivers are considered in Chapters 6 and 7 respectively.

For each metric a scorecard is given at the start of each section to indicate the confidence in the estimates given and the level of risk or opportunity. Confidence is assessed as high (H), medium (M) or low (L). Risks and opportunities are scored either high (3) medium (2) or low (1) (shown to the right). These are given for the lower (l), central (c) and upper (u) estimates for the 2020s, 2050s and 2080s. Further information is provided in Appendix 4. Where estimates are uncertain, or no data are available, this is stated in the scorecard.

### EN1: Flooding of infrastructure

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Confidence</th>
<th>Summary Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN1</td>
<td>Flooding of infrastructure (substations)</td>
<td>H</td>
<td>l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Methodology details

Since flooding events do not occur frequently and are dependent on location it was not possible to derive an empirical relationship between flooding faults and precipitation (see Section 4.1 for more details). Alternatively analysis from the Floods and Coastal Erosion sector is deemed more appropriate and is described here (Ramsbottom et al., 2012). In this analysis the response function uses the number of major electricity substations that are currently at significant likelihood of flooding (either fluvial or tidal) and scales these counts with future projections of future flood frequency projections. Significant flood likelihood is defined as an event with a 1 in 75 year return period. Note that gas infrastructure has not been considered since the vast majority of infrastructure is underground and is therefore considered resilient to flooding.
5.1.2 Data and baseline information

To calculate the current risk of flooding of infrastructure the following two sources of data were used:

1. Locations of electricity substations in England and Wales have been obtained from National Grid 2009 data.

2. The National Flood Risk Assessment 2008 (NaFRA08) has been used to identify which of the electricity substations are currently at significant risk of flooding.

Projections of future flood frequency have been derived by the Floods and Coastal Erosion Sector team for both fluvial and tidal flooding. They provide estimates on the increasing frequency of floods as fluvial flows and tidal water levels increase and are based on work by Defra and the Environment Agency using UKCP09 projections (Kay et al., 2010). The projections are summarised in Appendix 6.

The baseline period for fluvial flooding is 1961-90 and for tidal flooding is 2008. This is due to the difference in the information used to derive the flood frequency projections.

The consequences of flooding are not only dependent on meteorological conditions, but non-climate factors such as flood defences. In this analysis it is assumed that existing flood defences are maintained in their present condition over the long term for tidal and fluvial flooding, though under this scenario there may be some deterioration in the short term before repairs are carried out. Crest levels of the defences remain unchanged from present day. Flood barriers are assumed to operate under present day rules but, as for the fixed defences, it is assumed that the frequency of overtopping will increase with climate change.

This baseline does not, however, take account of current measures to reduce flood risk or the ongoing deterioration of defences. Flood risk reduction and climate change adaptation measures would, if/when implemented, reduce the level of risk. Deterioration of defences would lead to an increase in flood risk if maintenance and repairs are not carried out. There are programmes in place to improve/upgrade existing flood defences and to construct new flood defences. Other ongoing measures to reduce flood risk that are also not taken into account include the prevention of new development in floodplains and sector specific measures to increase flood resistance and resilience for properties. For example, the ENA Engineering Technical Report 138 (ENA, 2009), collated after the 2007 flooding events, has provided clear guidance to assess all substations and ensure they are resilient to a 1 in 100 (fluvial) or 1 in 200 (tidal) flood event for primary substations and 1 in 1000 year event for grid points.

Since this report the electricity networks have been investing in improving their resilience to flooding.

For the baseline condition of defences for coastal erosion it is assumed that defences affected by erosion in rural areas will not be effective after 30 years and defences for urban areas will be maintained on their present alignment.

5.1.3 Assumptions and limitations

All assumptions and limitations in this analysis are detailed in the list below.

1. The National Grid dataset is for transmission site locations in 2009. This includes 400-132kV substations. Each substation location may include one or more voltage level within that location; these locations are counted as one substation in the analysis as we consider just the major
substations. Lower voltage level substations that are served by the major substations may be reconfigured to minimise disruption to supplies.

2. The method does not cover Scotland and Northern Ireland (about 6% of overall risk) because of lack of suitable information.

3. The modelling dataset covers river and coastal flooding, but not surface water flooding. Surface water flooding is very important, but data to assess changes in risk caused by climate change were not available.

4. The analysis covers all areas at risk from flooding including both defended and undefended areas and is based on assets within the present day natural floodplain. It is recognised that the extent of the floodplain is likely to change with rising sea and river levels, but the above limit is considered to be a reasonable assumption in most areas, because flood areas generally extend to the edge of flat ground at the sides of valleys and coastal plains. The vast majority of the future change is caused by the increase in probability of flooding across the existing floodplain rather than the extension of the floodplain.

5. The analysis is based on the assumption that the increase in flood frequency at each location on the floodplain is proportional to the increase in frequency of river flows and tidal water levels. This is a simplification, particularly for defended areas, because the relationship between flood probability at a particular location on the floodplain and the frequency of the river flow or extreme sea level is not linear. This assumption is likely to underestimate the rate of growth of flood risk for assets in defended areas. This is because the volume of water that enters the floodplain (and causes the flooding) increases at a greater rate than the increase in fluvial flow or sea level.

6. There is a concern that future extreme events will become more extreme. In this analysis a range of projections have been considered that are based on different emission and probability levels from the UKCP09 projections.

7. Many of the results have been derived using broad-scale assumptions. Whilst it provides a national assessment it is not suitable for use at a detailed level. For example, specific assets such as power stations may have local defences that provide a higher standard of protection than assumed in the national overview.

5.1.4 Results

Results for the number of major electricity substations (classified as substations that transform 400kV to 132kV) in England and Wales at risk of significant flooding for both the baseline and future projections are given in Table 5.1. To put these results into context, there are 271 major substations in England and Wales (and 377 in the UK as a whole). Currently there are more substations at risk of fluvial rather than tidal flooding. The numbers of substations at risk of flooding (irrespective of whether it is fluvial or tidal) are projected to increase in the future.

The numbers of substations at risk of fluvial flooding are projected to be 32 (27 to 36) in the 2020s, 35 (27 to 41) in the 2050s and 36 (29 to 46) in the 2080s. This represents an increase of between 7% and 70% relative to the 1961-90 baseline by the 2080s. For tidal flooding, the numbers of substations at risk are projected to be 21 (21 to 24) in the 2020s, 29 (24 to 32) in the 2050s and 32 (28 to 33) in the 2080s. This represents
an increase of between 47% and 74% relative to the 2008 baseline by the 2080s. The uncertainty associated with these projections is associated with both the emissions scenario and the probability level.

Table 5.1  Number of electricity substations at significant risk (1:75) of fluvial and tidal flooding in England and Wales

<table>
<thead>
<tr>
<th>Projection</th>
<th>Fluvial flooding</th>
<th>Tidal flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>2020s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium p10</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>Medium p50</td>
<td>32</td>
<td>21</td>
</tr>
<tr>
<td>Medium p90</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>2050s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Low p50</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>Medium p50</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>High p50</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>High p90</td>
<td>41</td>
<td>32</td>
</tr>
<tr>
<td>2080s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>Low p50</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>Medium p50</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>High p50</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>High p90</td>
<td>46</td>
<td>33</td>
</tr>
</tbody>
</table>

There was insufficient information on the substations to extrapolate the risk of flooding to possible capacity losses. However, the risk of flooding to substations has also been considered by the Operations Directorate of the ENA in the Energy Networks Climate Change Adaptation Report\textsuperscript{25} (ENA, 2011). In this report a risk matrix has been compiled to highlight the possible risks of climate change on a number of impacts including substations at risk of river flooding, flash flooding and sea flooding (denoted in the report as AR10, AR11 and AR12). The risk matrix is provided in Appendix 7 and measures risk as a combination of the likelihood of the impact occurring and its relative impact (or in this report’s terminology its consequence). The risk of people affected by tidal and fluvial flooding of substations (AR12 and AR10) is ‘very high’ and for pluvial flooding (AR11) ‘high’. Tidal flooding is assessed as a having a ‘possible’ likelihood of occurrence, but having an ‘extreme’ impact due to the number of people that it would affect. Fluvial flooding is assessed as more likely to occur than tidal or flash flooding (‘probable likelihood’) and could have a ‘significant’ impact.

\textsuperscript{25} This report has been prepared for Defra to assess and act on the risks and opportunities of climate change under the obligations set out by the Climate Change Act 2008. More details: \url{http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/}
5.2 EN1b: Flooding of power stations

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Summary Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN1b</td>
<td>Flooding of power stations</td>
<td>M</td>
</tr>
</tbody>
</table>

### 5.2.1 Methodology details

The Floods and Coastal Erosion Sector team also analysed the risk of flooding of power stations, in addition to that of electricity substations, the results of which are detailed below. The methodology used is the same as that described for substations in Section 5.1.1. All types of power stations are included in the analysis: coal, gas, nuclear (including decommissioned plants) and renewables. As well as the number of power stations at risk, the methodology also considers the sum of energy capacity for all the power stations that are at significant risk of flooding. This provides an indicator of how a large flooding event could affect the security of energy supplies.

A separate analysis has been undertaken for proposed new nuclear power stations, radioactive waste stores and decommissioning sites. There are eight proposed new stations, twelve waste stores and sixteen decommissioning sites at a total of nineteen locations. Due to a lack of quantitative information, a qualitative assessment has been carried out indicating how many may be at no, low, medium or high risk to flooding or erosion.

### 5.2.2 Data and baseline information

To calculate the current risk of flooding of power stations the following two sources of data were used:

1. Locations of power stations in England and Wales have been obtained from the Environment IPCC licences and the UK TOT Power Station Listing.
2. The National Flood Risk Assessment 2008 (NaFRA08) has been used to identify which of the power stations are currently at significant risk of flooding.
3. Information and locations of proposed new nuclear power stations, radioactive waste stores and decommissioning sites for the qualitative assessment were obtained from DECC (2010e), NDA (2008) and Nirex (2005).

The flood frequency data and the baseline information provided in Section 5.1.2 for electricity substations also hold for this analysis.

### 5.2.3 Assumptions and limitations

The assumptions and limitations are the same as those listed in Section 5.1.3.
5.2.4 Results

Results for the number of power stations in England and Wales at risk of significant flooding for both the baseline and future projections and their capacities are given in Table 5.2. The baseline number of power stations at risk is 19. Unlike substations, there are more power stations currently at risk of tidal rather than fluvial flooding; it is likely that this is due to a greater number of power stations on the coast and therefore exposed to tidal flooding. To put this number into context there are 112 power stations in the UK; therefore approximately 17% are currently at risk from flooding.

The number of power stations at significant risk of fluvial flooding is projected to be 9 (6 to 10) in the 2020s, 10 (8 to 12) in the 2050s and 11 (9 to 12) in the 2080s. This represents an increase of between 50% and 100%, relative to the 1961-90 baseline, by the 2080s. For tidal flooding, the numbers of power stations at risk are projected to be 17 (15 to 17) in the 2020s, 24 (17 to 27) in the 2050s and 27 (22 to 29) in the 2080s. This represents an increase of between 70% and 123%, relative to the 2008 baseline, by the 2080s. The uncertainty associated with these projections is associated with both the emissions scenario and the probability level.

Table 5.2 Number of power stations in England and Wales at significant risk (1:75) of fluvial and tidal flooding and the sum of their capacity (MW)

<table>
<thead>
<tr>
<th>Projection</th>
<th>Fluvial flooding</th>
<th>Tidal flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Capacity (MW)</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2208</td>
</tr>
<tr>
<td>2020s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium p10</td>
<td>6</td>
<td>2200</td>
</tr>
<tr>
<td>Medium p50</td>
<td>9</td>
<td>3600</td>
</tr>
<tr>
<td>Medium p90</td>
<td>10</td>
<td>4300</td>
</tr>
<tr>
<td>2050s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>8</td>
<td>2700</td>
</tr>
<tr>
<td>Low p50</td>
<td>10</td>
<td>4300</td>
</tr>
<tr>
<td>Medium p50</td>
<td>10</td>
<td>4300</td>
</tr>
<tr>
<td>High p50</td>
<td>10</td>
<td>4300</td>
</tr>
<tr>
<td>High p90</td>
<td>12</td>
<td>6300</td>
</tr>
<tr>
<td>2080s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>9</td>
<td>4450</td>
</tr>
<tr>
<td>Low p50</td>
<td>11</td>
<td>6000</td>
</tr>
<tr>
<td>Medium p50</td>
<td>11</td>
<td>6000</td>
</tr>
<tr>
<td>High p50</td>
<td>12</td>
<td>6300</td>
</tr>
<tr>
<td>High p90</td>
<td>12</td>
<td>6300</td>
</tr>
</tbody>
</table>

Comparing the risk of tidal flooding, the number of power stations that are at risk of fluvial flooding as a result of climate change is relatively small. The capacity generated by the power stations at risk of tidal flooding is on average two to three times greater than the power stations at risk of fluvial flooding; this highlights that energy security at coastal sites is more vulnerable. The capacity generated by the number of power stations at significant risk of fluvial flooding is 4.3GW (2.7 to 6.3GW) in the 2050s and 6GW (4.4 and 6.3GW) in the 2080s. For tidal flooding the capacity generated is much higher; at 14.8GW (12 to 16GW) in the 2050s and 16GW (14.7 to 18.6GW) in the 2080s. Currently the total installed generating capacity in the UK is 83.6GW and is planned to increase to 109.8GW by 2015-16 (National Grid, 2009). Even with this increase in capacity, the power stations that are estimated to be at significant risk of fluvial flooding in the 2080s account for between 4% and 6% of the total capacity and for tidal flooding in the 2080s between 13% and 17%.
This analysis applies to existing power stations, but it is important to note that they are likely to be decommissioned before the 2080s since they have a life-cycle of approximately 40 years. This does, however, provide an opportunity for the sector to mitigate the long term flood risk by either choosing a location that is not prone to flooding or integrating flood defences into the design of a plant. If it is the former strategy that is adopted this could interact with risk EN4 (water abstraction). Siting thermal power plants away from areas with high risk of flooding may exacerbate risks associated with water abstraction (since moving plants inland from typical coastal or estuarine sites would result in abstraction from smaller rivers). The latter strategy is more likely since much of the infrastructure is in place hence existing sites will continue to be used. This means that the number of power stations at risk in the future will depend upon how flood defences have been integrated into new designs. Additionally, the capacity at risk is also likely to change since new power stations would generate different amounts of energy.

Due to the current commitment by the Government to facilitate the building of new nuclear power stations (see Section 1.4 for more details), the Floods and Coastal Erosion Sector team also carried out a qualitative analysis for sites for proposed new nuclear power stations, radioactive waste stores and decommissioning sites. There are eight proposed new stations, twelve waste stores and sixteen decommissioning sites at a total of nineteen locations. Table 5.3 shows the flood and coastal erosion risk to proposed new nuclear power station sites, existing radioactive waste storage sites and nuclear decommissioning sites. The assessment is qualitative and applies to the 2080s, based on site assessments (DECC, 2010e, Nirex, 2005 and NDA, 2008).

Table 5.3  The number of proposed new nuclear power stations, radioactive waste stores and decommissioning sites at risk of flooding or erosion
(Based on a qualitative site assessment; sources: DECC, 2010e, Nirex, 2005 and NDA, 2008)

<table>
<thead>
<tr>
<th>Flood Risk</th>
<th>Erosion Risk</th>
<th>Number of sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOTAL</td>
<td>New site</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>1</td>
</tr>
<tr>
<td>High</td>
<td>No</td>
<td>1</td>
</tr>
<tr>
<td>Medium</td>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>Medium</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>19</td>
</tr>
</tbody>
</table>

The analysis shows the following risks to nuclear sites in the UK by the 2080s:

- Of the total of nineteen sites with existing or future nuclear facilities, six would have a high risk of flooding if adequate protection is not provided. Four of these sites and one other site would also have a high risk of coastal erosion.

- Five of the eight sites for new nuclear power stations would have a high risk of flooding if adequate protection is not provided. Three of these sites would also have a high risk of coastal erosion.

- Five of the twelve sites used for radioactive waste storage would have a high risk of flooding if adequate protection is not provided. Four of these sites and one other site would also have a high risk of coastal erosion.
Five of the sixteen decommissioning sites would have a high risk of flooding if adequate protection is not provided. Four of these sites and one other site would also have a high risk of coastal erosion.

All of the high risk sites are on the coast or estuaries. They may therefore be exposed to sea level rise and coastal erosion. The sites are generally well protected, but sea level rise would gradually reduce the standard of protection unless defences are raised. Similarly, coastal erosion protection may require upgrading over time depending on changes at each site. It is important to note that there is regulation in place that existing power stations are designed with flood protection measures to protect against a 1 in 10,000 year flood event and that current planning requirements state that new nuclear build plants are also designed to take account of climate change impacts.

5.3 EN2: Cooling demand

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Summary Class</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Confidence</td>
<td>l c u</td>
<td>l c u</td>
<td>l c u</td>
</tr>
<tr>
<td>EN2</td>
<td>Demand for cooling</td>
<td>H</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

5.3.1 Methodology details

This analysis is split into two parts detailed below.

Part 1: Changes in cooling requirements via CDD

Cooling Degree Days (CDD) are used as a common climatic indicator of the demand for cooling services and is a measure of the average temperature’s departure from a certain base temperature (Isaac and van Vuuren, 2009). It is assumed that if air temperatures are below the base temperature, no energy for cooling is required. In this UK analysis CDD is defined as the day-by-day sum of the mean number of degrees by which the air temperature is more than a value of 22 °C and calculated using the method set out by Jenkins et al. (2009). Analysing future projections of CDD therefore provides a means to assess how cooling demand may change in the future based on climatic factors alone. The first part of this analysis focuses on only the projections of CDD as an indicator of how the burden of cooling demand may change in the future as a result of only climate factors.

Part 2: Qualitatively assessing the potential impacts in terms of energy demand

The objective of the second part of this analysis is to understand how a change in cooling requirements will impact the Energy Sector in terms of energy demand. Although there are not sufficient data available to carry out a quantitative analysis, there are projections of cooling demand available from Day et al. (2009) and DECC’s 2050 Pathway Analysis. These are used to assess qualitatively the impact of climate change on cooling demand, as measured in terms of energy increases.

5.3.2 Data and baseline information

Part 1: Changes in cooling requirements via CDD

Projections of CDD data have been calculated using the Met Office Regional Climate
Model (RCM). Eleven variants of the RCM were run using the medium emissions scenario as part of the UKCP09 methodology (Murphy et al., 2009). These simulations are configured from the Global Climate Model (GCM) HadCM3 (Gordon et al., 2000) and run at a 25km horizontal resolution. The variants differ from each other in the settings of certain key parameters within the model equations; this is known as a perturbed-physics ensemble (PPE) (Collins et al., 2006). In these simulations there is a one-to-one mapping between the parameter perturbations in the RCM and GCM ensembles. By using a PPE some of the uncertainty associated with modelling and natural variability can be quantified. More information on the RCM data and how it differs from the UKCP09 projections is available in the CCRA Evidence Report (CCRA, 2012).

Daily temperature data have been extracted from each of these runs to calculate CDD (using the methodology described in Jenkins et al., 2009). Changes in CDD were calculated relative to the 1961-1990 baseline for the 2020s, 2050s and 2080s (only for the medium emissions scenario). It is not possible to calculate CDD using the UKCP09 probabilistic projections since these represent thirty year means and the calculation requires daily data. It is also possible to use the Threshold Detector in the Weather Generator to calculate CDD, but since the resolution of the Weather Generator is at 5km it was not practical to run the Weather Generator and Threshold Detector for each grid square in the UK.

Part 2: Qualitatively assessing the potential impacts in terms of energy demand

Day et al. (2009) examines future air-conditioning forecasts that are all relative to a 2004 baseline. DECC (2010d) examine four scenarios for both domestic and non-domestic cooling, which are relative to a 2007 baseline.

5.3.3 Assumptions and limitations

Part 1: Changes in cooling requirements via CDD

1. The CDD data are derived from daily temperature data from 11 RCM runs. Although this does provide a spread of projections, it does not explore the same amount of uncertainty as the UKCP09 probabilistic projections. For example, the UKCP09 methodology takes into account a range of models from both the Met Office and other institutes.

Part 2: Qualitatively assessing the potential impacts in terms of energy demand

2. Day et al. (2009) assume the following trends in future air-conditioning systems:

   a. Reduction in individual split systems and low efficiency all-air systems.

   b. Strong growth in variable refrigerant flow (VRF); 3-5% per year.

   c. Moderate growth in ground coupled systems; 2% per year.

   They focus on building types which give rise to the majority of London’s cooling requirement: offices (open plan and cellular), retail, hospitality and leisure and residential.

3. DECC (2010d) considered four different scenarios for domestic and non-domestic cooling. The scenarios consider different levels of internal building temperature, thermal efficiency, hot water demand and cooling demand.
4. Day et al. (2009) consider cooling demand in London. This study is being used to scope out the potential impacts of energy using London as an example. The results should be considered as indicative only.

5.3.4 Results

Part 1: Changes in cooling requirements via CDD

The ensemble mean simulation of cooling degree days (CDD) for 1961-1990, and the mean changes in CDD for the three future periods 2020s, 2050s and 2080s, are shown in Figure 5.1 (top row), together with the model range within the ensemble (bottom row). These results show that the CDD are projected to increase significantly during the twenty-first century, especially over southern England. The average CDD over southern England for the 1961-1990 ensemble mean are simulated to be approximately 25 – 50, whereas by the 2080s they have increased by 125 – 175. The projected increase in CDD is reduced with increasing latitude, such that the increases over northern England and Scotland are much smaller (25 – 50). The variation between the projected changes in CDD also increases during the 21st century; the largest uncertainties are in the same locations as the largest increases in CDD.

From the projections of future CDD, it is possible to infer that cooling demand may increase in the future as a consequence of increasing temperatures. However it is important to consider these projections relative to current conditions since demand associated with cooling is currently small compared to heating. It could therefore be inferred that the increase in cooling demand based on climate factors alone could be met with the current capacity of the electricity network (particularly as the requirement for heating may reduce). This is confirmed by the work of Eskeland and Mideksa (2010) who estimated how energy demand may change as a consequence of climate change, but keeping all non-climate factors (for example building stock) at present day levels. They found that UK consumption of energy reduced by 6% due to a larger reduction in HDD compared to the increase in CDD. However, this assessment is based on the current levels of air conditioning penetration and of course these are likely to rise considerably due to an increase in building stock and the number of air-conditioning systems installed into properties (this would be an autonomous adaptation response to increasing temperatures). In fact, as Isaac and van Vuuren (2009) state air conditioning is a function of income and consequently also likely to increase in response to higher levels of income. Finally, mitigation policies set by the UK Government are also likely to influence cooling demand in the future. For example, measures to improve the efficiency of the UK housing stock are likely to change the thermal properties of UK houses.
Figure 5.1 Cooling Degree Days (CDD) from the 11 member RCM climate projections

The baseline data (left-hand column) are the ensemble mean numbers of cooling degree days over the period 1961 – 1990 (top) and the model range (bottom row). The next three columns show the projected changes in CDD from the ensemble mean changes (top row) and the model range in those changes (bottom row) for the 2020s, 2050s and 2080s.
Part 2: Qualitatively assessing the potential impacts in terms of energy demand

Although an analysis of CDD projections provides us with a means to understand how climate may affect the requirement of cooling, it does not allow us to assess what this impact will be in terms of energy demand. Alternatively a qualitative assessment is carried out using past studies.

Day et al. (2009) examined how changes to building stock, air-conditioning and climate affected energy demand projections for London only. First, projections of energy demand were calculated up to 2030 varying only the climate change scenarios (no, low and high climate scenarios). These highlighted that energy demand for the high climate change scenario was 49% more than when climate change was not considered and 5.2% more than a low climate change scenario. In terms of energy demand figures, under a high climate scenario cooling energy demand is projected to rise from approximately 1.6TWh in 2004 to 2.5TWh and under a low climate scenario is projected to rise from approximately 1.6TWh to 2.2TWh.

Non-climate factors were also considered in this study. Day et al. (2009) estimated projections of cooling energy demand for London under a base case where no efficiency measures or change in system mix occurs and an alternative scenario where there are efficiency improvements and the least efficient air-conditioning systems are replaced. In both cases a low climate change scenario is applied; therefore a comparison between the two provides information on how the efficiency changes affect the projections. Under the base case the energy consumption of 1.6TWh in 2004 rises to 3.1TWh by 2030. In this case the main demand is from offices, with retail featuring strongly and residential properties have a negligible impact. The efficiency improvements result in a 27% reduction in the amount of energy required for cooling in 2030.

Since the Day et al. (2009) study focussed on London, trajectories for UK future cooling demand from the 2050s Pathway Analysis (DECC, 2010d) are also presented here. The trajectories are provided for four different levels for both domestic and non-domestic sectors; they are illustrated in Figure 5.2. The domestic trajectories range from no additional domestic air conditioning (level 4) to all houses installing an air conditioning system (level 1). This results in a potential rise from 0 in 2007 to 50 TWh per year by the 2050s. It is stressed that these increases are primarily a response to increased wealth, although they do factor in future external temperature and climate change. They therefore reflect the total change, i.e. the combined effects of socio-economic and climate change together, rather than the marginal change due to climate alone. The non-domestic trajectories illustrate a range of scenarios including different uptakes of air-conditioning and efficiencies in existing systems. At best, there is a reduction of 90% compared to 2007 levels due to an increased use of passive air conditioning (level 4) and at worst an increase of approximately 330% if all non-domestic floor space install air-conditioning systems. These results highlight that domestic cooling demand may increase in the future as more air-conditioning systems are installed (due to increasing temperatures and wealth). This could be partially offset by the non-domestic sector if more efficient air-conditioning systems are installed there.

26 The figures include growth in dwelling numbers, the change in average dwelling heat loss, projected changes in external temperature and the effect of changes to internal gains from hot water heating, lights and appliances. A cooling set point at an internal temperature of 23.5°C has been assumed.
5.4 EN3: Heat-related damage

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Confidence</th>
<th>Summary Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN3</td>
<td>Heat related damage/disruption</td>
<td>L</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>l</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>c</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>u</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

This impact scored highly in the Tier 1 impacts list since it was associated with high temperatures (climate projections of which are associated with high confidence) and the consequences affect the security of energy supply. However, when incidences of faults due to solar heat were examined, the risk associated with heat-related damage was found to be low and within the level of planned adaptation. This is because electricity and gas equipment must be able to withstand a level of high temperatures set by industry design standards. As a result climate projections are not applied to this impact.
5.5 EN4: Water abstraction

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Confidence</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN4</td>
<td>Water abstraction</td>
<td>M</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

### 5.5.1 Methodology details

The response function for EN4 related the volume abstracted from sustainable sources (classed as green/grey under the CAMS colours system) for the power generation sector with changes in Q95 (see Section 4.5). Future projections of Q95 were calculated by the Water Sector team by deriving an empirical relationship between Q95 and relative aridity. Relative aridity is a hydrological measure of how warm and dry the climate is relative to 1961-1990 and is directly related to temperature and precipitation. Therefore, substituting future UKCP09 projections of temperature and precipitation into this empirical relationship provided projections of Q95.

### 5.5.2 Data and baseline information

The following data were used to estimate the impact of climate change with selected climate scenarios:

- The Environment Agency CAMS system (see Appendix 5 for more details).
- CAMS abstraction figures (Entec, 2010).
- UKCP09 projections of change in mean annual temperature (°C) (change in future 30-year average of annual average air temperature measured at 1.5m above ground level, from the baseline climate (1961-90) long term average).
- UKCP09 projections of change in annual average precipitation (%) (change in future annual average precipitation from the baseline climate (1961-90) long term average)\(^{27}\).

Sustainable abstraction and licensing is based on current policy although definitions of sustainable abstraction are complex, particularly in the context of climate change. This is because ecosystems are likely to change gradually and there are differing views, firstly on whether licensing should seek to preserve historic flow regimes as the best way to provide ‘room’ for aquatic ecosystems to adapt, and secondly on how any losses or gains in flow should be shared between different water users (e.g. public water supply, agriculture, industry, power generation and the environment).

\(^{27}\) The data were extracted at the river basin region scale (based on the Water Framework Directive River Basin Districts). Sampled UKCP09 data were extracted in the form of 10,000 equi-probable estimates of changes in precipitation and temperature. As these data were in the same UKCP09 ‘batch’ the represent the correlation between changes in these variables as reproduced by the Met Office’s emulator. The output format was csv.
5.5.3 Assumptions and limitations

1. The method does not cover Scotland and Northern Ireland because of lack of suitable information.

2. The analysis assumes that flow indicators provide a good estimate of the physical habitat required to meet good ecological status.

3. It is assumed that there is no change in other factors, such as sedimentation or chemical changes.

4. Current levels of abstraction for power generation are assumed to remain unchanged, i.e. no further abstraction licences are granted and current licences are used at a similar level.

5. The relationship provides a guide to regional sensitivity based on existing Environment Agency data – the analysis is subject to all the caveats outlined in Entec (2010).

6. The analysis is based on empirical relationships between Q95, relative aridity and meteorological variables such as temperature and precipitation; it is assumed that these empirical relationships will remain the same in the future.

5.5.4 Results

CAMS analysis was able to provide some insight into the pressure exerted by the power generation sector on water resources, both nationally and by UKCP09 river basin region for all water bodies (lakes, rivers and estuaries). It is important to consider how much water could be available because of the need for its use for cooling for power stations, both nuclear and conventional, and other supporting facilities in order to maintain electricity supplies. It should be noted that many abstractions for use in the power generation sector are non-consumptive, meaning that water is returned following its use.

Table 5.4 shows the abstractions for the power generation sector coming from sustainable sources in Megalitres (ML) per day; this is calculated using future projections of Q95 calculated in the Water Sector analysis. Table 5.5 shows the percentage changes. Figures are only given for the three river basin regions that showed notable changes (see Section 4.5).

Table 5.4 Power generation abstractions (ML/d) coming from sustainable sources (i.e. catchments classed green/grey), considering local catchment water availability

<table>
<thead>
<tr>
<th></th>
<th>Low Emissions</th>
<th>Medium Emissions</th>
<th>High Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>p10 (wet) p50 (mid) p90 (dry)</td>
<td>p10 (wet) p50 (mid) p90 (dry)</td>
</tr>
<tr>
<td>Humber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020s</td>
<td>317</td>
<td>315 293</td>
<td>317 290</td>
</tr>
<tr>
<td>2050s</td>
<td>312 277 249</td>
<td>294 260 234</td>
<td>278 246 220</td>
</tr>
<tr>
<td>2080s</td>
<td>312 277 249</td>
<td>294 260 234</td>
<td>278 246 220</td>
</tr>
<tr>
<td>Severn</td>
<td>7</td>
<td>5 5 5</td>
<td>7 5 5</td>
</tr>
<tr>
<td>2020s</td>
<td>5 5 5 5</td>
<td>5 5 5</td>
<td>5 5 5</td>
</tr>
<tr>
<td>2050s</td>
<td>5 5 5 5</td>
<td>5 5 5</td>
<td>5 5 5</td>
</tr>
<tr>
<td>2080s</td>
<td>5 5 5 5</td>
<td>5 5 5</td>
<td>5 5 5</td>
</tr>
<tr>
<td>Thames</td>
<td>36</td>
<td>0 0 0</td>
<td>36 0 0</td>
</tr>
<tr>
<td>2020s</td>
<td>19 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>2050s</td>
<td>19 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>2080s</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
</tbody>
</table>

Energy Sector Report 57
### Table 5.5 Projected percentage change in power generation abstractions coming from sustainable sources (i.e. catchments classed green/grey), considering local catchment water availability

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Humber</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020s</td>
<td>0</td>
<td>0</td>
<td>-3</td>
<td>0</td>
<td>0</td>
<td>-3</td>
<td>0</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>2050s</td>
<td>0</td>
<td>-3</td>
<td>-6</td>
<td>0</td>
<td>-4</td>
<td>-7</td>
<td>-1</td>
<td>-5</td>
<td>-8</td>
</tr>
<tr>
<td>2080s</td>
<td>-1</td>
<td>-5</td>
<td>-8</td>
<td>-3</td>
<td>-7</td>
<td>-10</td>
<td>-6</td>
<td>-8</td>
<td>-11</td>
</tr>
<tr>
<td>Severn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020s</td>
<td>0</td>
<td>-21</td>
<td>-21</td>
<td>0</td>
<td>-21</td>
<td>-21</td>
<td>0</td>
<td>-21</td>
<td>-21</td>
</tr>
<tr>
<td>2050s</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
</tr>
<tr>
<td>2080s</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
<td>-21</td>
</tr>
<tr>
<td>Thames</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020s</td>
<td>0</td>
<td>-17</td>
<td>-18</td>
<td>0</td>
<td>-18</td>
<td>-18</td>
<td>0</td>
<td>-18</td>
<td>-18</td>
</tr>
</tbody>
</table>

The largest percentage change in abstractions coming from sustainable sources is projected to be in the Severn river basin region, where there is a 21% decrease (0 to -21%) by the 2020s. However, overall abstractions for power generation in the Severn region are lower than in the other regions. There are also projected to be large percentage reductions in the Thames river basin region of 18% (0 to -18%) by the 2020s, from 36 Ml/d being abstracted sustainably to 0 Ml/d (central estimates). This could perhaps be due to existing pressures in the Thames region, where a slight reduction in Q95 could have large implications for certain abstractions. While there are smaller percentage reductions projected in the Humber river basin region, with no change (0 to -3%) by the 2020s, and decreases of 7% (-1 to -11%) by the 2080s, total abstractions for power generation are much greater than those in the Severn and Thames river basin regions. This could potentially mean that more licences and sites are affected in the Humber than in the other regions.

The importance of water availability for power stations is also evident from looking at the water demand figures for new and existing nuclear sites in the UK, provided by the Nuclear Decommissioning Authority (NDA). The total water use for all existing sites in the financial year 2009-10 was 8,682,103 cubic metres, or just over 8682 Ml and water demands vary widely by site. Figure 5.3 shows the water requirements in Ml/d for NDA sites by river basin region, ranging from almost 19 Ml/d in North West England to 0.05 Ml/d for the Thames river basin region. In addition, there are two proposed sites which would further add to the overall water requirements.
A key point to make is that sites would need to embrace water efficiency, particularly if they are located in regions that could experience high water stress. During the 2003 heat wave in Europe for example, extremely low river discharge levels were reported and insufficient cooling water was available in rivers, meaning that a number of power plants had to reduce their output (Fink et al., 2004). While there was no overall shortage in energy, there was an increase in electricity prices.

Water availability is not the only issue with the potential to affect the use of cooling water in power station processes. An increase in water temperatures has already been seen to affect the capacity of power plants in Europe due to its implications for the use of cooling water. For example, in Germany during the summer 2003 heat wave, any discharges of cooling water from power stations would have had ecological consequences for the aquatic ecosystems due to the already high river temperatures, and so the stations had to operate at reduced capacity (Eisenreich, 2005). Moreover, the river water was already too warm to meet the cooling requirements needed in the power station processes. This could become more of an issue with climate change, having potentially serious implications for energy supply if power stations have to work at a reduced capacity or in extreme cases, be forced to close.

A recent study by the Environment Agency investigated warming trends of rivers and lakes in England and Wales, finding that the highest mean monthly water temperatures occurred in the Thames region (11.98°C) and Anglian region (11.87°C) with the lowest in the North East region (9.51°C) (Hammond and Pryce, 2007). This provides some indication of where water temperature could be an issue for power station cooling processes.

**Figure 5.3** Total water use (ML/d) of Nuclear Decommissioning Authority sites by UKCP09 river basin region in financial year 2009/2010
5.6 EN10: Transmission capacity

<table>
<thead>
<tr>
<th>Metric code</th>
<th>Metric name</th>
<th>Confidence</th>
<th>Summary Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN10</td>
<td>Transmission capacity</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>l c u l c u l c u l c u</td>
<td></td>
</tr>
</tbody>
</table>

5.6.1 Methodology details

Table 4.2 details the response functions derived by Met Office (2008) and ENA (2011), which estimate the percentage of capacity losses per 1°C temperature increase for different types of equipment on the network. In this analysis the response functions are scaled with UKCP09 projections of maximum summer and winter daily temperatures to estimate projections of future capacity losses due to climate change. The analysis is carried out for all UKCP09 administrative regions and the minimum and maximum estimates are provided in the results (Section 5.6.4) to illustrate the variation that may be experienced throughout the UK. The individual estimates for the administrative regions are provided for one type of equipment (overhead line conductors on the distribution network) to investigate spatial variability (since the response function is constant throughout the UK any variability is attributable to a signal in the climate projections).

5.6.2 Data and baseline information

Response functions were calculated by Met Office (2008) and ENA (2011) using design standards IEEE STD 738 (overhead line conductors), BS CP 1010 (power transformers) and the suite of cable rating tools CRATER.

UKCP09 future projections of daily maximum temperature for both summer and winter are used to scale the response functions to produce future projections of capacity losses. The projections are obtained for all 16 administrative regions and the minimum and maximum capacity losses reported. To explore the uncertainty associated with the results, UKCP09 projections with different emissions scenarios, time periods and probability levels are applied (for more details on the UKCP09 projections see Section 2.6).

The baseline period for the projections is 1961-1990 (which is the UKCP09 baseline). In this analysis it is assumed that the baseline standard of the equipment examined is maintained to EU and international design standards.

The projected capacity losses are relative to the existing current rating of the type of equipment examined; these ratings are provided in Table 4.2. For example, a 500mm² Zebra overhead line conductor on the transmission network has an existing current rating of 1,600 Amps. The current is estimated to reduce by 0.63% per 1°C, which is approximately 10 Amps. Information on the composition of the entire network is not available; therefore it is not possible to calculate projections for future current losses over the network as a whole. However, capacity reductions are compared to load increases to provide an indication of their magnitude.
5.6.3 Assumptions and limitations

All assumptions and limitations in this analysis are detailed in the list below.

1. All equipment is well maintained and not susceptible to faults.

2. The response function for overhead line conductors is based on the relationship between temperature and asset rating. The rating is, however, also dependent on wind speed; de-rating is more likely in conditions of low wind speed (due to less cooling). The relationship used to estimate the values in Table 4.2 are based on average wind speed; the actual rating values could only be estimated by taking the wind fully into account. The assumption of a constant average wind speed is, however, deemed acceptable particularly in light of the recent release of UKCP09 probabilistic projections (Sexton and Murphy, 2010), which project only small changes in wind speed.

5.6.4 Results

Results for projections of future capacity losses relative to the existing current rating of each type of equipment are provided in Table 5.6; the key conclusions from this table are summarised in the bullet points below:

- Overhead line conductors on the distribution network are the most susceptible to de-rating. The highest projections indicate capacity losses of 6.4% in the 2020s, 12% in the 2050s and 19% in the 2080s. However, there is large uncertainty associated with these projections; capacity losses in the 2080s could be as low as 1.4% (for the 10% probability level and the low emissions scenario). Considering the existing current rating (Table 4.2), this relates to a reduction of between 2 and 25 Amps in the 2080s per 25mm² copper conductor, 4 and 60 Amps per 100mm² copper conductor and 5 and 65 Amps per 175mm² lynx conductor.

- Projections for the overhead line conductors on the transmission network are similar for both types (400 and 500 Zebra). In both cases the capacity losses are unlikely to be greater than 2% in the 2020s and 2050s and are unlikely to be greater than 5% in the 2080s. This relates to a reduction of no more than 62 Amps and 80 Amps in the 2080s per 400mm² and 500mm² zebra conductor respectively.

- The projected capacity losses for underground cables do not vary substantially for the different voltages. The central estimates for the medium emissions scenario in the 2020s is between approximately 1.5% and 2% capacity losses in for the 2050s between approximately 1.5% and 3.5%. In the 2080s capacity losses are unlikely to be greater than 12% and have a central estimate of between 2% and 5.5% for the medium emissions scenario and between 2.5% and 8% for the high emissions scenario. The existing current rating for underground cables varies from 335 Amps (low voltage) to 1,052 Amps (400kV).

- Power transformers at 11kV are at greater risk of de-rating than those at higher voltage. The UK central estimate for the medium emissions scenario for the 2050s ranges between 2.5% and 3.8% for 11kV and between 1.8% and 2.5% for 33kV or more. The highest capacity losses throughout the UK are unlikely to be greater than 12% (11kV) or 8% (33kV or more) based on a high emissions scenario.
Table 5.6  Projected percentage capacity losses for different UKCP09 climate scenarios and electricity infrastructure (rounded to 1 significant figure)

The projections have been calculated for all administrative regions and the UK minimum and maximum value provided here. They are relative to the existing current rating of each type of equipment given in Table 4.2.

<table>
<thead>
<tr>
<th>Projection</th>
<th>Overhead Line Conductors</th>
<th>Underground Cables</th>
<th>Power Transformers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distribution</td>
<td>Trans 400</td>
<td>Trans 500</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>2020s</td>
<td>Med p10</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Med p50</td>
<td>2.4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Med p90</td>
<td>4.5</td>
<td>6.4</td>
</tr>
<tr>
<td>2050s</td>
<td>Low p10</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Low p50</td>
<td>3.7</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Med p50</td>
<td>4.0</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>High p50</td>
<td>5.3</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>High p90</td>
<td>8.5</td>
<td>12.0</td>
</tr>
<tr>
<td>2080s</td>
<td>Low p10</td>
<td>1.4</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Low p50</td>
<td>4.5</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Med p50</td>
<td>5.9</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>High p50</td>
<td>7.5</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>High p90</td>
<td>13.3</td>
<td>19.0</td>
</tr>
</tbody>
</table>

62
The ENA (2011) report has also considered the risks of de-rating and included them in their risk matrix (AR1, AR2 and AR4; see Appendix 7). The overall risk of de-rating to overhead line conductors and underground cables has been defined as high and for power transformers medium. The difference in risk is due to the relative impact. Whilst the likelihood of de-rating due to higher temperatures has been assigned as possible for all three types of equipment, the relative impact for power transformers is minor and moderate for overhead line conductors and underground cables.

The results for the 16 UKCP09 administrative regions for overhead line conductors on the distribution network are provided in Table 5.6 for three climate scenarios in the 2050s. These projections are given to highlight the spatial variability in the results. There is little variation between the regions for the 10% probability level and low emissions scenario (the changes for all the regions range between 1% and 2%). There is greater variability for the 50% probability level, medium emissions and most for the 90% probability level, high emissions. The greatest percentage change is estimated for the South West, South East England and London and the smallest in Northern Ireland and Northern Scotland.

Table 5.7 Projected percentage capacity losses for different UKCP09 climate scenarios and each administration region for overhead line conductors on the distribution network

<table>
<thead>
<tr>
<th>Administration Region</th>
<th>2050s Low p10</th>
<th>2050s Med p50</th>
<th>2050s High p90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Islands</td>
<td>1.64</td>
<td>5.45</td>
<td>10.86</td>
</tr>
<tr>
<td>East Midlands</td>
<td>1.72</td>
<td>5.31</td>
<td>10.56</td>
</tr>
<tr>
<td>East of England</td>
<td>1.83</td>
<td>5.44</td>
<td>10.80</td>
</tr>
<tr>
<td>Eastern Scotland</td>
<td>1.80</td>
<td>4.81</td>
<td>10.09</td>
</tr>
<tr>
<td>Isle of Man</td>
<td>1.39</td>
<td>4.55</td>
<td>9.03</td>
</tr>
<tr>
<td>London</td>
<td>1.89</td>
<td>5.91</td>
<td>11.81</td>
</tr>
<tr>
<td>North East England</td>
<td>1.58</td>
<td>5.15</td>
<td>10.17</td>
</tr>
<tr>
<td>North West England</td>
<td>1.61</td>
<td>5.23</td>
<td>10.37</td>
</tr>
<tr>
<td>Northern Ireland</td>
<td>1.27</td>
<td>4.30</td>
<td>8.56</td>
</tr>
<tr>
<td>Northern Scotland</td>
<td>1.41</td>
<td>3.98</td>
<td>8.47</td>
</tr>
<tr>
<td>South East England</td>
<td>2.00</td>
<td>5.95</td>
<td>11.8</td>
</tr>
<tr>
<td>South West England</td>
<td>1.92</td>
<td>6.10</td>
<td>12.05</td>
</tr>
<tr>
<td>Wales</td>
<td>1.69</td>
<td>5.37</td>
<td>10.65</td>
</tr>
<tr>
<td>West Midlands</td>
<td>1.75</td>
<td>5.78</td>
<td>11.47</td>
</tr>
<tr>
<td>Western Scotland</td>
<td>1.42</td>
<td>4.72</td>
<td>9.34</td>
</tr>
<tr>
<td>Yorkshire and Humberside</td>
<td>1.62</td>
<td>4.89</td>
<td>9.71</td>
</tr>
</tbody>
</table>

Similar results were obtained by the Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change report (URS, 2010). The report states that increased temperature, combined with increased usage during summer months would lead to requirements for improvements to technical specifications for cabling, substations and transformers to enable effective cooling from air conditioning and provision of greater loads.

It is not possible to calculate projections of future absolute current losses over the entire network, since its composition in terms of the different types of equipment is not known. However, the above results of projected capacity losses per equipment type can be considered in context of historical load growth to provide an indication of their
magnitude. The networks have been subject to a load growth of approximately 1.5% to 2% per annum, therefore dealing with changes in capacity on the transmission and distribution network is not a new problem. This means that the impact of de-rating is not dissimilar to recent demand growth, which has been taken into account within the current design standards.

The ENA (2011) report states that the impact of rating reductions will vary from one circuit to another depending on how close the maximum demand on a particular circuit is to the circuit rating. For circuits of 33kV or more, when that limit is reached, the entire length of the circuit would have to be assessed, whereas for 11kV and LV circuits action on a proportion of the circuit would need to be considered. Possible actions would be to increase line height, re-conduct circuits to a higher operating temperature conductor, replace underground cables with larger cables or install additional circuits or substations to increase the capacity of the network. The cost of carrying out this type of work on the networks is discussed in Chapter 7.

This analysis is a reflection of the direct effect of temperature increases on the energy system as it is currently. However, due to current policy to move towards a low carbon economy (see Section 1.4 for more details), it is likely that the load on the network will double over the next forty years introducing new stresses on the electricity networks (for example due to the electrification of the transport system). Work undertaken by ENA and the Imperial College has found that 70% of this increase in demand could be incorporated into the existing network through the use of smart network technology, which would also respond to the impact of climate change on de-rating. This means that the use of smart network technology, although its primary function is mitigation through the transition to a low carbon economy, also provides an adaptation measure (ENA, 2011).
6 Socioeconomic Changes

It is recognised that many of the risk metrics in CCRA are influenced by a wide range of drivers, not just by climate change. The way in which the social and economic future of the UK develops will influence the risk metrics. Growth in population is one of the major drivers in influencing risk metrics and may result in much larger changes than if the present day population is assumed. Where possible, changes in socioeconomic drivers and their effect on the risks detailed in Chapter 5 are considered here (see Section 2.6 for more details on possible socioeconomic drivers).

6.1 EN1 & EN1b: Flooding of infrastructure and power stations

Future socioeconomic scenarios have not been applied to the future projections for energy generation and distribution installations at significant risk of flooding. This is because the future scenarios do not include assessment of the increases in energy requirements, or the ways in which future energy will be provided.

Considering current policy (Section 1.4) it may be speculated that there are likely to be major changes in energy generation including greater use of renewables and more large (nuclear) power stations. Much of the future renewable energy generation (including wind turbines, tidal and hydropower) is likely to be in flood risk areas. For example, some of the wind farms will be offshore and therefore subject to sea level rise and storminess. However renewable energy generation in flood risk areas is likely to be protected against present and future flood risk. The overall impact of future flood risk on energy generation is therefore difficult to predict.

6.2 EN2: Cooling demand

Analysis by Day et al. (2009) and DECC (2010d) take into consideration increases in building stock. Currently there is one area that does not contribute significantly to cooling demand: the domestic or residential sector. This is likely to change in the future due to an increase in population as well as an increase in market penetration of air-conditioning. Day et al. (2009) analysed an accelerated demand in the residential sector in London; this resulted in 10% of residential properties with mechanical cooling by 2030 (approximately 300,000 residencies) accounting for 0.28TWh of energy. In the future there may be increased expectations that new builds include cooling systems. Day et al. (2009) state that a key issue for the residential sector is to ensure that high efficiency cooling systems are designed into new development otherwise poorer systems may be installed at a later date.

There are many potential socioeconomic scenarios that are likely to affect cooling demand including population growth, mitigation policy and behavioural change. In future CCRA updates these should be considered in more detail.

6.3 EN3: Heat-related damage

Since the analysis for heat-related damage indicates that this risk does not pose a threat in the future, socioeconomic changes were not considered.
6.4 EN4: Water abstraction

Environmental flows are mostly affected by climate and hydrological conditions but the setting of acceptable environmental flows may change in future. For the purpose of the analysis no changes were considered.

6.5 EN10: Transmission capacity

Given the industry focus of this metric, socioeconomic projections have not been applied. Risk EN10 has considered how temperature changes may affect the capacity of the electricity networks. The capacity will of course also be impacted by other socioeconomic drivers and it is likely that these impacts will be greater. Both a rise in population and the transition to a low carbon economy would increase the requirements for energy. The ENA (2011) report states that the load growth on the electricity networks is likely to double over the next forty years due to changes such as the electrification of the transport system. This highlights that the consequences of de-rating due to temperature increases are likely to be small compared to the consequences of population growth and the low carbon transition. It is expected that the introduction of smart technology may account for 70% of this growth.
7 Economic Impacts

Climate change adaptation decisions that are designed to reduce climate change risks inevitably involve making trade-offs concerning the use of scarce economic resources. To the extent that economic efficiency is an important criterion in informing such decision-making, it is useful to express climate change risks in monetary terms, so that they can be:

- Assessed and compared directly (using £ as a common metric) and
- Compared against the costs of reducing such risks by adaptation.

For the CCRA, a monetisation exercise has been undertaken to allow an initial comparison of the relative importance of different risks within and between sectors. Since money is a metric with which people are familiar, it may also serve as an effective way of communicating the possible extent of climate change risks in the UK and help raise awareness.

Where possible, an attempt has been made to express the size of individual risks (as described in this report) in monetary terms (cost per year), however, due to a lack of available data it has sometimes been necessary to use alternative costs (repair or adaption) to provide an estimate. A summary of the results is provided in Table 7.1.

A variety of methods have been used to determine the costs with the approach used being reported in Table 7.2. In broad terms, these methods can be categorised according to whether they are based on:

- Market prices (MP)
- Non-market values (NMV) or
- Informed judgement (IJ).

Informed judgement has been used where there is no quantitative evidence and was based on extrapolation and/or interpretation of existing data.

In general terms, these three categories of method have differing degrees of uncertainty attached to them, with market prices being the most certain and informed judgement being the least certain. It is important to stress that the confidence and uncertainty of consequences differs. Therefore, care must be taken in directly comparing the results. Whilst we attempt to use the best monetary valuation data available, the matching-up of physical and monetary data is to be understood as an approximation only.

Further, it is important to highlight that some results are presented for a scenario of future climate change only, whilst others include climate change under assumptions of future socio-economic change. The approach used, and the relative baseline, is stated in Table 7.2. There are also some important cross-sector links, or areas where there is the risk of double counting impacts: these are highlighted on the table.

7.1 Summary of results

In this valuation section, qualitative estimates based on informed judgements have been applied to all the metrics in the Tier 2 analysis. This is because these metrics cannot easily be transformed into quantitative impacts for subsequent valuation. The resulting cost estimates should be treated with low confidence, i.e. they are only indicative. A number of other metrics (EN5-9) were considered in the earlier stage of
Table 7.1 shows that one risk metric – reduction in cooling demand – when expressed as energy used (MWh), has monetary impacts ranked as high (>£100 million/year) in the 2050s and possibly very high (>£1billion/year) in the 2080s, though the impact needs to be considered in light of the positive effects of less energy being used for winter heating, which is reported in the Built Environment sector report (Capon and Oakley, 2012). This metric also overlaps with other sectors, and there is a risk of double counting, i.e. cooling (EN2) offsets building overheating (BE3) and heat related mortality (HE1). Other metrics have a medium or low ranking.

It is stressed that consistent with the remit of the CCRA, the analysis does not include planned adaptation. However, in some metrics, the underlying sector report has assumed private sector adaptation in reporting residual risk levels.

<table>
<thead>
<tr>
<th>Risk metrics</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
<th>Estimation Method</th>
<th>Confidence ranking</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN1 &amp; EN1b Flooding of infra-structure &amp; power stations</td>
<td></td>
<td></td>
<td></td>
<td>Informed judgement Based on previous case studies and value of lost load.</td>
<td>L</td>
<td>Climate change only (no future socio-economics). Assumes no autonomous (private sector) or planned adaptation.</td>
</tr>
<tr>
<td>EN2 Cooling energy demand, MW (power and summer peak capacity)</td>
<td></td>
<td></td>
<td></td>
<td>Informed judgement</td>
<td>L</td>
<td>Climate change only (no future socio-economics). Low impacts due existing winter peak capacity in the UK (thus within summer reserve margin). Does not include potential issues of summer maintenance regime, or summer peak (extremes).</td>
</tr>
<tr>
<td>Cooling energy demand, MWh (energy used)*</td>
<td></td>
<td></td>
<td></td>
<td>Informed judgement Market values (for an autonomous adaptation response)</td>
<td>L</td>
<td>Climate change only (no future socio-economics). Range reflects climate projections only. Does not include urban heat island effect. Only includes costs of extra energy provision. Additional investment costs of air conditioning units would add to these costs significantly. Strong linkages to built environment and overheating. Note potential for double counting with overheating of buildings (BE3) and health and heat mortality (H1), as cooling reduces these impacts. Does not include Green</td>
</tr>
<tr>
<td>Low p10</td>
<td>-M</td>
<td>-H</td>
<td>-H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium p50</td>
<td>-M</td>
<td>-H</td>
<td>-H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High p90</td>
<td>-M</td>
<td>-H</td>
<td>-VH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk metrics</td>
<td>2020s</td>
<td>2050s</td>
<td>2080s</td>
<td>Estimation Method</td>
<td>Confidence ranking</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>------------------------------------------------------</td>
<td>--------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Cooling - ancillary impacts (GHG / Air Pollution)</td>
<td></td>
<td></td>
<td></td>
<td>Non market values</td>
<td>L</td>
<td>Deal, insulation or low zero carbon homes emissions standards.</td>
</tr>
<tr>
<td>Low p10</td>
<td>-M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Additional ancillary impacts of energy increases, assuming gas</td>
</tr>
<tr>
<td>Medium p50</td>
<td>-M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>provides marginal electricity demand - note only assessed for short</td>
</tr>
<tr>
<td>High p90</td>
<td>-M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>term (2020s), as later time periods assume low carbon energy.</td>
</tr>
<tr>
<td>Low p10</td>
<td>See ‘notes’ column</td>
<td>See ‘notes’ column</td>
<td>Non market values</td>
<td>L</td>
<td>Additional ancillary impacts of energy increases, assuming gas</td>
<td></td>
</tr>
<tr>
<td>Medium p50</td>
<td>See ‘notes’ column</td>
<td>See ‘notes’ column</td>
<td>Increased GHG and air pollution</td>
<td></td>
<td>provides marginal electricity demand - note only assessed for short</td>
<td></td>
</tr>
<tr>
<td>High p90</td>
<td>See ‘notes’ column</td>
<td>See ‘notes’ column</td>
<td>Increased GHG and air pollution</td>
<td></td>
<td>term (2020s), as later time periods assume low carbon energy.</td>
<td></td>
</tr>
<tr>
<td>EN3 Heat related damage **</td>
<td>L-M</td>
<td>L-M</td>
<td>L-M</td>
<td>Informed judgement</td>
<td>L</td>
<td>Climate only.</td>
</tr>
<tr>
<td>Medium p50</td>
<td></td>
<td></td>
<td></td>
<td>Adaptation cost (cost of upgrading)</td>
<td></td>
<td>Private sector adaptation by industry.</td>
</tr>
<tr>
<td>EN4 – Water abstraction</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>L</td>
<td>Can only be considered very indicative, as no qualitative or</td>
</tr>
<tr>
<td>EN10 Transmission Capacity*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>quantitative information exists.</td>
</tr>
<tr>
<td>Low p10</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Informed judgement</td>
<td>L</td>
<td>Climate only.</td>
</tr>
<tr>
<td>Medium p50</td>
<td></td>
<td></td>
<td></td>
<td>Adaptation cost (cost of upgrading)</td>
<td></td>
<td>Private sector adaptation by industry.</td>
</tr>
<tr>
<td>High p90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note**: - signifies a negative impact or loss; + signifies benefits or cost reductions.

* Require analysis of a combination of risk metrics to evaluate the cost.

**Impact Cost Ranking**: NQ = not quantified, L = £1-9m/pa, M = £10-99m, H = £100-999m, VH= £1000m+

**Monetisation Uncertainty Ranking:**

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Description</th>
<th>Colour code</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Indicates significant confidence in the data, models and assumptions used in monetisation and their applicability to the current assessment.</td>
<td>![Green]</td>
</tr>
<tr>
<td>Medium</td>
<td>Implies that there are some limitations regarding consistency and completeness of the data, models and assumptions used in monetisation.</td>
<td>![Yellow]</td>
</tr>
<tr>
<td>Low</td>
<td>Indicates that the knowledge base used for monetisation is extremely limited.</td>
<td>![Red]</td>
</tr>
</tbody>
</table>
7.2 Introduction to monetisation

The overall aim of the monetisation is to advance the knowledge of the costs of climate change in the UK, by generating initial estimates of the welfare effects.

The basic approach to the costing analysis is, for each impact category considered, to multiply relevant unit values (market prices or non-market prices) by the physical impacts identified in earlier sections of this sector report. The total value to society of any risk is taken to be the sum of the values of the different individuals affected. This distinguishes this system of values from one based on ‘expert’ preferences, or on the preferences of political leaders. However, due to the availability of data, it has sometimes been necessary to use alternative approaches (e.g. repair or adaptation costs) to provide indicative estimates.

There are a number of methodological issues that have to be addressed in making this conversion (Boyd and Hunt, 2004; Metroeconomica, 2006) including the compatibility between physical units and monetary units and the selection of unit values that address market and non-market impacts. As far as possible, physical and monetary units have been reconciled. The selection of unit values is justified in the explanation of the method used to monetise each risk metric. There are also other issues (beyond this scoping analysis) in terms of impacts that have non-marginal effects on the UK economy, the treatment of distributional variations in impacts, and the aggregation of impact cost estimates over sectors and time.

While the study has primarily used market and non-market estimates of Willingness to Pay (WTP), in some cases cost-based estimates have been used. These often centre on repair costs, which are used as a proxy for WTP. However, it is highlighted that in the current context these repair costs can be interpreted as adaptation costs, since they are incurred following the occurrence of the risk.

**Table 7.2 Monetisation of energy impacts**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Monetisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN1: Flooding of infrastructure and power stations</td>
<td>Analysis based on expert judgement using lost load case studies.</td>
</tr>
<tr>
<td>EN2: Cooling demand</td>
<td>For energy (kWh), analyses based on expert judgement using previous work and new DECC energy valuation guidance. Additional analysis considered for ancillary GHG and air quality from increased energy use as part of valuation analysis.</td>
</tr>
<tr>
<td>EN3: Heat related damage</td>
<td>Not possible to quantify, as Section 4.4 reports no impacts due to maintenance and upgrade, thus no indicator of lost load, or of cost of repair and impact assessment. Expert judgement used to consider possible monetisation.</td>
</tr>
<tr>
<td>EN4: Water abstraction</td>
<td>Not quantified.</td>
</tr>
<tr>
<td>EN5-9</td>
<td>Not considered in Tier 2 analysis. EN5: Demand by water suppliers (3); EN6: Electricity turbine efficiency (20); EN7: Gas pipeline compressor rating (23); EN8: Power station cooling processes (15); and EN9: Wind damage (33,34). Qualitative review of potential importance included.</td>
</tr>
</tbody>
</table>
7.3 Presentation of results, uplifts and discounting

Consistent with other sectors, the results below are presented in terms of constant current prices for the three time periods considered in the CCRA i.e. the 2020s, 2050s and 2080s. The results are presented in this way to facilitate direct comparison.

At this stage, we have not presented the values below as a present value or equivalent annual cost. However, the use of the values in subsequent analysis, for example in looking at the costs and benefits of adaptation options to reduce these impacts, would need to work with present values. For this, the values below would need to be adjusted and discounted. For discounting, the Green Book recommends 3.5% discount rates/factors (HMT, 2007) noting that for longer time periods as assessed here, this requires the use of the declining discount rate scheme.

7.4 Valuation of energy use, GHG and AQ

7.4.1 Valuation of energy use

There is supplementary HMT / DECC guidance on valuing energy use and GHG emissions (DECC, 2010f). This is accompanied by a spread-sheet calculation toolkit which provides carbon values, long run variable energy supply costs, emission factors and air quality damage costs over 2008-2050. There is also guidance on how to extend the analysis beyond 2050.

The guidance recommends that changes in energy use, for the purpose of economic appraisal, should be valued at the long-run variable cost of energy supply. The supply cost reflects the long-term variable cost components of energy supply and therefore excludes costs that will continue to be incurred at the same level in the long run despite marginal changes in energy use. The variable costs exclude taxes and other charges. The guidance stresses that these estimates of the long-run variable supply costs for different fossil fuel prices should not be considered forecasts, but as estimates to assist in policy appraisal.

The latest values in the guidance are shown in Table 7.3 for electricity price projections. The values are constant prices (2009 prices) – and do not change after the year 2040.

<table>
<thead>
<tr>
<th>ELECTRICITY</th>
<th>Pence/kWh (2009 prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable element: domestic</td>
<td>2010</td>
</tr>
<tr>
<td>Low</td>
<td>5.1</td>
</tr>
<tr>
<td>Central</td>
<td>7.4</td>
</tr>
<tr>
<td>High</td>
<td>8.5</td>
</tr>
<tr>
<td>High High</td>
<td>9.8</td>
</tr>
<tr>
<td>Variable element: residential</td>
<td>2010</td>
</tr>
<tr>
<td>Low</td>
<td>4.6</td>
</tr>
<tr>
<td>Central</td>
<td>6.8</td>
</tr>
<tr>
<td>High</td>
<td>7.8</td>
</tr>
<tr>
<td>High High</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Source: IAG and supplementary green book guidance on valuing energy use (current 2009 prices). Note that the use of full market prices (retail prices) would significantly increase the price projections (and thus any subsequent monetisation analysis).

There are also some issues of cross-sector consistency between CCRA sectors, as other sectors have used market prices, but in following the explicit DECC guidance, this analysis has used the long-run variable cost of energy supply.

The guidance also notes that the tables should not be used for non-marginal cases, i.e. those on a scale which would be big enough to affect the long run assumptions for factors such as the marginal cost of energy which underlie the values. We consider that the changes from climate change could be significant, and thus highlight that in future assessments, the level of changes predicted might be assessed using more detailed multi-sector energy modelling.

For the Energy Sector analysis, the focus is on increased cooling demand. However, these changes in energy use also have to be seen in the context of falling energy use for heating demand. These heating effects are considered in the Built Environment sector report (Capon and Oakley, 2012).

### 7.4.2 Effects on GHG and air pollution emissions

As well as the direct energy costs, the DECC/HMT guidance also provides unit values for monetising future GHG and air pollution emissions from changes in energy use. These are important here, because increasing energy use for cooling may increase UK GHG emissions and air pollutants, as electricity is currently the primary fuel source for cooling. However, the application of these values is challenging, because of the changes in the carbon intensity and emissions from the future electricity generation mix under future low carbon policy trajectories.

The DECC/HMT guidance requires analysis of GHG emissions first, before valuation. It provides future generation emission factors for electricity, which take account of the falling generation emissions, presented below, though these may not fully reflect the latest low carbon trajectories.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>Marginal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>0.46</td>
<td>0.39</td>
</tr>
<tr>
<td>2010</td>
<td>0.48</td>
<td>0.39</td>
</tr>
<tr>
<td>2015</td>
<td>0.46</td>
<td>0.39</td>
</tr>
<tr>
<td>2020</td>
<td>0.37</td>
<td>0.39</td>
</tr>
<tr>
<td>2025</td>
<td>0.30</td>
<td>0.39</td>
</tr>
<tr>
<td>2030</td>
<td>0.21</td>
<td>0.27</td>
</tr>
<tr>
<td>2040</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>2050</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

These changes are then valued using the recommended DECC values for carbon emissions, which are based on a target consistent approach, rather than the social cost of carbon. Factors for electricity generation are given for future years in Table 7.5 for the traded (including electricity) and non-traded sectors.
Table 7.5  Future GHG Values. Central values and Sensitivity for carbon prices 2008-2100, 2009 £/tCO$_2$e (2009 prices)

<table>
<thead>
<tr>
<th>Year</th>
<th>Traded</th>
<th>Non-traded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Central</td>
</tr>
<tr>
<td>2010</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>2020</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>2030</td>
<td>35</td>
<td>70</td>
</tr>
<tr>
<td>2040</td>
<td>68</td>
<td>135</td>
</tr>
<tr>
<td>2050</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>2060</td>
<td>120</td>
<td>266</td>
</tr>
<tr>
<td>2070</td>
<td>120</td>
<td>301</td>
</tr>
<tr>
<td>2080</td>
<td>107</td>
<td>306</td>
</tr>
<tr>
<td>2090</td>
<td>88</td>
<td>292</td>
</tr>
<tr>
<td>2100</td>
<td>67</td>
<td>268</td>
</tr>
</tbody>
</table>

Similarly, any increase in energy consumption would also increase air pollution emissions. These have important economic costs (externalities) and the DECC/HMT guidance provides estimates (damage costs) to allow their valuation. Note that the damage cost values are only really intended for minor effects on air quality – whereas the changes here might be large enough to warrant a more considered analysis using a full impact pathway assessment (as they last longer than 20 years, and could be material on a national scale). The current values for electricity generation are presented in Table 7.6. The damage costs associated with marginal electricity generation are currently 0.11p/KWh. This is based on the assumption that the marginal electricity generator is a CCGT. Note that the guidance recommends these unit prices are increased over time (a 2% uplift recommended by the IGCB, consistent with that applied in Government economic appraisal of health).

Table 7.6  Air quality damage costs for electricity generation, 2009 p/kWh

<table>
<thead>
<tr>
<th>Year</th>
<th>(p/KWh)</th>
<th>Year</th>
<th>(p/KWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.11</td>
<td>2040</td>
<td>0.21</td>
</tr>
<tr>
<td>2009</td>
<td>0.12</td>
<td>2050</td>
<td>0.26</td>
</tr>
<tr>
<td>2010</td>
<td>0.12</td>
<td>2060</td>
<td>0.32</td>
</tr>
<tr>
<td>2015</td>
<td>0.13</td>
<td>2070</td>
<td>0.38</td>
</tr>
<tr>
<td>2020</td>
<td>0.14</td>
<td>2080</td>
<td>0.47</td>
</tr>
<tr>
<td>2025</td>
<td>0.16</td>
<td>2090</td>
<td>0.57</td>
</tr>
<tr>
<td>2030</td>
<td>0.17</td>
<td>2100</td>
<td>0.70</td>
</tr>
</tbody>
</table>

However, there is an issue whether these values should be applied to the 2050s and 2080s, because of the very significant changes to the future electricity generation mix by this time. Consistent with the low carbon transition, electricity generation will need to become effectively zero carbon by 2050 (renewables, CCS or nuclear), and thus carbon and air quality emissions and monetary values will be closer to zero.

7.5  Valuation of energy supply (security)

The supplementary HMT / DECC guidance on valuing energy use and GHG emissions (DECC, 2010f) also has a discussion of energy security, though this is primarily associated with large policy initiatives and UK energy security.
It highlights the need to consider the potential effects of any major impact on energy consumption or production that could affect security of energy supply – i.e. the ability of the UK to meet its energy needs, with either quantitative evidence or a qualitative assessment to assess the security of supply impact. The guidance highlights the need to understand both the likelihood of physical interruption to energy supplies and the effects on price volatility.

It recommends the potential use of monetary values to estimate the expected energy unserved (i.e. the probabilities of different sizes of interruptions to the supply of energy relative to the demand at any point in time) multiplied by the Value of Lost Load (VOLL) (i.e. the value that customers attach to the energy unserved)\(^{29}\). It recommends this approach is used for electricity generation. However, the background documentation does not provide any values for use in appraisal.

In economic terms, the cost to consumers of a unit of electricity not supplied is much greater than the cost of the unit supplied. However, estimating the VOLL is not simple, and unit values vary with the amount of electricity not delivered in kWh (during the supply failure), the user (residential, commercial, or industrial), the time period and also the duration of loss.

There is some literature on various methods for estimating VOLL. These include revealed preference methods, stated preference methods, proxy methods and case studies (van der Welle and van der Zwaan, 2007). The previous pool value for a VOLL ranged between €3.8/kWh for a one-hour outage to €1.8/kWh for an outage of longer than 24 hours (Egenhofer et al., 2004). Survey work by Kariuki and Allan (1996) found a higher value of €4.6/kWh. This value is similar to that found in a study on the blackout in 2003 in New York City, where the estimated direct cost (e.g. lost production and wages) was €0.66/kWh, with indirect costs amounting to about €3.45/kWh. Similarly, US data from California indicate that confronted with the possibility of a one hour power outage on a summer afternoon, residents would pay between $2.87 and $3.97 per kWh for the undelivered power, 30 times the actual price had it been available.

There are recent studies that have applied stated preference methods to measure consumers’ willingness to pay/accept for changes in supply quality. This measures the marginal price of electricity supplied, in which consumers’ preferences are taken into account. The details of three most recent studies in the UK are summarised below.

- **Accent (2008)** applied a choice experiment method to measure consumers’ willingness to pay (WTP) for improvement in services provided by power distribution companies in the UK. Both domestic users and business users were surveyed in this study. The results show that for domestic users, the WTP for a reduction in the average duration of power cuts was estimated at £0.04 to 0.16 per minute/yr/household, the WTA for an increase was estimated at £0.04 to 0.20 per minute/yr/household in different regions of the UK. For business users, the WTP for a reduction was estimated at 0.04-0.05% of bill/minute, and at 0.06-0.07% of bill/minute for WTA.

- **In the study of Longo, Markandya and Petrucci (2006)**, which conducted a survey on residents in Bath, England, the WTP to avoid blackouts was estimated at £0.37 per minute or £22 per hour (2005 prices). This study applied a choice experiment approach.

- **In the EU-DG SECURE project, Chou et al. (2010)** used a valuation study based on the choice experiment method to estimate domestic users’ willingness to pay for energy security. The WTP to avoid power outage was

---

\(^{29}\) Conducting this analysis for each of the years of the lifetime of a project, and comparing this to the ‘do nothing’ counterfactual case, would provide a Net Present Value of security benefits that could be compared to the costs of delivering reductions in the probability of interruptions.
estimated at £19.23/hr/yr/household (2008 prices), or £0.32/minute/year/household. These estimates, however, cannot be readily converted into a £/kWh basis. To apply these estimates to measure the welfare effect as a result of a supply disruption (caused by production failure or transmission failure) the following is needed:

\[ \text{Welfare impact} = (T) \times (V) \]

Where \( T \) is the total minutes lost = (duration of a power cut in minutes) \( \times \) (number of consumers (households) affected); and \( V \) is the marginal WTP/minute (expressed in £/minute).

The latter could be extracted from the review of studies above. The difficulty for the current study is in arriving at appropriate estimates for \( T \), i.e. the total minutes lost. This is an area that needs significant further research.

7.6 EN1 & EN1b: Flooding of infrastructure and power stations

7.6.1 Outputs from the Risk Assessment

The EN1 and EN1b risk metrics consider the risk of flooding to infrastructure (plant, substations and underground transmission infrastructure, including gas) as a result of increased frequency and intensity of extreme precipitation.

The analysis for EN1 (Section 5.1) focuses on electricity transmission and primary distribution substations. Table 5.1 reports on how many electricity substations (both primary and secondary) could potentially be at significant risk (1:75) of coastal/tidal flooding and fluvial flooding in England and Wales. Metric EN1b undertakes a similar analysis of power stations, in numbers and capacity and is detailed in Section 5.2.

7.6.2 Methodology and unit values to be adopted

Substations

The loss of electricity supply from flooding of substations could be monetised using the Value of Lost Load (VOLL), if underlying information on the time and number of people affected can be estimated.

Section 5.1 provides a quantitative analysis of the number of substations that may be at risk of coastal/tidal and fluvial flooding in the future. The risk matrix provided in Appendix 7 also attempts to define the impact of this risk; for example substations affected by tidal flooding are defined as having an extreme impact, which means that a regional area would be affected with people off supply for a month or more. However, it does not quantify this in terms of the potential impacts (consequences), i.e. to allow analysis of the lost load that might result. In the absence of this information, an expert analysis has been undertaken, using case studies to try and estimate the potential order of magnitude of flood risks to substations.

The scoping analysis has first quantified the VOLL for previous historical flooding events, and then used these to interpret the findings above. Two case studies have been considered, based on the 2007 flood events. First, the case of Walham substation, which provides approximately 470MW of electricity supplies via four...
transformers to 450,000 domestic and commercial customers\textsuperscript{30}; while this did not flood, it did require extensive emergency response action. However, nearby Castle Mead substation did flood and power to 42,000 homes was cut whilst temporary defences were put in place\textsuperscript{31}. The station was working again by the following night.

For Castle Mead, using conservative estimates of the VOLL of £2/kWh (a conservative estimate of the literature values presented above), and assuming a 24 hours outage, combined with average UK household energy consumption per day, this translates to a total VOLL of £0.82 million. If we assume the same event had actually happened at Walham (a 24 hour outage), this would lead to a total VOLL of £9.8 million. This assumes that in most cases, localised substation flood events can be addressed quickly (though this estimate does not include the costs of response): note that if these events resulted in lost supplies for a longer period of time, the costs would continue to rise. This cost estimate includes the cost to domestic supply and does not include service, commercial or industrial users or the costs of repair. It should thus be considered a lower bound of the true economic welfare costs associated with such an event.

In order to scale these events to the national level picture, it is necessary to know the number of sites at risk. Some analysis of the number of substations at risk was undertaken by the Environment Agency in its 'Receptors Vulnerable to Flooding' project. This found 8,432 electricity sites at risk, or around 14% of overall site numbers.

The risk matrix in Appendix 7 presented some qualitative analysis of risk of people affected by flooding of substations, considering people at risk, relative impact and likelihood from coastal, river and flash flooding. This considered the highest likelihood with river flooding (a probable likelihood of a significant impact). Coastal flooding was given a lower likelihood (possible) but with the chance of a more significant (extreme) impact potentially affecting millions of people. However, as these risks are not presented in terms of an equivalent annual risk, informed judgement has been used (based on historic incidence levels) to consider a possible order of magnitude for monetisation.

**Power plants**

Note that the analysis of power stations is more difficult, because the system already runs with reserve margin in place, thus the analysis of actual lost load is complex. Moreover, the earlier analysis – based on the current location of existing plants – assumes that these risks remain constant in future periods, although the asset lifetime of UK power plants is approximately 40 years.

Whilst the potential stations at risk rises sharply in future time periods, future planning – and siting of future plants – would be expected to build in resilience and so reduce risks for the 2050s and 2080s (e.g. so that plants were not in areas of flood risk).

In this case, the analysis of VOLL also has complex linkages with security of supply standards, and the costs of reserve generation, which are passed on to final consumers. Note that this also would change significantly in future years with greater levels of intermittency from increasing wind generation on the system (in the absence of storage).

---

\textsuperscript{30} http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvfru/49/8020403.htm

\textsuperscript{31} http://www.environment-agency.gov.uk/static/documents/Research/infrastructurestudy_1917458.pdf
7.6.3 Results and discussion

Table 5.1 provides an estimate of the number of sites at risk and the ENA (2011) provides a qualitative indication of the possible people at risk and likelihood and impacts.

Assuming a mix of major and minor substations, the average costs of outages (from the case studies above) and a very indicative estimate of the likely equivalent annual rate of flooding (based on historic events and possible increases in risk levels), it is estimated that the potential impacts due to climate change could be medium in the 2050s (£10 – 100 million/year) and possibly medium to high (>£100 million) in the 2080s. This estimate can only be considered indicative.

Note that the analysis of power stations needs to consider that the system already runs with reserve margin in place, thus it is not easy to identify whether, or how much, lost load results. Whilst the number of potential stations at risk rises sharply in future time periods, future planning and siting of future plants would be expected to build in resilience and so reduce risks for the 2050s and 2080s. For example, placing new plant outside flood risk areas would reduce the risk although the number of large flat sites is limited. Most of the proposed next generation of nuclear power stations are in flood risk areas. As a consequence, the order of magnitude is judged to be ranked as low. Thus, for the EN1 and EN1b in total the suggested cost ranking is medium in the 2020s and 2050s, and medium/high in the 2080s, although this is highly uncertain.

7.7 EN2: Cooling demand

7.7.1 Outputs from the Risk Assessment

Day et al. (2009) report that cooling of buildings in the UK is already responsible for around 15 TWh per year of energy demand – or around 4% of the total electricity demand in the UK – and is rising rapidly as sales of air conditioning are increasing.

In Section 5.3, the CCRA assessed future projections of UKCP09 cooling degree days (CDD) as a metric for how cooling demand may change in the future based on climate factors alone. Additionally studies by Day et al. (2009) and DECC (2010d) were summarised to understand how changes in building stock and the mix of air conditioning systems also contribute. The changes in these studies have been assessed in this section, to provide an indicative order of magnitude for the future economic costs of this metric.

7.7.2 Methodology and unit values to be adopted

For energy used for cooling demand, the relevant initial climate metric is the change in CDD. This can be used to estimate the potential future electricity increase in cooling demand (kWh), with monetisation using the DECC energy appraisal values above. It is stressed that this should be categorised as an (autonomous) adaptation cost. In the context of climate change risk analysis, these costs can be interpreted as effectively the WTP for the energy provision.

It is also highlighted that in the UK, where there are very low levels of current AC use, there will be an additional capital cost associated with the purchase of units to cope with future cooling demand (in a future warmer climate). Consequently, the total cost for this metric should include the combination of the annualised capital cost of the new
AC that are introduced as a result of climate change, and the increase in operating costs (MWh) from the marginal increase in AC usage due to future climate change. Recent studies (Mima, forthcoming) have shown the capital costs of equipment can add as much as 20% to the costs of future demand.

Moreover, climate is only one driver in future cooling demand: the relationship between climate and cooling demand is complicated by baseline socioeconomic changes (without climate change), as future household cooling demand will be influenced by population, housing density, housing stock, insulation levels, technology, equipment penetration level, efficiency of cooling units, behaviour, perceived comfort levels, energy prices, income, etc. There are also a number of key policy drivers, notably the recent Green Deal as well as zero carbon homes emissions standards. All of these will be important in determining the physical impacts and subsequent economic costs for this metric.

Section 5.3 presented the quantified CDD changes (climate variable) and provided a summary of recent estimates of the change in energy demand. However, it did not provide a quantified analysis for this metric. In the absence of quantified energy demand changes, the monetisation analysis has combined the energy related estimates from previous studies with the DECC energy and GHG appraisal guidance to provide an order of magnitude for this metric.

Scoping the Potential Costs of Energy Demand for Cooling

Several previous studies have assessed future cooling demand from climate change, using the UKCIP02 projections. Early results from the Genesis project (Walsh et al., 2007) indicate a strong demand increase in electricity consumption for England and Wales with climate change. They reported an increase of around 10 TWh over the summer months by the 2080s under the UKCIP02 high emission scenario, over and above the low emission scenario. The economic costs of this increase can be valued using the DECC guidance on energy appraisal (Section 7.4.1). The results are summarised in Table 7.7, assuming constant current projections using the 2010 price projection (constant 2009 prices). They are also shown with future price projections included in Table 7.8, which increases the values significantly in future years (again in constant 2009 prices). Analysis of ancillary carbon and air pollutant emissions are also monetised and are found to be potentially important in monetary terms.

Table 7.7 Indicative analysis of Future Cooling Cost and Ancillary GHG and AQ Costs for the marginal increase 10TWh by the 2080s

<table>
<thead>
<tr>
<th>Energy units</th>
<th>Energy price (2010 price)</th>
<th>Carbon Emissions</th>
<th>Carbon Valuation</th>
<th>Air Pollution Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 TWh/year</td>
<td>£737 million/year</td>
<td>3.9 Million tonnesCO$_2$/year</td>
<td>£55 million/year</td>
<td>£12 million/year</td>
</tr>
</tbody>
</table>

**Assumptions**

- Assuming 2010 value of 7.3 p/kWh (residential)
- Assuming current marginal generation factor
- Assuming current recommended traded value of £14/tCO$_2$
- Assuming current recommended value of 0.12 p/kWh
Table 7.8  Indicative analysis of Future Cooling Cost and Ancillary GHG and AQ Costs for the marginal increase of 10 TWh over low emission scenario, by the 2080s

IAG future price projections projection (constant values, 2009 prices) with future emission profile.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10 TWh/year</td>
<td>£1400 million/year</td>
<td>0.2 Mtonnes/year</td>
<td>£45 million/year</td>
<td>0 to £26 million/year</td>
</tr>
</tbody>
</table>

Assumptions: Assuming post 2050 values of 14 p/kWh (residential) and assuming 2050 marginal generation factor.

Assuming 2050 recommended value of £200/tCO₂.

2050 marginal zero carbon (renewable/nuclear) up to 0.26p/kWh for CCGT.

Based on current price projections (constant 2009 prices), the marginal increase is around £800 million/year by the 2080s (note this is relative to the low emission scenario, not a counterfactual baseline). Based on future rising energy price projections (constant 2009 prices) and changing emission projections, the increase is around £1450 million/year.

Other studies also provide some additional figures for comparison. Watkiss et al. (2006) considered the potential increase in the domestic and service space cooling with the UKCIP02 climate projections, assessing the marginal increase over and above the socioeconomic future baseline. This is important as the underlying analysis reported strong increases in cooling in future years, even without future climate change.

The reported monetary values are presented in Table 7.9.

Table 7.9  Future Energy Cooling Cost (marginal increase due to climate change) for the UK for UKCIP02 projections [+ = increase in energy use] - original prices and reported estimates

<table>
<thead>
<tr>
<th>Source</th>
<th>Watkiss et al., 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Space cooling £Million</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>L/GS</td>
</tr>
<tr>
<td>Domestic</td>
<td>2.3</td>
</tr>
<tr>
<td>Service</td>
<td>11</td>
</tr>
<tr>
<td>2050</td>
<td>L/GS</td>
</tr>
<tr>
<td>Domestic</td>
<td>16</td>
</tr>
<tr>
<td>Service</td>
<td>38</td>
</tr>
<tr>
<td>2080</td>
<td>L/GS</td>
</tr>
<tr>
<td>Domestic</td>
<td>75</td>
</tr>
<tr>
<td>Service</td>
<td>179</td>
</tr>
</tbody>
</table>

The study reported increased costs (constant prices, no discounting) of £13 to 29 million/year in the 2020s rising to £54 to 182 million/year in the 2050s, and £254 to 1232 million/year by the 2080s. Note these did not capture the potential rise in demand from the additional uptake of air-conditioning units or the costs of additional air conditioning unit. For valuation, the numbers above assume the technical costs of generation, based around combined cycle gas cycle as the marginal plant to meet extra demand (around 2.8 pence/kWh). If the more recent DECC energy price guidance values are used, as described in Section 7.4.1 (7.4 pence/kWh for domestic and 6.9 p/kWh for commercial, 2010 costs, expressed in 2009 prices) this increases the monetised estimates in Table 7.9 by more than a factor of two, with medium costs.
(£10 – 99 million/year) for the 2020s, high costs for the 2050s (£100 – 999 million/year) and very high costs (>£1 billion/year for the 2080s).

The study by Day et al. (2009) for London investigated cooling in some detail and was reported in Section 5.3. In terms of energy demand figures, under a high climate scenario cooling energy demand is projected to rise from approximately 1.6TWh in 2004 to 2.5TWh by 2030 in London, and under a low climate scenario it is projected to rise from approximately 1.6TWh to 2.2TWh, mostly driven by office cooling. Using the current DECC guidance value of 6.8 pence/kWh (2010 commercial costs, expressed in 2009 prices), this equates to additional annual costs of £40 to 60 million/year. Using the DECC guidance values with the projected energy prices in 2030 (13 p/kWh) these figures would increase to £80 to 120 million/year. This implies medium costs (£10 – 99 million/year) for the 2020s for London alone (noting London is currently represents around 11% of current cooling demand). The study also considered a scenario of accelerated AC uptake in the domestic sector.

The Day et al. study also estimated that climate change could lead to an increase of 260,000–360,000 tonnes of CO₂ emissions by 2030 (assuming current grid average, not future low carbon mix). Using the DECC GHG value (of £70/tCO₂ in 2030), this indicates an additional ancillary impact of £18 to 21 million/year in 2030 from carbon emissions, though this would fall to £9 to 13 million with the projected reduction in the average carbon intensity of the mix projected in the DECC guidance, due to the decreased carbon intensity due to current UK mitigation policy.

Finally, Section 5.3 presented the 2050s Pathway Analysis (DECC, 2010d). The domestic trajectories in this study range from no additional domestic air conditioning (level 4) to all houses installing an air conditioning system (level 1). This results in a potential rise up to a maximum of 50 TWh per year by the 2050s, though the latter includes the combined effects of socioeconomic and climate change. The level of demand increase is five times greater than presented in Table 7.7 and Table 7.8. While these figures do not separate out the marginal effect due to climate change, and are primarily driven by increased wealth, they do indicate that climate change has the potential to increase energy cooling costs very significantly. Any increase in non-domestic cooling would also add to these values, though the pathway report highlights that these could largely be avoided through a passive response (adaptation).

The overall results are summarised in the next section. A number of important caveats are associated with these indicative values.

- The scoping analysis does not take account of any urban heat island effects. This may mean there is the potential to underestimate the cooling demand.

- The analysis does not take into account the costs of AC units. Also, it does not fully take account of the baseline future changes in demand that would arise from rising incomes, as AC is strongly income dependent and penetration rises rapidly with per capita income (see Isaac and Van Vuuren, 2009).

- The analysis does fully not take account of efficiency improvements or technological change in cooling appliances, or improved energy efficiency of the housing stock.

- The analysis does not include recently announced policy relating to the Green Deal. This is a major policy initiative to retrofit the housing stock with insulation, but will also have an influence on cooling demand (mostly positive, but in some cases negative, with respect of over-heating). Similarly it does not take account of the zero carbon homes emissions standards.
As above, the analysis does not take account of the effect of future price levels on demand (or price elasticity), or non-marginal effects.

The analysis does not consider how prices would change with future global emission scenarios. In reality, prices would vary with future socioeconomic scenarios, i.e. between the global low emission scenario and the high scenario, as these involve different global scenarios of energy use, mitigation, etc.

The analysis does not fully account for the changes in the energy mix for supplying residential cooling and the UK’s short- and long-term (2050) greenhouse gas emission target.

A number of other key issues and cross-sector linkages are highlighted. First, there may be additional cooling demand in the industrial and transport sectors, though the latter is considered in the Transport sector report (Thornes et al., 2012). Second, there are benefits of reduced space heating demand (BE9) that offset the energy impacts of increased cooling. These are included in the Built Environment sector report (Capon and Oakley, 2012).

There are also cross-sector linkages with non-residential building overheating in the Built Environment sector analysis (BE3 – Overheating of buildings), which overlap with cooling demand increases, because if there is cooling this will reduce the lost productivity and residential over-heating. There is therefore a risk of double counting if cooling demand and BE3 are added together. Similarly there is a risk of double counting between temperature-related (heat) mortality and morbidity (HE1 – Excess mortality (based on daily mean temperature and population)) as air conditioning has been shown (Ostro et al., 2010) to significantly reduce health impacts from heat.

### 7.7.3 Results and discussion

The scoping analyses for the monetisation section investigated changes in energy – applying the new DECC energy price projections to previous estimates of increased energy use from climate change in the UK.

The results suggest that the monetised values for this metric could be £10 – 99 million/year in 2020s (i.e. a medium ranking), £100 – 1000 million in the 2050s (high), and in excess of £1000 million in the 2080s (very high). Note that these costs are an autonomous adaptation response (i.e. an autonomous adaptation cost).

There are a very large number of caveats associated with these numbers (see above) and they can therefore only be considered indicative. Nonetheless, given the scale of impacts reported, this is one of the larger economic costs of climate change in the UK, and further detailed warranted modelling work and quantification is warranted for this metric. Interestingly, the analysis also shows that if this cooling demand is met through electricity use and air conditioning, the monetised GHG and air quality impacts are likely to be significant, assessed at a medium level (£10 – 99 million/year in 2020s) assuming current prices and electricity generation mix. It is highlighted that current mitigation policy would reduce these costs very significantly even for the 2020s, and almost entirely remove them in later time periods (2050s and 2080s).
7.8 EN3: Heat related damage

7.8.1 Outputs from the Risk Assessment

The EN3 risk metric considers heat related damage, assessing the level of energy disruption due to solar heat stress on the energy infrastructure.

While the high temperatures observed in 2003 and 2006 resulted in power cuts due to cumulative stresses of pre-existing faults topped by heat damage, the failure rates were low, as equipment currently used in the UK is built to resist average temperature that are much higher than peak temperatures. A factor in determining the potential scale of this risk is therefore the use — or replacement — of equipment that is currently associated with faults and that is particularly at risk of heat damage.

The earlier analysis in Section 4.4 did not consider there was a significant residual risk from climate change, and did not apply any climate projections, thereby making quantitative monetisation challenging. However, this assumes adaptation within the industry, and the costs of upgrading equipment have not been considered. Moreover, the fact that the costs may be internalised by industry does not mean there is not a social cost.

7.8.2 Methodology and unit values to be adopted

In cases of energy disruption due to heat damage, for example from overheating of equipment or infrastructure problems, there are damage costs, which imply a cost of repair (as in the 2003 and 2006 events). There is the potential for energy disruption and loss of load, which could be valued using the information presented earlier.

As highlighted in Section 4.4, the greatest risks are for equipment that is already faulty. The earlier section assumes that the planned maintenance operations will be effective in targeting such equipment and therefore that costs are internalised. However, it is possible an enhanced maintenance programme, or a faster turnover of equipment would be needed, to address the increased risk of heat damage in future time periods with climate change, i.e. there may still be a planned (private sector) adaptation cost. Alternatively, if the current maintenance programme is continued, then there might be a slightly higher risk of failure with higher future temperatures, which would lead to additional repair costs and might involve some lost load. It would be possible to explore these potential costs by examining the costs of the 2003 and 2006 equipment failures, but this information is not currently available. In the absence of this information, an indicative value has been attached to this metric to recognise there are likely to be some costs involved.

7.8.3 Results and discussion

At this stage there is no information upon which to base monetisation. However, there are some costs implied, either through an enhanced maintenance programme or from a slightly higher risk in future time period. As a very indicative assessment, it is plausible these costs could be in the range of £1 – 100 million/year (low-medium).
7.9  EN4: Water abstraction

7.9.1 Outputs from the Risk Assessment

Abstractions are assumed to be from the same catchment and same source in future, but the designation of that source as sustainable or unsustainable can change. Where the catchment changes from being classed as sustainable to unsustainable over time, the abstraction from it becomes classed as unsustainable. Section 5.5 identifies the percentage change in the number of water bodies with sustainable abstraction by UKCP09 river basin region.

The implication of this classification is that it is possible – under a future regulatory regime – that if a catchment moves from being classed as sustainable to being unsustainable abstraction licences may be withdrawn from power generation sector users. The loss of an abstraction licence could mean the user of the resource (such as power stations) is unable to fulfil their water requirements, or the risk to their business increases because of the reduced supply of water.

This metric has not been monetised. However potential costs for similar metrics for the agriculture and industry sectors can be found in the Water Sector report.

7.10  EN10: Transmission capacity

7.10.1 Outputs from the Risk Assessment

The EN10 risk metric considers transmission capacity, which can be affected by high temperature, causing potential impacts on overhead line conductors, power transformers and underground cables (see Section 4.6 for a description). This leads operators to de-rate the equipment, i.e. to reduce the capacity, in order to maintain appropriate operating conditions.

A quantitative response function was developed by previous work (Met Office, 2008 and ENA, 2011) and reported in Section 4.6. Scaling the response function with climate scenarios, losses of up to between 12% and 19% were projected at elevated temperatures depending on the type of equipment and network (distribution or transmission).

7.10.2 Methodology and unit values to be adopted

The potential reduction in capacity was considered for this risk metric, using a quantitative analysis (Section 5.6). It is difficult to assess these results within a monetised framework, without information on subsequent impacts, i.e. the time period and duration of de-rating, whether this leads to a loss of electricity supply, number of people affected, etc.

An alternative approach to consider the order of magnitude is to look at the costs of addressing de-rating, though these are adaptation costs, rather than welfare costs, and are therefore not consistent with the main objective of the CCRA. An indicative cost of adaptation has been calculated by the ENA (2011) study using Ofgem data on asset quantities and unit costs and applying a “worst case” climate de-rating projection and using a likely pessimistic pro-rata cost/rating assumption. This suggests a total cost of £2.6 billion over some 60 years which translates into a £40 million investment each
year. The costs identified are roughly divided into: £1.3 billion to make up for capacity losses in overhead lines, £0.75 billion to make up for capacity losses in underlying cables, and £0.5 billion to make up for the de-rating of transformers (132kV).

7.10.3 Results and discussion

The results are reported as the reduction in transmission capacity in Section 5.6, and are described in quantitative terms. While these indicate potentially high impacts, there is not sufficient information to allow monetisation of these risks.

The analysis also presents the estimated costs to address this potential risks, i.e. the adaptation costs, which suggest medium levels of costs (adaptation), i.e. in the range £10 – 100 million/year.

7.11 Impacts EN5 to EN9

The following additional risk metric were identified in the initial Tier 2 analysis:

- EN5: Demand by water suppliers
- EN6: Electricity turbine efficiency
- EN7: Gas Pipeline compressor rating
- EN8: Power station cooling processes
- EN9: Wind damage.

These impacts did not score highly enough to be considered in the quantitative Tier 2 analysis; however, a rapid review of the literature has been undertaken and where information is available a scoping analysis to investigate the potential economic costs they might involve has been undertaken. For those metrics where information was not available it has not been possible to undertake this analysis.

**EN5: Demand by water suppliers:**

There are potential energy demand increases with climate change due to water supply increases. This includes potential increases in energy use for increasing water supply (pumping, desalination, recycling, and water transfers) in areas where water availability is declining due to climate change. This is already an issue in some regions of Europe, and is potentially important for the south-east of the UK. There is little information about these effects as yet, but they are strongly related to other sectors (cross-sector linkages between water availability, domestic supply, agriculture, tourism, etc.). Indicative European work highlights that these demand increases could be important.

It is possible that they could constitute an additional medium (possibly high) level of cost. Note that this is an adaptation cost, to respond to the falling water supply demand deficit, thus there is a strong crossover with the Water sector report (Rance et al., 2012).

**EN6: Electricity turbine efficiency and EN8: Power station cooling processes:**

Climate change has the potential to reduce thermoelectric generation by decreasing plant efficiency and by affecting cooling capability. Furthermore, the generation of electric power in thermal (particularly coal-fired and nuclear) power stations relies on large volumes of water for cooling. During heat waves and drought periods, the use of cooling water may be restricted if limit values for temperature are exceeded, which may
lead to reduced capacity or even temporarily close plants, as has occurred in various locations in Europe during very warm summers.

Some of the previous literature has identified a potential fall in thermal (fossil) power station efficiency with temperature (Linnerud et al., 2009, Mideksa and Kallbekken, 2010) due to a combination of these effects. The literature reports some very simple indications that for a temperature increase of 1°C, coal and gas power output may decrease by 0.6% due to the thermal efficiency loss, with potentially higher decreases with nuclear.

It is possible that such effects could occur in the UK, though the loss of individual plants is unlikely to have major economic costs at the national scale (see earlier discussion of plant margins). However, they might imply low to medium economic costs.

**EN9: Wind damage:**

The current uncertainty over future wind speeds in UKCP09 makes the assessment of future wind damage uncertain, both in relation to transmission infrastructure but also wind power. However, given the very large increase projected for generation from wind power in the UK, including offshore, it is possible that potentially significant effects might arise from any changes to the wind regime. This would seem a priority for future consideration.
8 Adaptive Capacity

8.1 Overview
Adaptive capacity considers the ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Ballard, 2009, after IPCC, 2007). This can be considered as having two components; the inherent biological and ecological adaptive capacity of ecosystems and the socio-economic factors determining the ability to implement planned adaptation measures (Lindner et al., 2010). Considering adaptive capacity is essential for adaptation planning and the CCRA project has included work in this area that will contribute to the ongoing Economics of Climate Resilience study and the National Adaptation Programme. The CCRA work on adaptive capacity focuses on structural and organisational adaptive capacity and this chapter provides an overview of the assessment approach. The subsequent sections of this chapter provide an overview of the findings from other work on adaptive capacity in the Energy sector that has been carried out.

The climate change risks for any sector can only be fully understood by taking into account that sector’s level of adaptive capacity. Climate change risks can be reduced or worsened depending on how well we recognise and prepare for them. The consequences of climate change are not limited to its direct impacts. Social and physical infrastructure, the backdrop against which climate change occurs, must also be considered. If such infrastructure is maladapted, the economic, social or environmental cost of climate impacts may be much greater; other consequences could also be considerably more detrimental than they otherwise might have been. Avoiding maladaptation is one outcome of high adaptive capacity; high adaptive capacity lowers the negative consequence of climate impacts. Conversely, low adaptive capacity increases the negative consequences.

8.2 Assessing structural and organisational adaptive capacity
The methods used for assessing structural and organisational adaptive capacity in the CCRA are based on the PACT framework. The work included a preliminary literature-and expert interview-based assessment of all 11 sectors in the CCRA. This was followed by more detailed analysis for the following sectors:

- **Business, Industry and Services** (focusing on the finance sector)
- **Transport** (focusing on road and rail)
- **Built Environment** (focusing on house building)
- **Health**
- **Biodiversity and Ecosystem Services**
- **Water**

---

32 PACT was developed in the UK as one of the outcomes of the ESPACE Project (European Spatial Planning: Adapting to Climate Events) [http://www.pact.co/home](http://www.pact.co/home).
Structural adaptive capacity

The extent to which a system is free of structural barriers to change that makes it hard to devise and implement effective adaptation strategies to prepare for future impacts. This covers issues such as:

**Decision timescales:** This considers the lifetimes of decisions, from their conception to the point when their effects are no longer felt. The longer this period is, the greater the uncertainty as to the effects of climate change impacts. Cost-effective adaptation becomes harder. Potential climate impacts also become more extreme over longer timescales. This means that a greater scale of adaptation may need to be considered, and that the barriers to adaptation resulting from 'lock-in' to maladapted processes become more pronounced (Stafford-Smith et al., 2011). Adaptive capacity is therefore lower, and maladaptation more likely, when long-lasting decisions are taken.

**Activity levels:** This considers what opportunities are there for adaptation, and on what scale. The frequency with which assets are replaced or created determines how many opportunities there will be to take action which increases adaptive capacity. In addition, when a lot of asset replacement and/or new investment is expected, there will be more chances to learn from experience, which increases adaptive capacity.

**Maladaptation:** This evaluates the effect of decisions already made on adaptive capacity. Long-term previous decisions which have reduced adaptive capacity are often difficult or expensive to reverse. Such decisions were made either before climate change was recognised as an issue, or more recently as a result of poor organisational capacity. Such maladaptation makes implementing effective strategies much harder.

**Sector (or industry) complexity:** This refers to the level of interaction between stakeholders within an industry, or with outside industries and groups, that is required to facilitate effective decision-making. Complexity is higher (and adaptive capacity lower) when many stakeholders are involved in decision-making and when their agendas (e.g. their financial interests) differ substantially.

Organisational adaptive capacity

Organisational adaptive capacity is the extent to which human capacity has developed to enable organisations to devise and implement effective adaptation strategies. The framework used to assess this recognises different levels of adaptation, from entry level (‘Engaging’) to advanced levels (‘Pioneering’ and ‘Leading’), all of which may be needed for effective adaptation. Effective adaptation requires decision-making that takes account of an uncertain future and avoids locking-out future options that might be more cost-effective if climate impacts become more severe, or arrive more rapidly, than expected. The PACT framework used to assess this recognises different levels of adaptation. This framework is arranged in a hierarchy of ‘Response Levels’ (‘RLs’), as set out below, of increasing capacity. These levels do not supersede one another; instead, each one builds on the experiences and practices built up in the previous response level. Organisations may need to be active on all levels for an effective adaptation programme. An RL4 organisation focused on breakthrough projects still needs to be stakeholder-responsive, for example.

---

33This differs from ‘Decision timescales’ because investment in a sector is not continuous but varies over time, with periods of high investment being followed by periods of little or no investment.

34The PACT framework contains six response levels: those cited are the most relevant to the adaptation field.
**RL1: Core Business Focused:** At this level, organisations see no benefit from adapting; if change is required of them, it should both be very straightforward to implement and also incentivised, e.g. through ‘carrots’ and ‘sticks’.

**RL2: Stakeholder Responsive:** At early stages of adaptation, organisations lack basic skills, information, processes and also skilled people; they need very clear advice and information plus regulations that are straightforward enough to help them get started.

**RL3: Efficient Management:** As organisations begin to professionalise adaptation, they become more self-directing, able to handle short term impacts up to 10 years (Stafford-Smith *et al.*, 2011). They need professional networks, best practice guidelines, management standards, etc.

**RL4: Breakthrough projects:** When impacts beyond 10 years need to be considered, organisations may need to consider more radical adaptation options. As well as high quality support from scientists, they may need support with the costs of innovation.

**RL5: Strategic Resilience:** Adapting a whole region or industry for long-term climate impacts of 30 years or more requires lead organisations to develop very advanced capacity that is able to co-ordinate and support action by a wide range of actors over programmes that are likely to last for many years.

### 8.3 Adaptive capacity in the energy sector

The energy sector is large and includes many different industries. The overview of adaptive capacity in this section focuses mostly on the electricity network; for a more detailed assessment of the entire sector, further research would be required.

The structural adaptive capacity of the energy sector is characterised by the following elements:

- Decision timescales are often long, particularly for generation companies, with new power stations expected to last many decades. This presents a challenge for adaptation as decisions must take into account the uncertainty related to potential climate change impacts in the future.
- Activity levels are set to rise, with much capital expenditure being expected over the next decade, which provides an opportunity for relatively low-cost adaptation to take place.
- The high level of activity that is just about to begin makes any existing maladaptation (e.g. to flooding) less of an issue than it otherwise might be. However, if these opportunities to adapt are not taken, and seriously maladapted infrastructure results, change is likely to become much more difficult for several decades.
- While the overall sector is complex, the complexity of differing subsectors is relatively low, with relatively few large companies with long-established working relationships with each other and with regulators, etc.

It is unclear whether organisational adaptive capacity is sufficiently advanced to take advantage of anticipated opportunities to adapt. The capacity will need to be of a high
level, able to consider risks over many decades and establish pathways to manage uncertain impacts over extended periods.

A review for the Carbon Disclosure Project 2008 (CDP08; Acclimatise, 2009), which reviewed comparative performance among the FTSE 250 companies, reported on some aspects of adaptive capacity within the energy sector. The focus was on early stage adaptation activities rather than on the much more sophisticated activities that would be required at a period of major investment in the energy sector. The energy sector was divided into two groups: electric utilities and other energy companies. The project findings showed that more than 50% of electric utilities companies had carried out a physical risk assessment on climate change. The other energy companies reported lower activity with respect to climate change adaptation, with few having carried out risk assessments or having considered their regulatory risks in the context of climate change.

Considering access to capital (i.e. investment) and the effects of climate change on the energy sector, these findings from the CDP08 would seem to suggest a surprisingly low level of capacity within the sector. However, there are some signs that capacity is now higher than suggested by results at that time. In particular, electricity distribution companies report being well advanced with their adaptation programmes:

- **Programme management**: An industry working group recently reviewed long-run risks, identified appropriate responses and showed how companies can schedule upgrades into replacement cycles at low cost.

- **Flood resilience**: The serious flooding events in Carlisle in 2005 and in South Midlands and South Yorkshire during 2007 highlighted the potential vulnerability of electricity substations to flooding. Following these events a task group was set up consisting of representatives from network companies, DECC, Ofgem, EA, SEPA, Met Office and the Pitt Review. This working group produced technical guidance (Engineering Technical Report 138; ENA, 2009) on how to carry out a risk analysis on substations and companies have started a ten year work programme to improve substation resilience to flooding (ENA, 2011).

- **Weather sensitivities** are routinely taken into account in the Energy Sector such as planning maintenance or ensuring sufficient contractors are available during severe weather events (for example snow or gales).

- **Impacts on assets**: Studies have also been commissioned by this sector to further investigate the impacts of climate change on the sector’s assets, for example the Energy Phase 2 project (Met Office, 2008) and more recently a study to assess how climate change may affect the frequency of weather-related faults on the electricity transmission and distribution networks (McColl et al, 2011).

- **Government level actions**: More generally, the Cabinet Office’s Sector Resilience Plan for Critical Infrastructure (2010) addressed energy assets. Adoption of the adaptation agenda by a wide range of industry bodies (including Ofgem, electricity generators, transmitters and distributors and gas transporters, has been encouraged by designating them as ‘reporting authorities’ under the Climate Change Act, 2008., required to report on how they are assessing risks, considering adaptation options and acting on them.
9 Discussion

For all the Tier 2 impacts the key findings are summarised and the results discussed in the context of current Government policy. Information on the gaps in the analysis is also provided and suggestions on how these gaps could be improved in future work. The marginal impacts that could not be assessed in Tier 2 for the Energy Sector are also considered with emphasis on those for which little information is currently available. Finally the limitations of the analysis carried out for the Energy Sector are summarised; these should be addressed in any future CCRA update.

9.1 EN1: Flooding of infrastructure

9.1.1 Summary of findings

- Currently there are more substations at risk of fluvial than tidal flooding. This risk (both fluvial and tidal) is projected to increase in the future with more substations classed as being at significant risk of flooding (with a 1 in 75 year return period).
- These results have been assigned high confidence and are projected to have medium to high negative consequences over the period 2020s to 2080s.
- Past events such as the 2005 floods in Carlisle or the 2007 floods in Yorkshire provide a means to understand the large consequences of these risks. For example, the flooding in Carlisle caused 63,114 customer interruptions to electricity supply.
- A preliminary qualitative analysis of the monetary impacts of these risks has been estimated to be between £10 and £100 million per year by the 2050s and over £100 million by the 2080s.
- Following the Pitt Review, there is ongoing work within the Energy Sector to improve flooding resilience including the publication ETR 138 (ENA, 2009) which provides guidance on carrying out risk assessments on substations.

9.1.2 Gaps in evidence

- The analysis is based on information for England and Wales. Suitable information for analysis was not available for Scotland and Northern Ireland.
- The analysis is based on tidal and river flooding. There is much less information available for surface water flooding which meant that it could not be covered by the analysis.
- Information on water pumping stations and treatment works was not available for the analysis.
- The quality of coastal erosion data used in the analysis was relatively poor and better information should become available from the National Coastal Erosion Risk Map (NCERM).
9.1.3 Policy context

The analysis carried out for EN1 does not take account of current measures to reduce flood risk. Flood risk reduction and climate change adaptation measures will, when implemented, reduce the level of risk. Work on the vulnerability of substations to flooding and adaptation measures has been ongoing in the Energy Sector since the 2007 flooding events. The ENA Engineering Technical Report 138 (ENA, 2009), provides clear guidance on how to assess all substations and ensure they are resilient to a 1 in 100 (fluvial) or 1 in 200 (tidal) flood events for primary substations and 1 in 1000 year event for grid points. Adaptation measures to ensure that substations are resilient to these types of events are detailed in the electricity distributors’ Adaptation Reporting Power study (ENA, 2011). The ETR 138 task group consisted of stakeholders from the industry and representatives from Ofgem, DECC and the Cabinet Office. The work to review the vulnerability of the Energy Sector to flooding and secure funding to increase flood defences is supported by DECC and included in their Departmental Adaptation Plan (DAP). The DAP also aims to continue working with the Cabinet Office, the energy companies and Ofgem to extend the Sector Resilience Plans beyond flooding risk to an “all hazards” approach (for example considering other extreme weather such as storms, gales, heavy snow, heat waves and drought). This is now being addressed in the National Resilience Plan for Critical Infrastructure.

9.2 EN1b: Flooding of power stations

9.2.1 Summary of findings

- There are more power stations at coastal than inland locations, which have a higher exposure and risk to tidal rather than fluvial flooding. The risk of fluvial and tidal flooding of power stations could at most double by the 2080s.

- The consequence of flooding of power stations is estimated by the capacity of energy generated by those at significant risk. For tidal flooding this could be 16GW (14.7 to 18.6GW) by the 2080s which is between 18% and 22% of the present-day capacity of the UK energy network (of course this capacity will increase in the future).

- These results have been assigned medium confidence and are projected to have medium to high negative consequences over the period 2020s to 2080s.

- A separate qualitative analysis of both operating and decommissioning nuclear power stations and radioactive waste storage sites was undertaken. This found that in all cases over 30% of sites may be at high risk of coastal flooding if adequate defences were not built.

9.2.2 Gaps in evidence

- The analysis is based on information for England and Wales. Suitable information for analysis was not available for Scotland and Northern Ireland.
The analysis is based on tidal and river flooding. There is much less information available for surface water flooding which meant that it could not be covered by the analysis.

Information on water pumping stations and treatment works was not available for the analysis.

The quality of coastal erosion data used in the analysis was relatively poor and better information should become available from the National Coastal Erosion Risk Map (NCERM).

9.2.3 Policy context

The UK Government is committed to reducing greenhouse gas emissions by 18% on 2008 levels by 2020. One step to achieve this target is the 15% target for renewable energy contribution towards total energy demand for 2020; this equates to a 30% contribution towards electricity demand for 2020. Despite an increase in renewable electricity, there will still remain a reliance on fossil fuels, which means that the analysis on flooding of power stations (nuclear, coal and gas) will remain pertinent.

The life-cycle of a power station is approximately 40 years and therefore many of the power stations analysed in this study will have to be decommissioned before 2100. This provides a means to mitigate the long term flood risk on power stations. It is likely that existing sites will be used for new power stations, but flood defences could be integrated into any new designs to account for the type of events analysed for EN1b (tidal and fluvial flooding events with a 1 in 75 year return period).

Due to the current commitment by the Government to facilitate the building of new nuclear power stations (see Section 1.4 for more details), a qualitative analysis was carried out for sites for proposed new nuclear power stations, radioactive waste stores and decommissioning sites. This analysis highlighted that all of the high risk sites are on the coast or estuaries. They may therefore be exposed to sea level rise and coastal erosion. The sites are generally well protected, but sea level rise would gradually reduce the standard of protection unless defences are raised. Similarly, coastal erosion protection may require upgrading over time depending on changes at each site. These conclusions should be taken in context with current regulation that states all existing nuclear stations must be designed to withstand a 1 in 10,000 year flood event and planning regulations for new nuclear power stations require their design to take climate change impacts into consideration.

9.3 EN2: Cooling demand

9.3.1 Summary of findings

- UKCP09 projections of cooling degree days (CDD) suggest a mean increase of between 125 to 175 days in southern England and 25 to 50 days in northern England and Scotland. From these projections it is possible to infer that cooling requirements may increase in the future as a consequence of increasing temperatures.

- These results have been assigned high confidence and are projected to have medium to high negative consequences over the period 2020s to 2080s.
• Increased cooling requirements is an autonomous adaptation response given higher temperatures, but is also related to increased levels of wealth (Isaac and van Vuuren, 2009).

• Day et al. (2009) estimate that energy demand for cooling in London could rise from approximately 1.6 to 2.2TWh or 2.5 TWh under a low or high climate change scenario respectively.

• It is possible that increases in cooling energy demand could be offset in the non-domestic sector if better efficiency measures are introduced.

• The cost of an increase in cooling demand is estimated to be high; between £100 and £1000 million in the 2050s and in excess of £1000 million in the 2080s.

• These findings must be considered in context with the impact of climate change on demand for heating (BE9 in the Built Environment sector), which is projected to reduce by approximately 15% by the 2020s, 25% by the 2050s and 40% by the 2080s (for the p50 medium emissions scenario). These reductions would have associated economic benefits of up to between £1 and £3.4 billion per year by the 2080s.

9.3.2 Gaps in evidence

• This metric was based on UKCP09 CDD projections and on cooling energy demand projections from previous studies (Day et al., 2009 and DECC, 2010d).

• For this metric confidence could be improved by calculating cooling energy demand projections using the UKCP09 CDD projections. This would only be possible if future forecasts of energy demand for cooling in the domestic, service and industrial sectors were available.

9.3.3 Policy context

Mitigation policies set by the UK Government are likely to influence cooling demand in the future. For example, measures to improve the efficiency of the UK housing stock (such as insulation) are likely to change the thermal properties of UK houses which could have both positive and negative impacts on cooling requirements. Similarly Building Regulations to reduce the amount of heating required by new and refurbished buildings (since heating accounts for a far larger proportion of total energy demand), have led to changes in cooling requirements.

An important consideration in cooling requirements is the effect that efficiency measures can have; Day et al. (2009) found a 27% reduction in the amount of energy required in their projections for cooling in 2030. If more efficient air-conditioning systems are installed this may offset some of the increased requirements caused by increased temperature.
9.4 EN3: Heat related damage

9.4.1 Summary of findings

- The risk associated with heat-related damage was found to be low and within the level of planned adaptation. This is because electricity and gas equipment must already be able to withstand a level of high temperatures set by industry design standards.

- This assumes that maintenance operations must be carried out effectively and in a timely fashion with particular attention to old infrastructure.

- The results of this analysis have been assigned low confidence and are projected to have low negative consequences over the period 2020s to 2080s.

- As a result climate projections are not applied to this impact.

9.4.2 Gaps in evidence

- For this metric confidence could be improved by carrying out a quantitative analysis on future risk. One approach would be to use the design standards set by the industry (for example power transformers must sustain peak ambient air temperature not greater than 30°C average in one day or more than 20°C average in any one year) and to investigate how the frequency of these temperature thresholds may change in the future. This would quantitatively indicate whether the current standards are sufficient to sustain future climate change.

9.4.3 Policy context

Energy disruptions caused by weather (including heat stress) are maintained by the industry and regulated by Ofgem. Adaptation to changes to the frequencies of these types of incidences are therefore the responsibility of the industry and, as the regulator, Ofgem sets policy to ensure adaptation to climate change and security of supply.

9.5 EN4: Water abstraction

9.5.1 Summary of findings

- The risk of insufficient water sources of sustainable abstraction is projected to increase in the future. Although the size of the reduction in future abstractions varies throughout England; this reflects the current use of water within each region.

- In the Severn river basin region there is projected to be a 21% decrease (0 to -21%) in sustainable abstractions by the 2020s. There are also large percentage reductions projected in the Thames river basin region of 18% (0 to -18%) by the 2020s. While there are projected to be smaller percentage reductions in the Humber river basin region, with no change
(0 to -3%) by the 2020s, and decreases of 7% (-1 to -11%) by the 2080s, total abstractions for power generation are much greater than those in the Severn and Thames river basin regions.

- These results have been assigned medium confidence and are projected to have low to medium negative consequences over the period 2020s to 2080s.
- The total water use for nuclear power stations in financial year 2009/2010 was just over 8.5 million cubic metres; this emphasises the importance of water availability for generating electricity.

9.5.2 Gaps in evidence

- The analysis is based on information for England and Wales. Suitable information for analysis was not available for Scotland and Northern Ireland.
- This metric was calculated using data from Entec (2010) which links changes in Q95 with changes in water availability classes or CAMS colours for England and Wales.
- As Q95 is a poor indicator of ecological stress on river ecosystems on its own, the analysis for this metric provides only a partial view and further information on understanding hydro-ecological stress from modifications of the flow regime as a whole is needed. This metric would be further enhanced if similar data were available for Scotland and Northern Ireland. The WFD river basin management planning process should provide a mechanism for improving our understanding of the impacts of climate on ecological status.

9.5.3 Policy context

The current UK Government is committed to facilitate the building of new nuclear power stations (see Section 1.4 for more details). It is clearly important that the issue of future water abstraction is taken into consideration in plans for any new power plants that are proposed to be built inland and rely on river water abstraction. The same issues will not be apparent for proposed plants on the coast. These types of decisions will be taken by the new Major Infrastructure Planning Unit.

9.6 EN10: Transmission capacity

9.6.1 Summary of findings

- The risk of de-rating the electricity networks (both transmission and distribution) is estimated to increase in the future to increasing temperatures. Lower voltage systems are more susceptible to de-rating.
- Dealing with changes in capacity is not a new problem since the networks have been subject to a load growth of approximately 1.5% to 2% per annum. Therefore the impact of de-rating is not dissimilar to recent
demand growth, which has been taken into account within the current design standards.

- These results have been assigned high confidence and are projected to have low to high negative consequences over the period 2020s to 2080s.
- Possible actions available to reduce de-rating include increasing the heights of overhead lines or replacing underground cables with larger cables. The cost of this work is estimated to be up to £2.6billion over 60 years.

9.6.2 Gaps in evidence

- This metric is based on up-to-date research published by ENA (2011) and UKCP09 climate projections. As a result the confidence in this metric is assumed to be high.

9.6.3 Policy context

It is likely that the load on the electricity network will increase over the next forty years due to current policy and the move to a low carbon economy (for example due to the electrification of the transport system). Work by the ENA and Imperial College has found that 70% of this increase in demand could be incorporated into the existing network through the use of smart network technology, which would also respond to the impact of climate change on de-rating. This means that the use of smart network technology, although its primary function is mitigation through the transition to a low carbon economy, also provides an adaptation measure (ENA, 2011).

9.7 Impacts assessed as marginal or cross-sector

A narrative of the potential risks and consequences of a number of remaining impacts is provided in Section 3.3. These impacts were either scored as marginal, identified as gaps in the analysis or were cross-sector impacts that had been assessed in other sector reports. The four impacts assessed in the Tier 2 analysis of other sectors, but identified as being of importance to the Energy Sector are:

- **Demand by water suppliers (EN5)**: the Water sector found that there are significant pressures on water availability in the UK that could increase due to drier conditions and rising demands.
- **Demand for heating (BE9)**: the Built Environment sector found that there is a clear reduction in the projected levels of energy demand to heat homes across all regions in future decades.
- **Arctic shipping routes (MA5)**: the Marine and Fisheries sector found a projected increase in navigable days in the Arctic particularly for the North East Passage which is key for the UK economy.
- **Ocean acidification (MA4)**: the Marine and Fisheries sector quantified how ocean acidification may change in the future, but the impacts on marine economies and resources remain unknown.

For the remaining impacts some information was available from previous studies, but often there were few or no data to quantify the risks. For these impacts (such as
electricity turbine efficiency or power station cooling processes) further research is advised to fully understand their risks.

9.8 Limitations

- All of the impacts related to renewable sources (with the exception of wind damage) were not selected as marginal or priority for the Tier 2 analysis. It is likely that current UK policy has not been fully considered when scoring these impacts for, although reliance on renewable sources of energy is currently low, this is likely to change in the future.

- Since the representatives at the Energy Sector workshop were mainly energy distribution and transmission stakeholders, the risk metrics derived are primarily focussed on the gas and electricity networks. This may be a limitation in the metric selection; a bias towards industry rather than policy focus.

- Where possible a UK analysis was carried out, but there were some metrics (EN1, EN1b and EN4) for which data were not available for Northern Ireland and Scotland. In these cases the results are only available for England and Wales.

- Quantitative assessments have been carried out for the majority of the Tier 2 impacts, but have often relied on relationships derived by previous studies. These relationships may need to be checked in future CCRA updates to ensure that they remain true.

- The results of this study must be interpreted in light of climate modelling uncertainties. There is greater certainty in some climate variables than others (e.g. mean temperature rise is confidently expected, changes in summer precipitation are less well-constrained, and there is no clear signal of change in wind speed). These uncertainties feed through into the uncertainties in the sector-specific impacts.

- The interactions between energy risks have not been investigated in detail (for example if the location of power plants was changed to reduce the risk of flooding, this could adversely impact the risk of reduced water abstraction). Any adaptation assessments should consider these risks collectively.

- The socioeconomic assessment in this report is limited and should be addressed in further detail.
10 Conclusions

The objective of this report is to provide a comprehensive overview of the risks (and opportunities) presented by climate change to the Energy Sector. A tiered methodology has been undertaken to identify and, where possible, quantify these risks, where the level of detail has increased with each tier. This report summarises the results and information obtained during each tier of the methodology.

The UK Energy Sector is largely reliant on fossil fuels; in 2009 5% of the UK energy mix came from nuclear or renewable generated electricity. The sector plays an important role in the UK economy contributing to 3.7% of GDP and employing 150,200 people (5% of industrial employment). It also contributes a large fraction of the UK’s total CO2 emissions (emissions from power stations currently account for just under one-third of total CO2 emissions).

Energy policy relating to climate change (both mitigation and adaptation) will have an impact on the sector. The UK Government is committed to reducing greenhouse gas emissions by 18% on 2008 levels by 2020. Some of these reductions will be achieved through greater reliance on electricity from renewable sources, investing in carbon capture and storage technologies and facilitating the development of new nuclear power stations. Other measures, such as the electrification of the transport system, will add stress to the existing electricity network. Consequently, the Government is taking action to create a bigger, smarter grid. Whilst this is related to mitigation, a smart grid will also play an important role in future adaptation. For example, a more efficient grid is likely to be able to adapt to changes in energy demand patterns or changes in the capacity of the networks, which are both potential impacts of climate change.

Adaptation measures are considered across government and by individual stakeholders; for example in DECC’s Departmental Adaptation Plan (DAP), the Cabinet Office’s Sector Resilience Plan for Critical Infrastructure 2010 and the stakeholder assessments for Defra’s Adaptation Reporting Power.

The Tier 1 list consisted of 37 impacts that were clustered into four groups: energy generation, renewables, infrastructure/supply and energy demand (illustrated in Figure 3.1). During the Tier 2 selection processes, there were impacts with high scores from all of these clusters with the exception of renewables. On further consideration it is likely that impacts associated with renewable sources of energy have scored lower because current reliance is low; however this is likely to change in the future and should be readdressed in future CCRA updates.

Impacts associated with power generation are mostly related to risks of energy security through either a decrease in efficiency of generation (for example through reduced water abstraction) or a disruption to supply (for example the flooding of a substation). For renewables, the impacts relate to the amount of energy generated since this is directly correlated with a climate variable (for example the amount of solar power generated depends on fluctuations in solar radiation). Infrastructure impacts largely overlap with the renewables and power generation cluster; they are either related to disruptions in supply caused by weather or the capacity of the electricity or gas networks which can be adversely affected by high temperatures. Lastly, energy demand impacts reflect how the pattern of demand may change as a result of climate change (for example changes to cooling or heating requirements).

Based on the impacts selected for the Tier 2 analysis, the risks of climate change on the Energy Sector are found to be increasing and to have negative consequences. The key findings from this assessment are:
• The risks facing the industry, which includes flooding, reduced water supply and extreme temperatures, could adversely affect the ability of the UK Energy Sector to meet projected energy demand.

• Power stations, electricity substations and other energy infrastructure located in vulnerable areas are likely to face an increased risk of flooding, potentially disrupting energy supplies.

• The number of power stations at risk of flooding in England and Wales is projected to rise to 26 (21 to 27) in the 2020s to 38 (31 to 41) in the 2080s. The risk of flooding to major substations is projected to rise from 46 today to 53 (48 to 60) by the 2020s and 68 (57 to 79) by the 2080s.

• The requirements for cooling are likely to increase in the future due to higher temperatures. Energy demand for cooling in London could rise from approximately 1.6 to between 2.2TWh and 2.5 TWh, which could have significant associated costs.

• The findings for cooling demand must be considered in context with the impact of climate change on demand for heating (BE9 in the Built Environment Sector), which is projected to reduce by approximately 15% by the 2020s, 25% by the 2050s and 40% by the 2080s (for the p50 medium emissions scenario). These reductions would have associated economic benefits.

• The risk associated with damage to equipment directly caused by increased temperatures was found to be low, since electricity and gas equipment are already designed to withstand high temperatures.

• Increases in temperature are, however, expected to reduce the capacity of the electricity networks since in high temperatures certain types of equipment can be “de-rated” (i.e. the amount of current carried must be reduced). De-rating is part of a wider issue since the network experiences approximately 1.5-2% load growth per year and this may increase substantially if the transport system or heating becomes dependent on electricity.
References

DIST/PRICECNTRLS/DPCR4


DECC (2010b) Carbon dioxide emissions and energy consumption in the UK (March 2010). Energy Trends Article. Available at:
DECC (2010c) 

DECC (2010d) 
*2050 Pathway Analysis.* Available at: http://www.decc.gov.uk/en/content/cms/tackling/2050/2050.aspx

DECC (2010e) 
https://www.energynpsconsultation.decc.gov.uk/nuclear/nominated_sites

DECC (2010f) 
*Valuation of energy use and greenhouse gas emissions for appraisal and evaluation.* Available at: http://www.decc.gov.uk/en/content/cms/about/ec_social_res/iag_guidance/iag_guidance.aspx

DECC (2011a) 

DECC (2011b) 
*Departmental Adaptation Plan.* Available at: http://www.defra.gov.uk/environment/climate/government/departmental-adaptation-plans/

Defra (2010) 

Defra (2011) 

EEA (2004) 
*Impacts of Europe’s Changing Climate - an Indicator Based Assessment.* EEA Report No 2/2004


*Climate Change and the European Water Dimension*, European Commission- Joint Research Centre, Ispra, Italy. EUR 21553 EN.

ENA (2009) 

ENA (2011) 

Entec (2010) 


Appendices
Appendix 1  Workshop Outputs

Attendees at the sector workshop, held in Reading on 27th May 2010, reviewed the list of Tier 1 energy sector impacts. Specifically they were asked to:

- Review the impacts and consequences work, identifying any important omissions to the list, any concerns or disagreement with the list and to give views on how they have been scored (in terms of pedigrees and levels of confidence (see the methodology));
- Provide guidance as to which impacts should be considered in the Tier 2 list; and
- Identify potential ‘risk metrics’ for key impact areas.

Stakeholders identified gaps in the analysis carried out in the Tier 1 report and in the impacts, but after review by the team many of these were considered low priority within the context of the CCRA and already incorporated into the routine risk analysis carried out by companies. Stakeholders also noted that other work was being done in parallel to this study with many similarities including the Critical Infrastructure Resilience Plan, the work by the Met Office for the Energy Networks Association, work by PwC and Cranfield University on the effect of climate change on energy infrastructure, the Exercise Watermark from the Environment Agency on the impacts of flooding on power stations and a study on smart metering by Imperial College.

The workshop thus highlighted areas for further analysis and 3 new impacts were identified in addition to the 34 from the Tier 1 report. These were:

1. Maintenance schedule (35): variation in precipitation makes the maintenance of excavation, cable repairs and pipe work more difficult;
2. Lightning (36), increased incidence of lightning could impact the resilience of the electricity transmission lines; and
3. Coastal and river bed erosion exposing gas infrastructure (37), thus making exposed infrastructure more vulnerable to weather related faults.

These impacts were added to the list and scored based on the methodology described in the Methodology Report (Defra, 2010).

Following the sector workshop, the information and ideas developed were used by the project team as one element of the selection process for Tier 2 impacts. Further meetings were also held with some trade associations already actively working on adaptation in order to explore areas of opportunity for joint working.
Appendix 2  Social Vulnerability Checklist
<table>
<thead>
<tr>
<th>Sector</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster/Theme</td>
<td>Coal/ gas power generation, renewables, infrastructure/supply, energy demand[^35]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category of social vulnerability factor</th>
<th>Questions to ask</th>
<th>Comment (general answer)</th>
<th>Evidence (opinion, reports, research)</th>
<th>Extent (specifics including data where available)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place</td>
<td>Which locations are affected by these impacts? Is it spread evenly across regions or not?</td>
<td>All regions affected, urban areas more affected than rural areas due to power station locations and energy demand. Renewable power generation could have a greater effect on the South West, the Midlands and Scotland than other areas, as this is where most renewable projects are being developed[^36].</td>
<td>Energy sector report[^37], workshop discussions, energy map of the UK[^38], DECC energy statistics by region[^39].</td>
<td>Mainly the South West, Midlands and Scotland and in urban areas.</td>
</tr>
<tr>
<td>Social deprivation</td>
<td>How will people with poor health (physical or mental) be affected by these impacts?</td>
<td>People could experience discomfort depending on the season, due to temporary electricity and gas disruptions. Prolonged period of disruption could exacerbate health symptoms due to cold/heat related impacts.</td>
<td>Mortality in southern England during the 2003 heat wave by place of death, Clare Griffiths, Helen Johnson. R Sari Kovats, Health Statistics Quarterly, no 29, pp 6-8.</td>
<td>About 2% of the total UK population is considered at risk of health problems[^40].</td>
</tr>
</tbody>
</table>

[^35]: All impacts in the energy sectors result in problems with efficiency in transmission or in power generation with the effect that people have or do not have energy (gas + electricity). This means that in case of a power outage (no gas or electricity) there will always be some vulnerable groups affected but the severity depends on how long the energy disruption lasts for, and when this happens during the year (if a blackout happens in non extreme temperatures, consequences are more limited). Here we discuss vulnerable groups in a general way without making scenarios or assumptions, as at this stage this would be purely speculative.

[^36]: Map of planned renewable project is available at: [http://www.renewables-map.co.uk](http://www.renewables-map.co.uk)

[^37]: The first UK climate change risk assessment: energy sector early issues report, March 2010, Met Office


[^40]: Available at: [http://www.statistics.gov.uk/articles/hsq/1419.pdf](http://www.statistics.gov.uk/articles/hsq/1419.pdf)
<table>
<thead>
<tr>
<th>Sector Cluster/Theme</th>
<th>Energy Coal/ gas power generation, renewables, infrastructure/supply, energy demand 35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category of social vulnerability factor</td>
<td>Questions to ask</td>
</tr>
<tr>
<td>How will people with fewer financial resources be affected?</td>
<td>Lower income groups less likely to be able to afford to maintain a satisfactory heating regime, which could contribute to health problems.</td>
</tr>
<tr>
<td>How will people living or working in poor quality homes or workplaces be affected?</td>
<td>These people could be the most affected as they could need more energy to reach an appropriate level of comfort (both for heating and cooling).</td>
</tr>
<tr>
<td>How will people who have limited access to public and private transport be affected?</td>
<td>People with reduced access to transport links could have fewer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector Cluster/Theme</th>
<th>Energy</th>
<th>Questions to ask</th>
<th>Comment (general answer)</th>
<th>Evidence (opinion, reports, research)</th>
<th>Extent (specifics including data where available)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category of social vulnerability factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>transport be affected?</td>
<td>opportunities to seek more comfortable environments, e.g. in case of power outage.</td>
<td>expert judgment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>How will people with lack of awareness of the risks be affected?</td>
<td>Energy outages are very rarely anticipated. There are limited means to raise awareness of decreased power generation and potential disruptions. Here we consider the whole population lacking awareness, however, generally speaking the majority of the population can cope well even in case of prolonged disruptions (e.g. days).</td>
<td>Energy sector report, workshop discussions, expert judgment.</td>
<td>Whole UK population.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How will people without social networks be affected?</td>
<td>No serious impacts on healthy people, but blackouts and gas outages could be a burden for people with health issues or the elderly who cannot rely on others for help.</td>
<td>Energy sector report, workshop discussions, expert judgment.</td>
<td>Mainly the elderly (7.3 mn people in the UK are over the age of the 70)(^6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How will people with little access to systems and support services (e.g. health care) be affected?</td>
<td>See above</td>
<td>Energy sector report, workshop discussions, expert judgment.</td>
<td>Same as above.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>Changes in geographic distributions of population within the UK could require changes to the existing energy infrastructure. Substantial energy infrastructure such as the Severn barrage could also affect the local population at all levels.</td>
<td>Energy sector report, workshop discussions, expert judgment.</td>
<td>Areas where substantial infrastructures are being developed. E.g. Severn Barrage.</td>
</tr>
</tbody>
</table>

\(^6\) Population statistics, Office of National Statistics,
**Appendix 3  Scored Tier 1 Impacts**

The following notes accompany the below table. Full details of the method applied for the scoring of impacts can be found in the Method Part II Report (Defra, 2010).

**Note 1 Name of 'rationalised' impacts (including individual reference numbers from Table 1)**

The impacts in the Tier 1 list in Table 1 have been grouped according to similarity and this column lists the resulting 'rationalised' impacts. The numbers in brackets identify which, of the Tier 1 list impacts in Table 1, relate to the impacts listed here. The reference numbers correspond to the 'Ref' number identified in Table 1.

**Note 2 Economic score**

A score of 3 (high), 2 (medium) or 1 (low) is assigned to each rationalised impact to evaluate the magnitude of the economic consequences arising from the impact occurring. The evaluation considers a broad range of factors, including the potential for asset damage, transport disruption and consequences on business and the functioning of the economy.

**Note 3 Environmental score**

A score of 3 (high), 2 (medium) or 1 (low) is assigned to each rationalised impact to evaluate the magnitude of the environmental consequences arising from the impact occurring. The evaluation considers a broad range of factors, including the potential for impacts on valued species and biodiversity and impacts on ecosystem services.

**Note 4 Social score**

A score of 3 (high), 2 (medium) or 1 (low) is assigned to each rationalised impact to evaluate the magnitude of the societal consequences arising from the impact occurring. The evaluation considers a broad range of factors, including the risk to life, health and wellbeing; consequences on disadvantaged groups; disruption to services; and cultural and symbolic consequences.

**Note 5 Vulnerable groups Y/N**

Yes/No is used as an indication of whether vulnerable groups have been identified (via the social vulnerability checklist in Appendix x) as being particularly affected by this impact. This information was not used to select Tier 2 impacts but provides context.

**Note 6 Likelihood score**

A score of 3 (high), 2 (medium) or 1 (low) is assigned to likelihood of the impact and its consequences occurring. As a guideline, high likelihood is assigned where it is likely that consequences will occur within the next century; medium where it is about as likely as not to occur in the next century; and low where it is unlikely that consequences will occur within the next century.

**Note 7 Urgency score**

A score of 3 (high), 2 (medium) or 1 (low) is assigned to the urgency for decision making related to the potential impact. The evaluation was based on whether major decisions are required before 2020 (high) or 2050 (medium) or not at all (low) that affect future resilience to this impact from climate change. It also considers whether there is significant (high), some (medium) or little (low) shortfall in adaptive capacity.
**Note 8 Total Score**

The total score combines the scores described above in the following way:

$$100 \times \left( \frac{\text{Social+Environmental+Economic}}{9} \cdot \frac{\text{Likelihood}}{3} \cdot \frac{\text{Urgency}}{3} \right)$$

The lowest possible score is four\(^{47}\), an average score for the impacts identified in the CCRA is around 30, and 100 is the highest theoretically possible.

**Note 9 Ranking**

The ranking shows how each impact ranks compared to the others in Table 2. The impacts that were selected for Tier 2 analysis are highlighted in blue and marginal impacts that were considered in the broader overview of impacts discussed in Chapter 3 of this report are highlighted in yellow.

**Note 10 Average Pedigree**

A ‘pedigree’ scoring system was applied to the collective evidence available to support each impact identified as follows:

0 - Non-expert opinion, unsubstantiated workshop discussion with no supporting evidence

1 - Expert view based on limited information, e.g. anecdotal evidence

2 - Estimation of potential impacts, using accepted methods and with some agreement across the sector

3 - Reliable analysis and methods, subject to peer review and accepted within a sector as 'fit for purpose'

4 - Comprehensive evidence using the best practice and published in the peer reviewed literature; accepted as an ideal approach.

---

\(^{47}\) Lowest score would be 3.7 and mid score 29.6 ~ the quoted low and mid figure are rounded
<table>
<thead>
<tr>
<th>Name of 'rationalised' consequences (incl. individual impact reference numbers from sectors summary report)</th>
<th>Economic Score</th>
<th>Environ. Score</th>
<th>Social Score</th>
<th>Vulner. Groups Y/N</th>
<th>Likelihood Score</th>
<th>Urgency Score</th>
<th>Total Score</th>
<th>Ranking</th>
<th>Average Pedigree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding of Infrastructure (4,29)</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Y</td>
<td>3</td>
<td>2</td>
<td>52</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Demand for Cooling (14,16,25)</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>Y</td>
<td>3</td>
<td>2</td>
<td>44</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Heat Related Damage/Disruption (13,24)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>Y</td>
<td>3</td>
<td>2</td>
<td>37</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Water Abstraction for energy generation (6)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>37</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Flooding of Power Stations (28)</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Y</td>
<td>2</td>
<td>2</td>
<td>35</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Demand by Water Suppliers (3)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Electricity Turbine Efficiency (20)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Gas Pipeline Compressor Rating (23)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Power Station Cooling Processes (15,19)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Wind Damage (33,34)</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>Y</td>
<td>2</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Transmission Capacity - overhead (22)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>2</td>
<td>30</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Cold Related damage/Disruption (02,12)</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Y</td>
<td>3</td>
<td>1</td>
<td>26</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Lightnings (36)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>Y</td>
<td>2</td>
<td>2</td>
<td>25</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Dam Spills (7)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>Y</td>
<td>2</td>
<td>1</td>
<td>22</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Hydroelectricity Production (6,9)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Wind Power (31,32)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Demand for Heating (5,8,11)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Y</td>
<td>3</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Maintenance schedule (35)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>1</td>
<td>15</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Regional Energy Demands (26)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>N</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Subsidence &amp; Heave (01)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>3</td>
<td>1</td>
<td>11</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Coastal and river bed erosion exposing gas</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>infrastructure (37)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Renewables (30)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Solar Power (10)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Transmission Capacity - under ground (17)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Bio Fuel Yields (27)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>Diurnal Energy Demands (21)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>Vegetation Management (18)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>27</td>
<td>2</td>
</tr>
</tbody>
</table>
Appendix 4   Magnitude, Confidence and Presentation of Results

Table A2.1 defines the magnitude classes used in the assessment. These were used for scoring impacts in the Tier 2 selection process as well as for scoring risk levels for the scorecards presented for each metric in Chapter 5. For the scorecard, the risk/opportunity level relates to the most relevant of the economic/environmental/social criteria.
Table A4.1 Guidance on classification of relative magnitude: qualitative descriptions of high, medium and low classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Economic</th>
<th>Environmental</th>
<th>Social</th>
</tr>
</thead>
</table>
| High  | • Major and recurrent damage to property and infrastructure  
              • Major consequence on regional and national economy  
              • Major cross-sector consequences  
              • Major disruption or loss of national or international transport links  
              • Major loss/gain of employment opportunities  
              ~ £100 million for a single event or per year | • Major loss or decline in long-term quality of valued species/habitat/landscape  
              • Major or long-term decline in status/condition of sites of international/national significance  
              • Widespread Failure of ecosystem function or services  
              • Widespread decline in land/water/air quality  
              • Major cross-sector consequences  
              ~ 5000 ha lost/gained  
              ~ 10000 km river water quality affected | • Potential for many fatalities or serious harm  
              • Loss or major disruption to utilities (water/gas/electricity)  
              • Major consequences on vulnerable groups  
              • Increase in national health burden  
              • Large reduction in community services  
              • Major damage or loss of cultural assets/high symbolic value  
              • Major role for emergency services  
              • Major impacts on personal security e.g. increased crime  
              ~million affected  
              ~1000’s harmed  
              ~100 fatalities |
| Medium | • Widespread damage to property and infrastructure  
              • Influence on regional economy  
              • Consequences on operations & service provision initiating contingency plans  
              • Minor disruption of national transport links  
              • Moderate cross-sector consequences  
              • Moderate loss/gain of employment opportunities  
              ~ £10 million per event or year | • Important/medium-term consequences on species/habitat/landscape  
              • Medium-term or moderate loss of quality/status of sites of national importance  
              • Regional decline in land/water/air quality  
              • Medium-term or Regional loss/decline in ecosystem services  
              • Moderate cross-sector consequences  
              ~ 500 ha lost/gained  
              ~ 1000 km river water quality affected | • Significant numbers affected  
              • Minor disruption to utilities (water/gas/electricity)  
              • Increased inequality, e.g. through rising costs of service provision  
              • Consequence on health burden  
              • Moderate reduction in community services  
              • Moderate increased role for emergency services  
              • Minor impacts on personal security  
              ~thousands affected, ~100s harmed, ~10 fatalities |
| Low   | • Minor or very local consequences  
              • No consequence on national or regional economy  
              • Localised disruption of transport  
              ~ £1 million per event or year | • Short-term/reversible effects on species/habitat/landscape or ecosystem services  
              • Localised decline in land/water/air quality  
              • Short-term loss/minor decline in quality/status of designated sites  
              ~ 50 ha of valued habitats damaged/improved  
              ~ 100 km river water quality affected | • Small numbers affected  
              • Small reduction in community services  
              • Within ‘coping range’  
              ~1000’s affected |

The levels of confidence used by the CCRA can be broadly summarised as follows:

Low - Expert view based on limited information, e.g. anecdotal evidence.

Medium - Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector.
High - Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'.

The lower, central and upper estimates provided in the scorecards relate to the range of the estimated risk or opportunity level. For risk metrics that have been quantified with UKCP09 and response functions, this range relates to the results that are given for the low emissions, 10% probability level (lower); medium emissions, 50% probability level (central); and high emissions, 90% probability level (upper). For the risk metrics that have been estimated with a more qualitative approach, these estimates cover the range of potential outcomes given the evidence provided.

The CCRA analysis uses three discrete time periods to estimate future risks up to the year 2100: the 2020s (2010 to 2039), 2050s (2040 to 2069) and the 2080s (2070 to 2099). This is consistent with the UKCP09 projections.
Appendix 5  Water Quality and Environmental Metrics

Six colours are used on maps to denote the availability of water in each CAMS catchment – the most extreme case being where the catchment is currently ‘over-abstracted’. Table A5.1 describes the classifications of ‘CAMS colours’ and Figure A5.1 shows an example of a recently updated CAMS map of water availability in the ‘local’ catchment.

Data relating to abstractions and discharges in the Water Resources GIS (WRGIS) are assigned to a water use sector. This allows the breakdown of the CAMS resource availability by sector to investigate potential consequences. Sectors include Agriculture, Amenity/Environmental, Industry, Power Generation and Public Water Supply.

The use of metrics based on CAMS deals with a critical policy issue, i.e. abstraction licensing in the context of finite and declining water resources. The classification of individual catchments will change if river flows decrease or increase, thereby providing an indicator of the impacts of climate change on abstraction licences that could be lost if policies remain unchanged.

<table>
<thead>
<tr>
<th>Resource Availability Results (for Q95, Q70, Q50 and Q30)</th>
<th>Summary Definition</th>
<th>Full Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>FL flows &gt;10% above Natural Flow</td>
<td>Both Recent Actual and Fully Licensed flow predictions are more than 10% higher than the current natural flow. New licences may be granted depending on local impacts.</td>
</tr>
<tr>
<td>Green</td>
<td>FL flows &gt; EFI</td>
<td>Both Recent Actual and Fully Licensed flow predictions are above the EFI environmental flow. New licences may be granted depending on local impacts.</td>
</tr>
<tr>
<td>Yellow</td>
<td>FL flows just &lt; EFI</td>
<td>Recent Actual flows are above the EFI, but Fully Licensed predictions would be just below this environmental flow. There will be a presumption against the licensing of further impacts under these flow conditions but recovery of licensed resource is probably not required.</td>
</tr>
<tr>
<td>Orange</td>
<td>FL flows &lt; EFI</td>
<td>Recent Actual flows are above the EFI, but Fully Licensed predictions would be more than 10% below this environmental flow. There will be a presumption against the licensing of further impacts under these flow conditions. Recovery of licensed resource may need to be investigated subject to environmental cost-benefit and sustainability appraisal.</td>
</tr>
<tr>
<td>Red</td>
<td>FL &amp; RA flows &lt; EFI</td>
<td>Both Fully Licensed and Recent Actual Flow predictions are below the EFI. There will be a presumption against the licensing of further impacts under these flow conditions. Further investigations into the actual impacts of abstraction and ecological effects are recommended. These may consider the reduction of abstraction impacts subject to environmental cost-benefit and sustainability appraisal.</td>
</tr>
<tr>
<td>Purple</td>
<td>FL &amp; RA flows &lt;&lt; EFI</td>
<td>Both Fully Licensed and Recent Actual Flow predictions are well below the EFI. There will be a presumption against the licensing of further impacts under these flow conditions. Investigations into the actual impacts of abstraction and consequential ecological effects should be prioritised. These may result in the reduction of abstraction impacts subject to environmental cost-benefit and sustainability appraisal.</td>
</tr>
</tbody>
</table>
The Environment Agency uses SIMCAT modelling software to estimate water quality along the length of rivers, based on known concentrations and locations of point and diffuse pollution discharges into them. This modelling helps the Environment Agency to judge whether a river is likely to meet the conditions set out in the Water Framework Directive (WFD) for 'good' quality. Under the WFD, biological and chemical elements are combined to provide an overall status assessment for surface waters. Ecological status consists of various biological, chemical and physicochemical and hydromorphological quality elements. The Environment Agency SIMCAT modelling looks only at the status of physicochemical quality elements. The modelling also helps
to investigate the likely impacts on water quality of granting further discharge licences to a river and thereby aids decisions as to whether new licences should be granted and what the conditions of those licences should be. The SIMCAT system is able to provide statistics on the lengths of rivers (in km) which fall into each of five WFD classes:

- High
- Good
- Moderate
- Poor
- Bad.

The amount of water flowing in a river affects the dilution of pollutants discharged into it and is one of the major factors in their resulting concentrations downstream. Estimates of future river flows affected by climate change can be used in SIMCAT to model the likely associated changes in river water quality. In total, data are available for 50,418km of UK rivers assessed in this way for future climate change scenarios. With further analysis these data can provide good indications of the likely impacts of climate change on river water quality.
Appendix 6  Future Flood Sector Scenarios

The following projections of future flood frequency have been derived by the Floods and Coastal Erosion Sector team for both fluvial and tidal flooding. They are based on work by Defra and the Environment Agency using UKCP09 projections (Kay et al., 2010).

The two main climate drivers for increased flooding are increases in river flow (arising from increased precipitation) and sea level rise.

Table A6.1 shows the increases in river flow that have been used for the analysis by UKCP09 Region. Table A6.2 shows the sea level rise data that have been used based on UKCP09 data.

The data in Tables A6.1 and A6.2 have been used to develop tables showing increases in flood frequency for fluvial and tidal floods. These are presented in Tables A6.3 and A6.4 respectively. These data can be used to estimate the increase in frequency of flooding for a range of different receptors.

### Table A6.1 Increases in river flows

<table>
<thead>
<tr>
<th>Nation</th>
<th>UKCP09 Region</th>
<th>2061-90 baseline</th>
<th>Relative increase in peak flow from baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1961-90</td>
<td>2020s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low p10</td>
<td>Medium p50</td>
</tr>
<tr>
<td>England</td>
<td>East Midlands (44% Anglian, 47% Humber, 2% Severn, 2% North West, 1% Thames)</td>
<td>0</td>
<td>0.1%</td>
</tr>
<tr>
<td>England</td>
<td>East of England (67% Anglian, 13% Thames)</td>
<td>0</td>
<td>0.8%</td>
</tr>
<tr>
<td>England</td>
<td>East Midlands (50% Thames)</td>
<td>0</td>
<td>3.3%</td>
</tr>
<tr>
<td>England</td>
<td>North of England (91% Northumbria, 8% Tweed, 1% Solway)</td>
<td>0</td>
<td>0.3%</td>
</tr>
<tr>
<td>England</td>
<td>North West (75% North West, 21% Solway, 2% Dee, 2% Northumbria)</td>
<td>0</td>
<td>5.0%</td>
</tr>
<tr>
<td>England</td>
<td>South East (53% Thames, 42% South East, 4% Anglian, 1% South West)</td>
<td>0</td>
<td>0.4%</td>
</tr>
<tr>
<td>England</td>
<td>South West (53% Solway, 24% Severn, 8% Thames)</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>England</td>
<td>West Midlands (71% Solway, 21% Humber, 2% North West, 1% Dee)</td>
<td>0</td>
<td>5.0%</td>
</tr>
<tr>
<td>England</td>
<td>Yorkshire and The Humber (95% Humber, 3% North West, 2% Northumbria)</td>
<td>0</td>
<td>0.2%</td>
</tr>
<tr>
<td>Wales</td>
<td>Wales (59% Western Wales, 33% Severn, 8% Dee)</td>
<td>0</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

### Table A6.2 Sea level rise

<table>
<thead>
<tr>
<th>Nation</th>
<th>UKCP09 Region</th>
<th>2061-90 baseline</th>
<th>Relative sea level rise from baseline in m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2008 p10</td>
<td>Medium p50</td>
</tr>
<tr>
<td>England</td>
<td>East Midlands (50% Thames)</td>
<td>0</td>
<td>0.051</td>
</tr>
<tr>
<td>England</td>
<td>East of England (50% Thames)</td>
<td>0</td>
<td>0.053</td>
</tr>
<tr>
<td>England</td>
<td>London (Thamesmead)</td>
<td>0</td>
<td>0.048</td>
</tr>
<tr>
<td>England</td>
<td>North East (Newcastle)</td>
<td>0</td>
<td>0.055</td>
</tr>
<tr>
<td>England</td>
<td>North West (Wirral)</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>England</td>
<td>South East (Chatham)</td>
<td>0</td>
<td>0.049</td>
</tr>
<tr>
<td>England</td>
<td>South West (Lands End)</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>England</td>
<td>Yorkshire and the Humber (Flamborough)</td>
<td>0</td>
<td>0.049</td>
</tr>
<tr>
<td>Wales</td>
<td>Wales (Cardigan)</td>
<td>0</td>
<td>0.044</td>
</tr>
<tr>
<td>Region</td>
<td>1961-90</td>
<td>2020s Med</td>
<td>2050s Med</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Northumbria</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>Humber</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>Anglian</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>Thames</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>South-East</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>Severn</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
</tbody>
</table>

Table A6.3 Change in fluvial flood frequency

Data are shown as annual probabilities of flooding for present day events with annual probabilities of 0.1 (1:10), 0.04 (1:25), 0.02 (1:50) and 0.01 (1:100).
Data are shown as annual probabilities of flooding for present day events with annual probabilities of 0.1 (1:10), 0.04 (1:25), 0.02 (1:50) and 0.01 (1:100).

<table>
<thead>
<tr>
<th></th>
<th>P10</th>
<th>P50</th>
<th>P90</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Return Period</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1961-90</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2020s Med</td>
<td>0.126</td>
<td>0.052</td>
<td>0.026</td>
</tr>
<tr>
<td>2050s Med</td>
<td>0.154</td>
<td>0.066</td>
<td>0.034</td>
</tr>
<tr>
<td>2080s High</td>
<td>0.195</td>
<td>0.070</td>
<td>0.037</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.130</td>
<td>0.055</td>
<td>0.028</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2050s High</td>
<td>0.126</td>
<td>0.055</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Return Period</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1961-90</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2020s Med</td>
<td>0.126</td>
<td>0.052</td>
<td>0.026</td>
</tr>
<tr>
<td>2050s Med</td>
<td>0.154</td>
<td>0.066</td>
<td>0.034</td>
</tr>
<tr>
<td>2080s High</td>
<td>0.195</td>
<td>0.070</td>
<td>0.037</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.130</td>
<td>0.055</td>
<td>0.028</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2050s High</td>
<td>0.126</td>
<td>0.055</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Return Period</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1961-90</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2020s Med</td>
<td>0.126</td>
<td>0.052</td>
<td>0.026</td>
</tr>
<tr>
<td>2050s Med</td>
<td>0.154</td>
<td>0.066</td>
<td>0.034</td>
</tr>
<tr>
<td>2080s High</td>
<td>0.195</td>
<td>0.070</td>
<td>0.037</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.130</td>
<td>0.055</td>
<td>0.028</td>
</tr>
<tr>
<td>2050s Low</td>
<td>0.100</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>2050s High</td>
<td>0.126</td>
<td>0.055</td>
<td>0.027</td>
</tr>
</tbody>
</table>
### Table A6.4 Change in tidal flood frequency

Data are shown as annual probabilities of flooding for present day events with annual probabilities of 0.1 (1:10), 0.04 (1:25), 0.02 (1:50), 0.01 (1:100), 0.004 (1:250), 0.002 (1:500) and 0.001 (1:1000).

Data are shown for the p50 Medium Emissions Scenario only. Data for the other scenarios are available.

<table>
<thead>
<tr>
<th>UKCP09 Region</th>
<th>Flood frequency: p50 Medium Emissions Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP: 10 25 50 100 250 500 1000</td>
</tr>
<tr>
<td></td>
<td>Frequency: 0.1 0.04 0.02 0.01 0.004 0.002 0.001</td>
</tr>
<tr>
<td>England</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td>East Midlands (Skegness)</td>
<td>2020a 0.158 0.062 0.038 0.018 0.006 0.004 0.002</td>
</tr>
<tr>
<td></td>
<td>2050a 0.309 0.117 0.070 0.027 0.012 0.007 0.004</td>
</tr>
<tr>
<td></td>
<td>2080a 0.682 0.259 0.153 0.065 0.023 0.015 0.008</td>
</tr>
<tr>
<td>East of England (Happisburgh)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.146 0.056 0.031 0.013 0.006 0.003 0.001</td>
</tr>
<tr>
<td></td>
<td>2050a 0.251 0.098 0.056 0.021 0.010 0.006 0.003</td>
</tr>
<tr>
<td></td>
<td>2080a 0.485 0.190 0.106 0.044 0.017 0.011 0.005</td>
</tr>
<tr>
<td>London (Thamesmead)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.147 0.059 0.033 0.014 0.006 0.003 0.001</td>
</tr>
<tr>
<td></td>
<td>2050a 0.281 0.103 0.061 0.022 0.010 0.006 0.003</td>
</tr>
<tr>
<td></td>
<td>2080a 0.521 0.209 0.120 0.050 0.018 0.011 0.006</td>
</tr>
<tr>
<td>North East (Newcastle)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.134 0.053 0.028 0.013 0.005 0.003 0.001</td>
</tr>
<tr>
<td></td>
<td>2050a 0.212 0.083 0.047 0.018 0.009 0.005 0.002</td>
</tr>
<tr>
<td></td>
<td>2080a 0.372 0.146 0.082 0.033 0.014 0.009 0.004</td>
</tr>
<tr>
<td>North West (Walney Island)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.130 0.052 0.027 0.012 0.005 0.003 0.001</td>
</tr>
<tr>
<td></td>
<td>2050a 0.237 0.094 0.055 0.022 0.010 0.005 0.002</td>
</tr>
<tr>
<td></td>
<td>2080a 0.329 0.129 0.071 0.026 0.012 0.007 0.003</td>
</tr>
<tr>
<td>South East (Shoreham)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.170 0.059 0.033 0.013 0.006 0.003 0.001</td>
</tr>
<tr>
<td></td>
<td>2050a 0.370 0.108 0.060 0.021 0.009 0.005 0.002</td>
</tr>
<tr>
<td></td>
<td>2080a 0.948 0.304 0.185 0.084 0.016 0.010 0.005</td>
</tr>
<tr>
<td>South West (Lands End)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.201 0.073 0.043 0.016 0.007 0.004 0.002</td>
</tr>
<tr>
<td></td>
<td>2050a 0.550 0.184 0.101 0.043 0.015 0.009 0.004</td>
</tr>
<tr>
<td></td>
<td>2080a 1.806 0.581 0.321 0.122 0.045 0.021 0.011</td>
</tr>
<tr>
<td>Yorkshire and The Humber (Flamborough)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.167 0.063 0.037 0.014 0.007 0.004 0.002</td>
</tr>
<tr>
<td></td>
<td>2050a 0.357 0.128 0.075 0.029 0.013 0.008 0.004</td>
</tr>
<tr>
<td></td>
<td>2080a 0.856 0.315 0.179 0.071 0.027 0.015 0.009</td>
</tr>
<tr>
<td>Wales (Cardigan)</td>
<td>2008 0.100 0.040 0.020 0.010 0.004 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td>2020a 0.162 0.063 0.037 0.014 0.007 0.004 0.002</td>
</tr>
<tr>
<td></td>
<td>2050a 0.329 0.129 0.075 0.029 0.013 0.008 0.004</td>
</tr>
<tr>
<td></td>
<td>2080a 0.784 0.310 0.177 0.072 0.028 0.016 0.009</td>
</tr>
</tbody>
</table>

Examples of the data from Table A6.4 are shown in Figures A6.1 and A6.2.
Figure A6.1  Increase in tidal flood frequency – East of England  
(P50 Medium Emissions climate change scenario)

Figure A6.2  Increase in tidal flood frequency – Wales  
(P50 Medium Emissions climate change scenario)
Appendix 7  Risk Matrix

ENA (2011) adaptation to climate change risk matrix showing overall impact (refers to UKCP09 projections for the end of the century assuming a high emissions scenario and 90% probability level and no adaptation measures taken).

Table 4B ENA Adaptation to Climate Change Risk Matrix Showing Overall Impact (Refers to UKCP09 projections for the end of the century assuming a High Emissions Scenario and 90% probability level and no adaptation measures taken)

<table>
<thead>
<tr>
<th>Relative Impact</th>
<th>AR13</th>
<th>AR12</th>
<th>AR11</th>
<th>AR10</th>
<th>AR9</th>
<th>AR8</th>
<th>AR7</th>
<th>AR6</th>
<th>AR5</th>
<th>AR4</th>
<th>AR3</th>
<th>AR2</th>
<th>AR1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Relative likelihoods
Probability of a climate change effect having an impact under the change scenarios considered in the report.

Definitions of relative impacts

Extreme: Regional area affected with people off supply for a month or more OR asset de-rating exceeds ability to reinforce network leading to rota disconnections on peak demand.

Significant: County or city area affected with people off supply for a week or more OR asset de-rating requires a significant re-prioritisation of network reinforcement and deferral of new connection activities.

Moderate: Large town or conurbation off supply for up to a week OR significant increase in cost of network strengthening.

Minor: Small town off supply for a 24 hour period OR significant increase in cost of network maintenance requirements.

Limited: Limited impact - can be managed within “business as usual” processes.

A more detailed matrix showing the changing risk profile during the century is shown in Appendix 8.

---

48 Areas affected can be as a result of single or multiple events.