Climate change risks & adaptation responses for UK electricity generation

A sector overview 2015

Energy UK

The voice of the energy industry

Contents page

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Energy UK is the trade association for the energy industry. Energy UK has over 80 companies as members that together cover the broad range of energy providers and suppliers and include companies of all sizes working in all forms of gas and electricity supply and energy networks. Energy UK members generate more than 90% of UK electricity, provide light and heat to some 26 million homes and invested over £13 billion in the British economy in 2013.

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Energy UK

The voice of the energy industry

CEO's Foreword

Lawrence Slade
CEO Energy UK

Most people have a view on climate change and most accept the science that says it is an ever-present threat to our world and way of life. When you ask people they will tell you about the threat of deforestation or rising sea levels or concerns about the permanent loss of wildlife habitats. School children will tell you about changes to the Gulf Stream or the loss of living coral in the Great Barrier Reef. People think of food shortages, drought and hurricanes. They have in their minds the plains of central Africa, lone polar bears isolated on shrinking ice floes or the blue seas around the Maldives. What they might not be thinking about is the effect on power stations in the Trent Valley or wind farms in Argyll. But energy is vital for the economy, for critical services and for the everyday necessities of life. Everyone depends on secure energy supplies that can provide homes and businesses with the power they need, precisely when they need it. So, the UK needs to continue to invest to ensure we prepare for the worst case scenarios.

That is part of the underpinning motivation behind the Government's need to understand how well prepared the UK would be in the event of serious changes to our climate and weather patterns – changes which could bring more severe rainfall or higher winds or even colder weather if the protecting Atlantic flows no longer buffer the British Isles.

Electricity generators have been working to audit, review and improve their own plant and processes. A great deal of work has gone into making Britain's energy system as robust as it can be and that work has led to a marked reduction in risk since the Adaptation Reporting process began in 2010. But, although we can be confident in the ability of our power stations to withstand climate challenges, the industry can never be complacent. Energy UK and its members are continuing to work with other interest groups to make sure we can continue to withstand everything the British weather can throw at us.

August 2015
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Summary

Electricity generation sits within the UK's Energy Sector alongside the complementary functions of oil and gas production, transmission and distribution system operation and energy supply/customer services. In 2010, nine electricity generating companies received Directions under the provisions of the Climate Change Act (CCA) 2008 to report to Defra on how they were assessing and acting on the risks posed to their businesses by climate change. A report summarising the findings of the individual companies' reports, which drew broad conclusions that were applicable to the UK generation sector as a whole, was delivered in July 2011.

In 2013, Defra notified Energy UK of a second reporting round for organisations, this time to be undertaken on a voluntary basis. Energy UK agreed to produce a second summary report on behalf of the electricity generating sector. The reporting is aimed to help the Government understand the level of capacity to adapt in the sector; information provided will inform the next UK Climate Change Risk Assessment to be published in 2017 and the subsequent update of the National Adaptation Programme.

In this report, Energy UK has collated information on the progress in delivery of actions planned by generating companies as a result of the first CCA reporting initiative. Substantial progress has been made by generating companies in completing actions identified in the first reporting round. The vast majority of actions have been started and a majority have now been completed. This has led to a decrease in risk from future climate change for the sector, albeit from an already low risk base established in 2011.

The generating companies and Energy UK participate in a number of fora which seek to exchange information on climate change adaptation issues and which seek common approaches to maintaining or improving resilience to identified consequences of the future changing climate. These include the Infrastructure Operators' Adaptation Forum; the Energy Emergency Executive Committee; the Joint Environmental Programme's Water Working Group; Defra's Abstraction Reform Advisory Group; and the National Water Resource Steering Group.

The extreme weather conditions occurring in Winter 2013/14 provided the sector with the opportunity to evaluate its climate change adaptation assessment and resilience profile in the context of real extreme events. Electricity generation demonstrated a high level of resilience to potential disruption from the weather events that occurred. All of the reporting companies have corporate risk management processes which are covered by company policies and have procedures that are subject to regular internal review and audit. These reviews not only ensure the delivery of policies, but also capture any change in the risk appetite or altered thresholds that might change the nature of a risk. The decision of whether, and when, investments should be made to mitigate climate change risks is therefore an integral part of those companies' risk management processes, ensuring that essential investments are made in a timely manner but also enabling close management of investment appraisals in areas of greater uncertainty.

1. Introduction

Electricity generation sits within the UK's Energy Sector alongside the complementary functions of oil and gas production, transmission and distribution system operation and energy supply/customer services. In 2010, nine electricity generating companies received Directions under the provisions of the Climate Change Act (CCA) 2008 to report to Defra on how they were assessing and acting on the risks posed to their businesses by climate change. In October 2011, the Resilience and Adaptation Working Group (READ WG) of the Association of Electricity Producers (now known as Energy UK) produced a summary of climate change risks and adaptation responses on behalf of the nine companies (AEP 2011 and Appendix A). The company reports will hereafter be referred to as the Climate Change Adaptation reports (CCARs).

In 2013, Defra notified Energy UK of a second reporting round for organisations, this time to be undertaken on a voluntary basis. Energy UK agreed to produce a second summary report on behalf of the electricity generating sector. The reporting is aimed to help Government understand the level of capacity to adapt in the sector; information provided will inform the next UK Climate Change Risk Assessment to be published in 2017 and the subsequent update of the National Adaptation Programme.

The READ WG provides a forum for the sector to manage climate change adaptation issues and has co-ordinated the collection of information presented in this second report. The terms of reference of READ WG include:

- co-ordinate Energy UK's contribution to the revision of DECC's Energy Sector Resilience Plan, the scope of which will be expanded to include generation;
- co-ordinate Energy UK's input to the Cabinet Office's Critical Infrastructure Resilience Programme;
- co-ordinate the drafting of a sector-level response to Defra's Climate Change Adaptation Reporting Directions;
- liaise with all relevant Government departments and agencies to minimise the duplication of work in the area of resilience and adaptation and to promote certain, consistent, proportionate and risk-based regulation of the Power Generation Sector;
- ensure appropriate representation of the Power Generation Sector in iterations of the UK Climate Change Risk Assessment and the UK National Adaptation Programme;
- facilitate the exchange of information between generators and other key stakeholders such as environmental regulators, the Met Office, National Grid, Energy Networks Association, Energy Emergency Executive Committee (E3C), Adaptation Sub-Committee of the Committee on Climate Change, Infrastructure Operators' Adaptation Forum, UK Climate Impacts Programme, etc; (and from 2015, the National Water Resource Steering Group (NWRSG) which has water resilience, drought planning and climate change adaption within its remit).

The subsequent sections of this report provide the requested voluntary update for the electricity generation sector.

2. Developments in understanding of climate change risks

2.1 Summary of Section 2

Nine electricity generating companies who received Directions under the provisions of the Climate Change Act 2008 to report to Defra in 2011 have periodically reviewed developments in understanding of climate change risks since that time.

Understanding of the science of climate change amongst the science community has increased since 2011 and improvements to global climate models have been made, although overall uncertainty in some areas has not reduced. However, increased understanding has not led to significant improvements to the projected changes to regional weather characteristics and the replacement of the UK 2009 Climate Projections (UKCP09) datasets on which the analyses in 2011 were based. The main hazards identified in AEP 2011 remain the same, and as a consequence, it is concluded that the risks to the industry due to climate change remain relatively low.

2.2. Summary of Appraisal of Risks from Climate Change 1st Sector Report

The risk assessments undertaken by the generating companies in 2011 used data available from the UK Climate Impacts Programme (UKCIP) as the principal source of information on changes to weather-related variables impacting each power station site.

UKCIP was established in 1997 to help co-ordinate scientific research into the impacts of climate change, and to help organisations adapt to those impacts. UKCIP provided a web-based interface and data interrogation tools which enabled users to analyse the UKCP09 datasets that had been created by the Met Office for this purpose. The generating companies participating in the Adaptation Reporting process in 2011 used UKCP09, which represented the latest climate information available for qualitatively and quantitatively assessing specific climate change impacts in the UK. UKCP09 produced probabilistic climate projections and hence allowed a measure of the uncertainty in future climate projections to be built into the datasets and subsequent analysis.

UKCP09 states that local-scale differences between projections from different models are no smaller now than those shown in UKCIP02 seven years previously, despite improvements to models. For this reason, UKCP09 states that ‘we cannot assume that continuing model improvements will quickly lead to a reduction of uncertainties in projections’.

Unlike in previous climate change projections for the UK (e.g. UKCIP02), the UKCP09 probabilistic climate projections use projections from other global climate models to give a more comprehensive range of uncertainties than could be provided from the Met Office Hadley Centre model alone. Twelve of the global climate models used in the Intergovernmental Panel on Climate Changes (IPCC) Fourth Assessment Report were incorporated in the UKCP09 projections of climate change, forming a multi-model ensemble, and thus allowing the incorporation of uncertainty in the future climate projections. UKCP09 reflected scientists' best understanding of how the climate system operated at that time and how it might change in the future based on internationally recognised global climate models.

In UKCP09, projections were developed under three different world emissions scenarios, two of which come from the A1 storyline, and one from the B1 storyline developed by the IPCC Special Report on Emissions Scenarios (SRES). Within UKCP09 the emission scenarios were labelled based on their relative greenhouse gas emissions levels - High (SRES A1FI), Medium (SRES A1B) and Low (SRES B1) - and comprised a wide range but not the full set of SRES emissions scenarios.

In projections of future climate change, uncertainty arises from three causes:

1. Natural climate variability – arising from both external influences on the climate and internal chaotic climate processes.
2. Modelling uncertainty – arising from incomplete understanding of Earth-Climate system processes and incomplete representation in climate models.
3. Emissions uncertainty – arising from not knowing the amount of future global greenhouse gas emissions.

Improvements in future climate predictions focus on reducing these three uncertainties. However, greater understanding of the climate system and mechanisms of anthropogenic perturbation does not necessarily reduce uncertainty, although it will lead to an improved knowledge of the uncertainties. Hence, developments in the understanding of future weather-related impacts do not necessarily improve the quantification of risk.

For the CCAR assessments, generators generally made assumptions and choices that reduced the chance that uncertainties would lead to an underestimate of likely risk. Thus, in the case of emissions uncertainty, generators assumed the "High Emission Scenario", which causes the highest change in future climate and hence highest impact. In using UKCP09 projections, generators have assessed climate impacts against climate projections which are "very unlikely" to be exceeded in the reference future time period of 2010-2039 (the 2020s).

In UKCP09, the HadRM3 model was used to down-scale the global climate simulations to a spatial resolution better suited for impacts and adaptation assessments. This Regional Climate Model operates at 25 km resolution. Use of a tool known as the Weather Generator enabled the 25 km information to be down-scaled to 5 km providing a set of climate variables at a 5 km resolution that were consistent with the underlying 25 km resolution climate projections and allowing probabilities of weather extremes to be estimated.

The analyses undertaken by the companies for their CCARs used the UKCP09 Weather Generator version 2.0, which became available in February 2011. This tool is discussed in more detail in AEP 2011, and the individual CCARs.

UKCP09 offers projections of future changes in relative sea level and storm surge heights for 12 km coastal grid squares around the UK over the period 1999 to 2099 and for three emissions scenarios, plus a high risk, low probability scenario. These projections fed into generators' site-specific flood risk assessments.

UKCP09 remains to this day the most comprehensive analysis tool available for the companies to use in climate change risk assessment and its data sources, analysis tools, and breadth of scope are essentially unchanged from those existing in 2011.

2.3 Sector Assessment of Risks from Climate Change

Building on previous work undertaken by generators and using a common approach to risk assessment, the reporting companies identified 17 hazards from climate change in the period 2010 to 2039. This timeframe was selected and agreed with Government to reflect the expected lifetime of existing power stations, and remains valid for this second report. The hazards most relevant to the sector were identified as those associated with flooding, extreme high temperature and drought. In the vast majority of cases, the hazards assessed were considered "low risk" or "very low risk". Only in a few instances were they classed as "medium risk".

It was further concluded that current short-term weather events presented more risks to generation than long-term trends in climate change. Furthermore, these risks were relatively low compared to engineering-related faults leading to loss in generation. Climate change was not considered to introduce any new types of risk to operation, but rather to change the likelihood or severity of risks which are currently managed. For example, power stations are pro-actively managing potential specific vulnerabilities to events of extreme weather (e.g. heavy snowfall, river flooding or high tides/tidal surges). These risks are consequently picked up in the Business Impact Assessments and Continuity Plans of companies.

Adaptive capacity across the sector as a whole is ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and this high level of resilience to potential disruptions from extreme events was expected to continue over the next 20 years.

The 17 sources of risk (hazards) identified were included in a Climate Change Impacts Register (CCIR). A common methodology was used by each reporting company to estimate the risk posed by each hazard in the CCIR and a risk profile was built up. Each reporting company defined and implemented its own specific classification of consequence of risk according to its own business-related metrics. These were collated and summarised in AEP 2011.

The vast majority of these hazards were assessed to be of "very low" or "low" risk in the 2020s (~95% of the scores determined in the risk assessment were in these categories). A small number were classified as "medium" risks (~5% of the scores), while no company considered climate change risks in the 2020s to have sufficiently high rating to come into the "high" or "very high" risk rating categories. The main areas of risk were related to water availability and quality; air temperature; and for some plant 'flood'.

Key uncertainties, assumptions and constraints in the analysis of climate change impacts included: uncertainties in the climate change projection data and uncertainties in future generation (including the UK energy mix and changes in patterns of power station operation). Regulatory uncertainty, such as that due to the Government review of the principles of water rights allocation, was also identified as a barrier to the implementation of appropriate adaptive measures and as creating risk and uncertainty.

AEP 2011 identified that risks to generators from climate change could not be viewed in isolation from risks to other parts of national and local infrastructure (power distribution, water infrastructure, etc.), because many of these risks are regulatory and indirect. It was identified that risks within generation were therefore, to some extent, dependent on other sectors and the regulators. The importance of working with external stakeholders in some areas was also noted.

2.4 Developments in sources of climate change data since 1st Round of Adaptation Reporting

This section describes developments in the field of international climate change scientific knowledge; additional sources of information on river flows; and sector involvement with external stakeholders to mitigate identified water-related risk.

2.4.1 Recent Reports from the Intergovernmental Panel on Climate Change

Periodically, the Intergovernmental Panel on Climate Change (IPCC) produces new climate change assessments based on the latest scientific consensus. The Fourth Assessment Report (AR4) from the IPCC in 2007 said that "it is very likely that anthropogenic greenhouse gas increases caused most of the observed increase in global average temperatures since the mid-20th century".

At the time of producing the CCARs, the latest IPCC report on climate change projections was AR4. In the Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) published in 2013 (IPCC 2013), new evidence of climate change is considered based on many independent scientific analyses from observations of the climate system and other sources. It builds upon the Working Group I contribution to AR4, and incorporates subsequent new research findings. As a component of the fifth assessment cycle, the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) provides additional information on changing weather and climate extremes and their impacts.

A leading quote from AR5 is "Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years (medium confidence)."

The following terms have been used in AR5 to indicate the assessed likelihood of an outcome or a result: *Virtually certain* 99–100% probability, *Very likely* 90–100%, *Likely* 66–100%, *About as likely as not* 33–66%, *Unlikely* 0–33%, *Very unlikely* 0–10%, *Exceptionally unlikely* 0–1%. Additional terms (*Extremely likely* 95–100%, *More likely than not* >50–10 0% and *Extremely unlikely* 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g. *very likely*. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high. AR5 concludes that there have been improvements in climate models since AR4. For example, models reproduce observed continental scale surface temperature patterns and trends over many decades, and predictions of surface temperatures on regional scales are assigned greater confidence in AR5 than in AR4. There is high confidence that regional-scale surface temperature is better simulated than at the time of the AR4. Progress in increasing the confidence of precipitation at regional scales has not, however, improved.

The assessed rates of change are consistent with the AR4 Summary for Policy Makers statement that, 'For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios'.

However, in AR5 the implied rates of warming over the period from 1986–2005 to 2016–2035 are lower: 0.10°C to 0.23°C per decade, and AR5 concludes that the AR4 assessment was near the upper end of current expectations for this specific time interval.

The parameter *equilibrium climate sensitivity* quantifies the response of the climate system to constant radiative forcing on multi-century time scales. It is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration. AR5 states that equilibrium climate sensitivity is *likely* to be in the range 1.5°C to 4.5°C (high confidence), *extremely unlikely* less than 1°C (high confidence), and *very unlikely* greater than 6°C (medium confidence).

The lower temperature limit of the assessed *likely* range is less than the 2°C in AR4, but the upper limit is the same. This subtle change in assessment reflects improved understanding, the extended temperature record in the atmosphere and ocean, and new estimates of radiative forcing.

A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations instead of the SRES scenarios that were used in AR4 and previous assessments. AR5 concludes that projected climate change based on RCPs is similar to AR4 in both patterns and magnitude, after accounting for scenario differences. This is especially so in the near term, but for aerosol and ozone precursor emissions the RCPs are much lower than SRES by factors of 1.2 to 3.

Projections of sea level rise are larger than in AR4, primarily because of improved modelling of land-ice contributions. Confidence in projections of global mean sea level rise has increased since AR4 because of the improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamic changes.

AR4 presented research showing that, especially in the near term, and on regional or smaller scales, the magnitude of projected changes in mean precipitation was small compared to the magnitude of natural internal variability and AR5 has confirmed this result.

In AR4 it was reported that cold episodes were predicted to decrease significantly in a future warmer climate and it was considered *very likely* that heat waves would be more intense, more frequent and last longer towards the end of the 21st century. These conclusions have generally been confirmed in subsequent studies in AR5.

Near-term projections for Europe from General Circulation Model–Regional Climate Model (GCM–RCM) model series for mean and extreme temperatures in the period 2016 to 2035 relative to the reference period 1986– 2005 were discussed in AR5. In terms of mean June, July and August (JJA) temperatures, projections show a warming of 0.6°C to 1.5°C, with highest changes over the land portion of the Mediterranean. The north–south gradient in the projections is consistent with AR4. Daytime extreme summer temperatures in southern and central Europe are projected to warm substantially faster than mean temperatures.

For the 21st century, AR4 and the SREX concluded that heavy precipitation events were likely to increase in many areas of the globe. AR5 largely confirms this at a global scale but reports that at a regional scale this is more uncertain.

Table 1 summarises the conclusions of AR5 regarding some types of extreme weather event. Where this conclusion has changed from AR4, the AR4 conclusion is included in brackets.

Table 1. Summary of conclusions of AR5 for some types of severe weather event.

Extreme weather and climate events: Global-scale assessment of recent observed changes and projected further changes for the early (2016–2035) and late (2081–2100) 21st century.	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Likelihood of further changes in early 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely*	*Virtually certain*
Warmer and/or more frequent hot days and nights over most land areas	*Very likely*	*Virtually certain*
Warm spells/heat waves. Frequency and/or duration increases over most land areas	*Likely* in large parts of Europe, Africa and Australia (*likely*). Medium confidence on a global scale.	*Very likely*
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely* more land areas with increases than decreases	*Very likely* over most of the mid-latitude land masses and over wet tropical areas. (*very likely* over most land areas)
Increases in intensity and/or duration of drought	*Likely* changes in some regions e.g. Mediterranean. Low confidence on a global scale. (*likely* in many regions)	Likely, medium confidence, on a regional to global scale (*likely*)
Increases in intense tropical cyclone activity	Low confidence in long term changes. Virtually certain in North Atlantic since 1970. (*likely* in some regions)	More likely than not in Western North Pacific and North Atlantic (*likely*)
Increased incidence and/or magnitude of extreme high sea level	*Likely* since 1970	*Very Likely* (*likely*)

AR5 concludes that there has been substantial progress in the assessment of extreme weather and climate events since AR4. Simulated global-mean trends in the frequency of extreme warm and cold days and nights over the second half of the 20th century are generally consistent with observations.

Based on the AR5 conclusions, there are, therefore, some changes to the latest predictions on future climate change which will filter through to improved predictions for the UK. However, UKCP09 is based on many of the leading GCMs that have also provided input into AR5. It is therefore concluded that, for the time being at least, UKCP09 remains an appropriate source of information and data to use as a basis for a climate change impacts risk assessment.

2.4.2 River Flow projections: Future Flows

It was noted in AEP 2011, that UKCP09 was not entirely comprehensive and information on other industry-relevant impact parameters (e.g. river flow) were limited and would need to be explored through additional climate data or impact models. At the time that the CCARs were being created, the best available river flow data were two national studies based on previous climate projections (UKCIP02) commissioned by the UK Water Industry Research (Vidal JP and Wade SD 2007) and the Environment Agency (EA 2008).

A new assessment of the impact of climate change on river flows and groundwater levels across England, Wales and Scotland has been published by the NERC Centre for Ecology and Hydrology (CEH) and the NERC British Geological Survey since the CCARs were produced (Prudhomme et al. 2012). The Future Flows and Groundwater Levels project (FFGWL) uses a consistent assessment methodology applied across all catchments in England, Wales and Scotland, incorporating the latest projections from the UK Climate Impact Programme (UKCIP), including the UKCP09 probabilistic climate projections from the Met Office Hadley Centre. The FFGWL project ran between March 2010 and Spring 2012 and data from it was not used in the CCARs' development.

Future Flows Climate is a dataset derived from 11 plausible climate projections used in UKCP09. It consists of projections of available precipitation and potential evapo-transpiration (rainwater lost from the system) from 1950 to 2098 for Great Britain and is specifically developed for hydrological and hydro-geological application, i.e. enabling projections of river and groundwater flows. A 'down-scaling' analysis converted the 25 km grid resolution output from HadRM3-PPE into a higher resolution 1 km grid-set appropriate for use by hydrological models. There are 11 separate datasets in Future Flows Climate corresponding to each input climate projection. In addition to data in grid format, precipitation and potential evapo-transpiration data are also available per catchment area (this latter data is used to calculate the river flows in Future Flows Hydrology).

Future Flows Hydrology consists of 11 datasets of daily river flow and monthly groundwater level time series, for the period 1951 to 2098, for 282 river catchments (actually flow station sites on rivers) and 24 boreholes in Great Britain. These were created using Future Flows Climate as input, and using hydrological and groundwater models developed within the project. For each site they provide 11 plausible realisations of the river flow and groundwater level regime.

Although the 11 datasets capture some of the main climate variability and climate modelling uncertainties, it is not possible to derive any probabilistic information from the output. 'The [RCM] ensemble does not sample structural uncertainty in the atmospheric processes using alternative climate models, does not explore uncertainty arising from the carbon cycle, sulphur cycle and ocean physics, and is only run for the A1B (medium) emission scenario' (Sexton et al. 2010).

Furthermore, the range of future flows predicted by the 11 datasets is large, for example, the change on mean flows predicted for 2025 in the Trent region varies from +40% to -40% depending on the dataset used but each has an unknown probability of occurrence. In addition, the impact on future river flows of potential reforms to the water abstraction management system (see Section 2.4.3) are not represented in these datasets.

For these reasons, the use of the data currently available from the FFGWL project is of limited value in a risk analysis, and it has not been considered worthwhile updating the CCARs based on this new information.

2.4.3 Water related risk

Climate change is a contributing factor affecting future water resource in the UK. Some of the main risk areas identified in the AEP 2011 report (low to medium risk) were related to water availability, effects of higher air temperatures on discharge temperatures, and future water abstraction legislation.

Since 2011, the generation sector has been very engaged with Defra regarding the proposed introduction of a reformed water abstraction management system designed to promote resilient economic growth while protecting the environment.

These proposals are designed to:

- Maximise the amount of water available to abstractors;
- Facilitate trading, maximising the economic value from available water and allowing new entrants to access water;
- Provide reasonable certainty for abstractors for planning their business;
- Protect water ecosystems in line with legal requirements, particularly ensuring that reform does not create risks of environmental deterioration;
- Promote efficient use of water through charging for actual use; and
- Ensure the new system is able to respond to longer-term changes in water availability.

Two potential water management systems are currently under consideration:

1. Current System Plus

- Additional abstraction at high flows
- Refine Hands-off Flow conditions
- Introduce a regulatory minimum level to stop abstraction at very low flows

2. Water Shares

- Give each abstractor a share of available water that varies depending on availability.
- In exceptional cases the allocation could be reduced to zero in which case abstraction would have to stop.

It is expected that the water management system selected will be dependent on the characteristics of a given catchment and in some cases a hybrid solution may be appropriate. It is proposed by Defra that the new system should be in place by the early 2020s.

The Joint Environmental Programme (JEP) supports a programme of research into the environmental impacts of electricity generation funded by nine of the leading producers in the UK (RWE npower, E.ON UK, Drax Power, Scottish & Southern Energy, EDF Energy, ENGIE (formerly GDF SUEZ), Eggborough Power, Centrica and Scottish Power). As well as managing an R&D programme covering issues that are relevant to the member companies, the JEP provides a vehicle for the power sector operators to discuss and negotiate collectively on sector-level issues with the UK Environmental Regulators. These collective discussions are carried out via a forum facilitated by Energy UK and subject-specific working groups.

The emphasis is on developing an environmental regulatory “level playing field”, within which individual operators can then carry out their commercial activities and decisions.

The JEP Water Working Group, which comprises individual company representatives, has been providing a technical forum for discussions primarily with the Environment Agency on its development of the aforementioned proposals for water management reform. It also supports Energy UK, which represents the power generation industry in policy discussions with Defra and Regulators.

The JEP provides technical comment on draft proposals and modelling tools presented by the Environment Agency, and works with the Regulator to ensure that both the operational aspects of electricity generation and the constraints of the electricity market are adequately represented.

A key goal of the power industry is to ensure that the supply of electricity to consumers remains robust in a potential future where river flows are impacted more significantly by prolonged drought and water availability is consequently reduced.

The power industry also has representation on the Government’s Abstraction Reform Advisory Group (ARAG). This group, with representatives from the main users of water in and from rivers, lakes and aquifers, advises the UK and Welsh Governments on proposals for the reform of the water abstraction management system in England and Wales. Membership includes industry, NGOs, water companies, waterways organisations and the farming and fishing sectors. It also includes Defra, Welsh Government, OFWAT, Environment Agency, Natural England and National Resources Wales.

Ad hoc meetings are also taking place with Defra to keep the generating companies and Energy UK up to date on water reform activities. By entering into constructive discussion within these fora, the generating companies are actively participating in a risk reduction process in the areas related to water that they collectively identified in the 2011 CCARs.

The work of the JEP Water Working Group is also highlighted in Section 3.2, illustrative case studies under ‘Reform of the water resource allocation system’.

3. Actions taken to address climate change risks or increase resilience

3.1 Progress and Mitigation

In the first round of CCA reporting, sector companies developed action plans to address identified risks resulting from future changes to certain climate change hazards. These were site- or company-specific actions.

Table 5 in the AEP 2011 summary report (see Appendix A), illustrates the level of change in risk associated with the hazards identified by companies through the 2020s. The table provides a weighted average of the findings at a plant level. As mentioned in Section 2, the vast majority of these hazards were assessed to be of "very low" or "low" risk. The main areas of risk were related to water availability and quality; air temperature; and for some plant, flooding.

For the purposes of this report, companies provided Energy UK with an update on progress made on their actions and also the assessed success of the actions in reducing risk to acceptable levels (mitigation).

The submissions were collated and synthesised into a summary table for the sector as a whole, see Table 3. Progress on each action was categorised as 'completed'; 'in progress'; and 'not started', and the assessed success in mitigating a risk was categorised as 'mitigated'; 'partially mitigated'; 'not mitigated'; or 'not yet evaluated'.

The colour key is shown in Table 2.

Table 2. Key to Table 3

Progress key		Mitigation key	
complete	(green)	mitigated	(green)
in progress	(blue)	partially mitigated	(blue)
not started	(yellow)	not mitigated	(yellow)
		not yet evaluated	(purple)

Table 3. Summary of sector progress with CCA actions since first report in 2011.

Underlying Climate Change Hazard	Number of Actions	Progress on implementation	Degree of risk mitigation achieved
1. Flooding of Site	20		
2.Flooding of Access Routes to Site	6		
3.Flood Events & Extreme High River Flow	2		
4.Storm Surges	4		
5.Extreme High Temperature on Steam Turbine	5		
6.Extreme High Temperature on Gas Turbine	4		
7.Extreme High Temperature on Water Discharge	5		
8.Drought on Water Availability	15		

9.Drought on Water Discharge (Permitting)	1		
10.Drought & Change in Water Abstraction Legislation	3		
11.Extreme Snowfall	2		
12.Extreme Low Temperature on Cooling Tower Fans	2		
13.Extreme Low Temperature on External Systems	7		
14.Extreme Low Temperature on Cooling Tower	3		
15.Extreme Winds	4		
16.Weather Conditions Causing Plume Grounding	1		
17.Subsidence / Landslide	4		

The table shows that substantial progress has been made by generating companies in completing actions identified in the first reporting round. The vast majority of actions have been started and a majority have now been completed. This has led to a decrease in risk, albeit from an already low risk base.

3.2 Illustrative case studies

The following are examples of how the sector has been actively addressing climate change risks and increasing sector resilience. They illustrate actions that have taken place to address climate change risks as identified in the first CCARs.

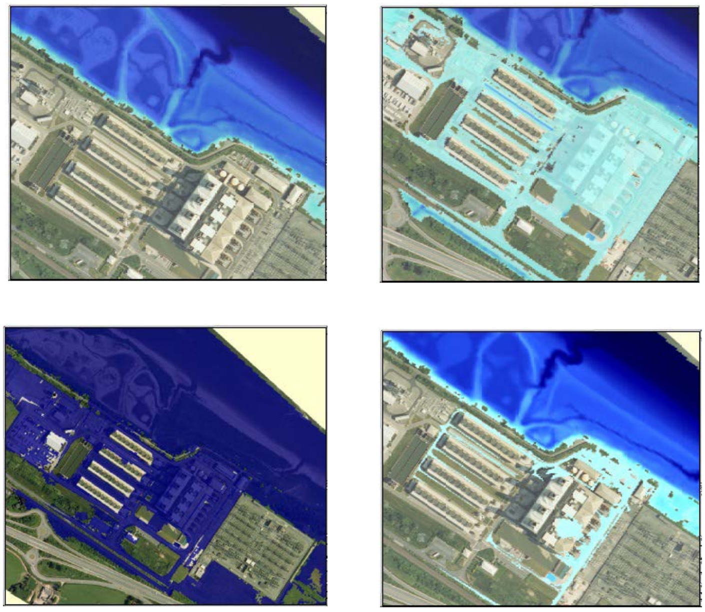
Comparison of Flood Risk Assessment against December 2013 River Dee levels

Underlying Climate Change Hazard: Flooding of Site

One of the primary concerns of a changing climate for the Electricity Supply Industry is the potential for increased risk of flooding as a result of rising water levels. A significant proportion of power stations are situated adjacent to estuaries, rivers, or coastal regions owing to the requirements for large volumes of water to be employed for cooling during the power generation process. As a consequence, there is a concern that these power stations are vulnerable to elevated water levels, and the first round of the Resilience and Adaptation reporting in 2011 identified flooding as a major threat.

In order to quantify this risk, E.ON UK has undertaken Flood Risk Assessments (FRAs) for those stations which may be susceptible to flooding. These risk assessments look at predictions to assess the levels that water could potentially rise to and model the consequences of flooding events on the power stations for a range of scenarios, typically 1 in 100, 1 in 200 and 1 in 1000 year high water levels.

The graphic below illustrates flood analysis scenarios for Connah's Quay Power Station.



Whilst these predictions use the most current information available, the validation of model predictions with real-life events gives operators greater confidence in their reliability. In December 2013, the River Dee in Flintshire experienced levels concurrent with a 1 in 100 year flooding event which could have affected E.ON's Connah's Quay Power Station. In this instance, the predictions outlined within the FRA were proven to be accurate, and the resilience measures implemented by E.ON were shown to offer appropriate protection. The station did not sustain any damage, there was no loss of generation and the water level, as predicted, did not breach any of the station's flood defences. However, the elevated water levels have highlighted some areas where improvements could be implemented to ensure continued resilience against any future extreme tidal levels.

Upgrading cooling water pumps at Deeside Power Station

Underlying Climate Change Hazard: Flood Events & Extreme High River Flow

In recent years the cooling water pumps at the ENGIE (formerly known as GDF SUEZ) plant in Deeside have been operating close to their maximum ratings. At times of high turbidity water the station was experiencing tripping of the cooling water pumps on high current. As part of the ENGIE adaptation report in 2011 it was identified that changing patterns in precipitation are likely to contribute to a reduction in water quality. Higher volumes of suspended solids in the abstracted water will only increase the risk of lost generation due to cooling water pump trips.

In the period since the first ENGIE adaptation report our Deeside plant has acted on internal recommendations and has replaced one of the two motors with a new one of a higher power rating (1100 kW instead of the original 1000 kW). In addition and following internal examination of the removed rotor, it became apparent that the winding wedges had been deteriorating on service. This motor was completely rewound thus increasing its reliability and was subsequently returned to service in place of the remaining second motor, which has also been rewound and is retained as a spare. This will increase the long term strategic reliability of the plant.

Since the work was completed, we have not suffered a high current trip on either the uprated or the refurbished motor. The photograph below shows the two current motors in service with the new one on the left and the original refurbished one on the right.

Heavy rainfall South Coast December 2013 - February 2014

Underlying Climate Change Hazard: Flood Events & Extreme High River Flow and Flooding of Site

During the persistent storms in January 2014, the local river (Kennet) and canal (Kennet & Avon) broke their banks and flooded the area and lakes around SSE's Burghfield Power Station. Site operations were lost on 7 February 2014, but the loss had no direct impact on electricity supplies to the local communities.

The main contributing factor to the flooding was that local ditches and waterways were not clear of debris and free-flowing. The incident was resolved with the help of the Army. In addition, SSE hired in a company to clear and open up a local road-side ditch.

Although Burghfield Power Station was not included in the SSE Generation climate change adaptation report in 2011 because it was outside the scope agreed with Defra, SSE carried out a review using the same methodology to validate the shared learnings from discussions with other generators. There were some additional flood mitigation measures identified: install permanent high-volume flood pumps and pipe system; improve flood defence barriers; investigate re-locating of site discharge point; improve pit/trench water detection system; seal cable trench into the 11 kV switchroom and control room; investigate possible procurement of site emergency diesel generator; improve communications with local sub-station and investigate issues with the Environment Agency's Floodline. SSE subsequently decided to dam the entire switchroom building to a height of 1.2 m using a technique employed by electricity distribution companies to flood proof their own assets.

Biomass fuel supply resilience to extreme weather

Underlying Climate Change Hazard: Storm Surges

Drax Power is transforming its business to become one of the largest renewable power generators in Europe and it will convert at least three of the six coal-fired generating units at Drax Power Station to run on biomass. Climate change resilience and adaptation has been considered at every stage of the process, notably in the logistics chain. Drax has implemented a multi-port strategy in order to maintain supplies of fuel to the power station. As part of this, the geographic split of the ports to ensure resilience to localised events such as storm surges and other potential climate change related impacts has been considered.

During the severe storm surge of 2013, Immingham lost power to large areas of the port due to localised flooding in sub-stations, although the main coal and biomass terminal areas were not affected by the flooding. To mitigate against potential impacts from a similar event, port operator ABP have installed new power mains to supply power to the main terminal operations area.

The new biomass terminal at Immingham has been designed to withstand a similar event with sub-station levels raised one metre above ground level. The underground conveyor tunnels below Phase I of the terminal development have storm surge barriers erected to stop flood waters getting into the below ground tunnels. On the Phase II development, the tunnels have been raised above ground level to achieve similar protection.

Other terminals have been constructed behind sea walls offering protection against higher sea levels caused by storm surge. Dock levels are maintained below the ground level allowing any flood waters that breach the sea defences to dissipate across the entire dock system. Rail operations are run using diesel locomotives to haul uniquely designed biomass rail wagons. Transport of fuel to Drax by train does not require overhead cables to power the trains, mitigating the risk of these become damaged in severe weather. The measures implemented in the logistics chain were robust enough to ensure that there was no disruption in supply of fuel to Drax Power Station during the storm surge of 2013 and have been designed to be resilient to future severe events.

East Coast tidal surge December 2013

Underlying Climate Change Hazard: Storm Surges and Flooding of Access Routes to Site

During the tidal surge experienced by the East Coast of the UK in December 2013, the River Trent was at risk of overtopping. Due to the work carried out over a number of years on the flood defences the overtopping never occurred. However, there were several breaches to those defences. One of those breaches to the defences close to Keadby Power Station (SSE) site entrance prevented normal access to site. Alternative access was gained via the rear of the site.

SSE carried out a review of the site risks identified during the initial round of Resilience and Adaptation reporting and the flood response plan for the installation. Additional measures identified were; other areas of the site which require flood door defences and additional emergency equipment, lightweight sand bags and door flood defences. All necessary items were purchased and the flood response plan was updated.

During recent storms, having well-designed flood plans proved invaluable. The power station also reported good co-operation and communications with the Environment Agency.

Rainwater harvesting at the Langage Energy Centre

Underlying Climate Change Hazard: Drought on Water Availability

Langage Energy Centre (Centrica) is one of the most modern power stations in the UK and started commercial operation in 2010. This station burns natural gas in two advanced gas turbines and uses combined cycle technology to recover energy from the exhaust gases. The recovered energy is used to turn water into steam which is then used to drive the steam turbine. The additional electricity generated by this process helps to make Langage Energy Centre one of the most efficient stations of its type in the world.

There is strong evidence in the latest climate projections that precipitation patterns will change significantly in the 21st century with UK winters becoming wetter and summers becoming drier. Therefore, hazards such as water scarcity are very likely to increase in intensity and frequency in the 21st century. Hence potential constraints on water availability due to water scarcity were identified as a risk in Centrica's climate adaptation report in 2011.

In order to reduce the demand for fresh water for steam generation, the Langage Energy Centre has initiated a programme of rainwater recovery using storage facilities available on the site. This has allowed the collection of approximately 12,000 m^3 per year which is then treated before being fed to the boilers. This leads to significant cost savings for the company as well as reducing the demand for fresh water.

Reform of the water resource allocation system

Underlying Climate Change Hazard: Drought & Change in Water Abstraction Legislation

The Government's engagement with stakeholders on reform of the water resource allocation system in England and Wales was a key action in the 2011 adaption report. This policy measure is intended to adapt society for the future combination of climate change and population growth leading to increasing water stress in some areas.

Sufficiently reliable access to sufficient quantities of water is a pre-requisite for the continuing operation of, and investment in, existing freshwater-dependent power stations. It is vital for investment in new such power stations. This class of station contributes to the diverse mix of technologies which together provide a thermal-efficient, resilient generation infrastructure. Operator responses to water abstraction licence reform may affect this generation mix.

Energy UK participates in Defra's Abstraction Reform Advisory Group, in the National Water Resource Steering Group and sector-specific workshops, in particular those supporting the catchment modelling of potential reform options. This initiative is one of many involving the energy-water nexus. Energy UK and its members have also contributed to improving awareness of the way the sector uses water through participation in an EU-wide project in 2014 seeking to quantify the industrial use of water (Ecofys 2014).

The photograph below shows Didcot Power Station intake and pumphouse on the River Thames (RWE npower).

4. Addressing barriers and understanding interdependencies

Risks to generators from climate change cannot be viewed in isolation from risks to other parts of national and local infrastructure (power distribution, water infrastructure, transport infrastructure, etc.) as many of these risks are regulatory and indirect. This is described more fully in Appendix A (AEP 2011), Sections 7 and 10.

The generating companies and Energy UK participate in a number of fora which seek to exchange information on climate change adaptation issues and which seek common approaches to maintaining or improving resilience to identified consequences of the future changing climate.

For example, Energy UK represents the power industry at the Infrastructure Operators' Adaptation Forum, which exists to support and challenge national and local climate change policy on matters related to infrastructure and the National Adaptation Plan. The cross-industry representation coupled with Regulators and Government should enable a more integrated and evidence-based approach to be adopted. This should provide the opportunity to learn of existing and new approaches to adaptation, to access knowledge and information in support of adaptation, and to highlight the potential to reduce vulnerability to points of dependence on other systems.

Energy UK also participates in the Energy Emergency Executive Committee (E3C). E3C and its associated task groups exist to support and foster effective Government, Regulator and industry-wide collaboration on issues relating to energy sector resilience. All participants commit to engage and co-operate on a voluntary basis in the development of system-wide arrangements to assess, mitigate and manage risks which, if not addressed, can impact on overall system resilience and ultimately impact on consumers of electricity and gas.

As discussed in Section 2.4.3, the JEP Water Working Group has been providing a technical forum for discussions primarily with the Environment Agency on its development of proposals for water management reform, and has been supporting Energy UK in policy discussions with Defra and Regulators.

A further example is the power industry's involvement with Defra's Abstraction Reform Advisory Group (ARAG). This group, with representatives from the main users of water in and from rivers, lakes and aquifers, advises the UK and Welsh governments on proposals for the reform of the water abstraction management system in England and Wales. The power sector is a major user of water, and ARAG provides the opportunity to highlight the essential contribution that water makes to the generation of UK electricity and allows all stakeholders to understand how future water management proposals will impact on future electricity production.

5. Monitoring and evaluation

5.1 Status of sector monitoring and evaluation

One of the main conclusions from the CCARs produced in the last round is that climate change does not generate sources of risk that are not already analysed, treated, reported, reviewed, monitored and audited under the existing corporate risk management procedures within companies. However, the CCARs have led to the achievement of a consistent and comprehensive prioritisation of those climate risks with potentially significant impacts over the lifespan of the existing fleet which can be incorporated into a company risk inventory alongside other business risks.

All of the reporting companies have corporate risk management processes which are covered by company policies and have procedures that are subject to regular internal review and audit. These procedures not only ensure the delivery of policies, but also capture any change in the risk appetite or altered thresholds that might change the nature of a risk.

The decision of whether, and when, investments should be made to mitigate climate change risks is therefore an integral part of those companies' risk management processes, ensuring that essential investments are made in a timely manner but also enabling close management of investment appraisals in areas of greater uncertainty. This process will enable a flexible response to any future changes in risk drivers.

5.2 Evaluation of the robustness of the sector to the extreme weather conditions of winter 2013/14

The extreme weather conditions occurring in winter 2013/14 provided the sector with the opportunity to evaluate its Climate Change Adaptation assessment and resilience profile in the context of real extreme events. Further details of the evaluation may be found in Energy UK (2014), included as Appendix B to this report. This section provides a brief summary of the conclusions.

The hazards relevant to the weather events of winter 2013/14 were:

1. Flooding of site
2. Flooding of access roads to site
3. Flood events and extreme high river flow
4. Storm surges
5. Extreme winds

All of these are recognised in generating companies' risk registers.

Table 4 summarises the conclusions of the assessment.

Table 4. Summary of evaluation of Winter 2013/14 extreme weather events on electricity generating sector.

Hazard	Potential consequences for plant	Actual effect on plant	Evaluation
Flooding of Site	Possible generation unit shutdown; water damage to infrastructure on a variety of scales; pipeline fracture due to erosion.	Only one reported incident of lost generation due to flooding (groundwater). River water levels of 1:100 years were experienced, but flood defences were not breached.	Current levels of flood protection, agreed at the project design/planning stage are adequate. Site with disruptive flooding is taking action.
Flooding of Access Routes to Site	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown.	Some breaches in flood defences along the River Trent. The consequent fluvial flooding prevented normal access to a power station in the vicinity, but alternative access was gained via the rear of the site in accordance with the operator's flood management plan and no production was lost. No other sites reported issues.	Site plans to ensure access routes in case of flooding are adequate.
Flood Events & Extreme High River Flow	Higher maintenance.	No issues reported.	Site flood management plans are adequate.
Storm Surges	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown	No reported incident of lost generation due to storm surges, but there was some disruption to fuel supply chains as a result of damage to East Coast ports.	Storm surge defences adequate at sites. Coal supply ports may suffer disruption during extreme events. Site coal stocks provide a buffer against fuel supply difficulties.
Extreme Winds	Damage to installations; Health & Safety.	Two reported incidents of lost production due to extreme winds.	At these sites, operators have investigated the cause of the damage and effected repairs, incorporating design changes.

Electricity generation demonstrated a high level of resilience to potential disruption from weather events. From the 55 power stations (59 GW of installed generating capacity) covered in the report (Appendix B), there were only three reports of lost production caused by incidents connected to severe weather. Estimated lost production over the three months from December 2013 through February 2014 amounted to about 193 GWh (about 0.3% of total generation).

Resilience across the electricity sector as a whole is ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and, in the last decades, electricity generation has demonstrated a consistently high level of resilience to potential disruptions from extreme events. This was maintained through the exceptional weather events of winter 2013/14.

6. Conclusions

Energy UK has collated information on the progress in delivery of actions planned by generating companies as a result of the first CCA reporting initiative. This has been undertaken on a voluntary basis in response to a request from Government.

Substantial progress has been made by generating companies in completing actions identified in the first reporting round. The vast majority of actions have been started and a majority have now been completed. This has led to a decrease in risk from future climate change for the sector, albeit from an already low risk base established in 2011.

The generating companies and Energy UK participate in a number of fora which seek to exchange information on climate change adaptation issues and which seek common approaches to maintaining or improving resilience to identified consequences of the future changing climate. These include the Infrastructure Operators' Adaptation Forum; the Energy Emergency Executive Committee; the JEP Water Working Group; Defra's Abstraction Reform Advisory Group; and the National Water Resource Steering Group.

The extreme weather conditions occurring in Winter 2013/14 provided the sector with the opportunity to evaluate its climate change adaptation assessment and resilience profile in the context of real extreme events. Electricity generation demonstrated a high level of resilience to potential disruption from the weather events that occurred.

All of the reporting companies have corporate risk management processes which are covered by company policies and have procedures that are subject to regular internal review and audit. Climate change risks are assessed as part of these processes and this will enable a flexible response to future changes in climate risk drivers.

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Appendix A: Association of Electricity Producers sector summary report to Government 'Climate change risks and adaptation responses for UK electricity generation – a sector overview October 2011'

Climate change risks and adaptation responses for UK electricity generation – A sector overview

October 2011

Summary

Electricity generation sits within the UK's Energy Sector alongside the complementary functions of oil and gas production, transmission and distribution system operation and energy supply/customer services. Nine electricity generating companies received Directions under the provisions of the Climate Change Act 2008 to report to Defra on how they are assessing and acting on the risks posed to their businesses by climate change. This report summarises the findings of the individual companies' reports delivered in July 2011 and aims to draw broad conclusions that are applicable to the UK generation sector as a whole. Awareness of climate change issues in the UK electricity generation industry is high. Building on previous work undertaken by generators and using a common approach to risk assessment, the reporting companies identified 17 hazards from climate change in the period 2010 to 2039. This timeframe was selected and agreed with Government to reflect the expected lifetime of existing power stations. Current regulations require that climate change is factored into new power station projects at the design and planning stage. The hazards most relevant to the sector are associated with flooding, extreme high temperature and drought. In the vast majority of cases, the hazards assessed were considered "low risk" or "very low risk"; only in a few instances were they classed as "medium risk". Over the lifespan of the operating fleet, short term variation in current weather patterns, which are already managed through well-developed risk management systems, will remain more significant as a source of risk than the trend to a changed mean climate. The probability in any given year that an engineering fault will force a generating unit to stop operating is considered significantly higher than the additional risks arising from climate change effects over the next two decades. In a competitive electricity market, regulatory, policy and market uncertainties present greater risks to companies than those posed by climate change.

All the reporting companies operate in a competitive market and have well-developed approaches to risk management and business resilience. Business resilience policies ensure that appropriate measures, where cost effective, are in place to ensure that businesses can react appropriately and promptly to unexpected events and continue to operate, without business-threatening disruption. Power stations manage specific potential vulnerabilities to events of extreme weather (e.g. heavy snowfall, river flooding or high tides/tidal surges). Climate change is not considered to introduce any new types of risk to operation, but rather to change the likelihood or severity of risks which are currently managed. These risks are consequently picked up in Business Impact Assessments and Continuity Plans and are already analysed, treated, reported, reviewed, monitored and audited under existing corporate risk management procedures.

Adaptive capacity across the sector as a whole is ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and, in the last decades, electricity generation has demonstrated a consistently high level of resilience to potential disruptions from extreme events. Provided that these key factors are maintained over the next 20 years, this intrinsic 'robustness' is not expected to change.

Foreword

The Climate Change Act 2008 introduced a discretionary power for the Secretary of State for the Environment to require selected organisations (Reporting Authorities) to report on how they are assessing and acting on the risks posed to their business by climate change. Under the 2009 Strategy for using the Adaptation Reporting Power, electricity generating companies with an annual output in excess of 10 TWh were deemed to be Reporting Authorities. Consequently, nine companies, all of which are members of the Association of Electricity Producers (AEP), received Directions to submit reports to Defra by 31 July 2011. Although each company reported separately, they considered that it would be helpful to present a summary of the electricity generation sector's approach to managing climate change adaptation. This overview provides an introduction to the sector, identifies the risks posed by climate change and provides some conclusions as to how electricity generating companies are addressing those risks. The structure of the document broadly follows the format suggested in Defra's Statutory Guidance to Reporting Authorities (Defra 2009).

The Association of Electricity Producers (AEP) represents large, medium and small companies accounting for more than 95 per cent of the UK generating capacity, together with a number of businesses that provide equipment and services to the generating industry. Between them, the members embrace all of the generating technologies used commercially in the UK, from coal, gas and nuclear power, to a wide range of renewable energies. Members operate in a competitive electricity market and they have a keen interest in its success – not only in delivering power at the best possible price, but also in meeting environmental requirements. Contact details for the Association are given below.

24 October 2011

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1. Introduction and overview

The electricity industry consists of three main parts: generation (making electricity), networks (transporting it from where it is generated to where it is used), and retail or ‘supply’ (selling it to the end consumer). A few energy companies operate across all three of these areas, while others operate in only one or two. The electricity market in Great Britain is entirely privatised and liberalised, meaning that there is full competition between private companies.

Generation

Electricity producers generate electricity using a variety of fuels and technologies. There are many companies in the electricity generation sector, from large multinationals operating a diverse generation portfolio to small, family-owned businesses running a single site. Most electricity is generated ‘in bulk’ at large power stations connected to the national transmission network. However, electricity can also be generated in smaller scale installations which are connected to the regional distribution networks. How many power stations are built and of what type is up to companies to decide on the basis of market signals and government policy on issues such as the environment, security of electricity supply and affordability for consumers.

Networks

There are two types of electricity network: transmission and distribution. Transmission networks carry electricity long distances around the country at high voltages, while distribution networks operate at lower voltages, taking electricity from the transmission system into homes and businesses. Electricity networks are regulated monopolies, which means that they are built, owned and maintained by only one company in a particular area. These companies make their revenue by charging electricity producers and suppliers to use their networks. The regulator (Ofgem) sets the maximum return that the network companies can earn on their assets. The electricity network companies have been directed to report separately to Defra.

System Operation

The transmission system throughout Great Britain is operated by National Grid, which is responsible for balancing the system and ensuring that supply of electricity equals demand on a second-by-second basis. Electricity is a ‘just in time’ product, which technology does not yet allow to be stored in large quantities. National Grid has been directed to report separately to Defra.

Supply

Suppliers buy electricity from generators in the wholesale market and sell it on to end consumers. Suppliers operate in a competitive market and customers can choose any supplier to provide them with electricity. The domestic supply market contains six major suppliers (supplying over 99% of electricity to households), as well as a few smaller ones. There are more suppliers supplying business and industrial customers. Retail supply is outside the scope of the Direction to report.

Electricity market

Electricity producers sell their electricity to suppliers in the wholesale market. A single set of wholesale electricity market arrangements, known as the British Electricity Trading and Transmission Arrangements (BETTA), operates across England, Wales and Scotland. The wholesale electricity market operates in half-hourly blocks and is based on a system of bilateral trades. Under these arrangements, electricity producers determine when to run their plant on the basis of commercial considerations, with the System Operator able to secure additional or reduced electricity production close to real time in order to balance demand and supply at all times.

Regulation

The electricity market in Great Britain is regulated by the Gas and Electricity Markets Authority, operating through the Office of Gas and Electricity Markets (Ofgem). Ofgem's role is to protect the interest of consumers by promoting competition where appropriate. Ofgem issues companies with licences to carry out activities in the electricity sector, sets the levels of return which the monopoly networks companies can make, and decides on changes to market rules.

Scope of the sector reporting

The agreed scope of the reporting in the individual climate change adaptation reports encompasses each company's generating plant over 100MWe capacity, not including plant which has been 'opted-out' of the Large Combustion Plant Directive (LCPD) and may only operate until the end of 2015. Wind turbine arrays, both on- and off-shore, have also been excluded by agreement with Government. Also by agreement with Government, the projections of climate change on which the assessment is based are those for the 30 years 2010-2039 ('the 2020s') published by UKCIP (2009) as this represents a realistic timescale for continued operation of existing plant. The reports have regard to the Statutory Guidance issued by Government (Defra, 2009) as required under Section 3(3) of the Climate Change Act 2008.

Power stations are dependent for their operation, *inter alia*, on delivery infrastructure for fuels and other essential chemicals and raw materials, water for steam raising and cooling, a functioning electricity transmission system, routes for waste disposal and access to a range of supporting services. The performance of a station is the result of the influence of ambient conditions on a combination of generation systems or components: gas turbine, boiler, steam turbine, auxiliary systems and cooling systems. The electricity generation sector is thus necessarily aware of the sensitivity of its operations to variations in weather and has long recognised the consequences of climate change for its business.

Figure 1 shows the locations of the power stations which are included in company adaptation reports. The number in brackets after each power station name is the capacity in MWe. The geographical spread of these powers stations is evident, as is the division between coastal and inland sites.

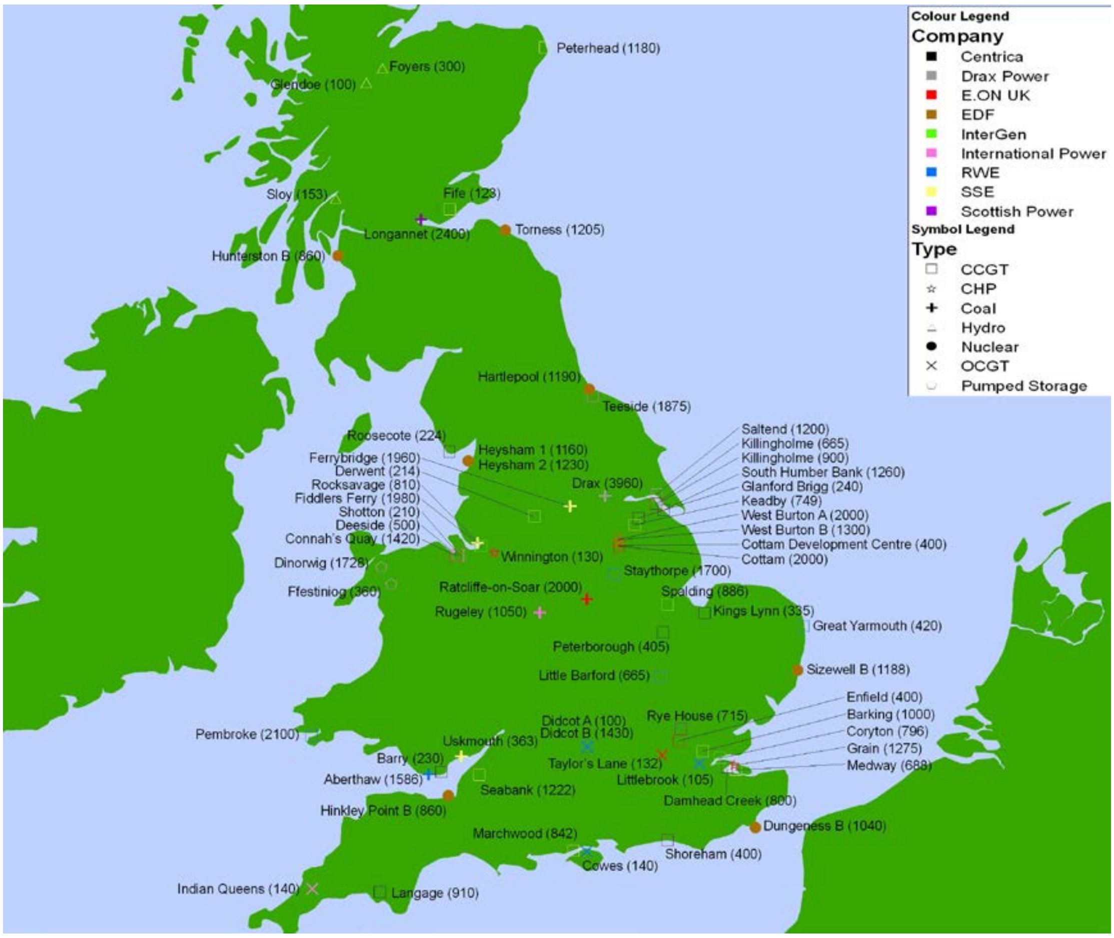


Figure 1: Location of power stations included in the electricity generation sector reports on Climate Change Adaptation

2. Power generation technologies

In 2009 a total of 378 TWh of electricity were supplied in the UK from a diverse portfolio of power station types. A range of generating technologies has proven essential to ensure that the UK is not over-reliant on one fuel source and it also enables flexibility in the delivery of power to meet demand. The power stations in the UK have a generating capacity of approximately 85GW. Table 1 shows the share of different fuels in the UK's electricity supply in 2009.

Table 1: Share of different fuels in the UK's electricity supply in (Data from DUKES – Digest of UK Energy Statistics 2010)

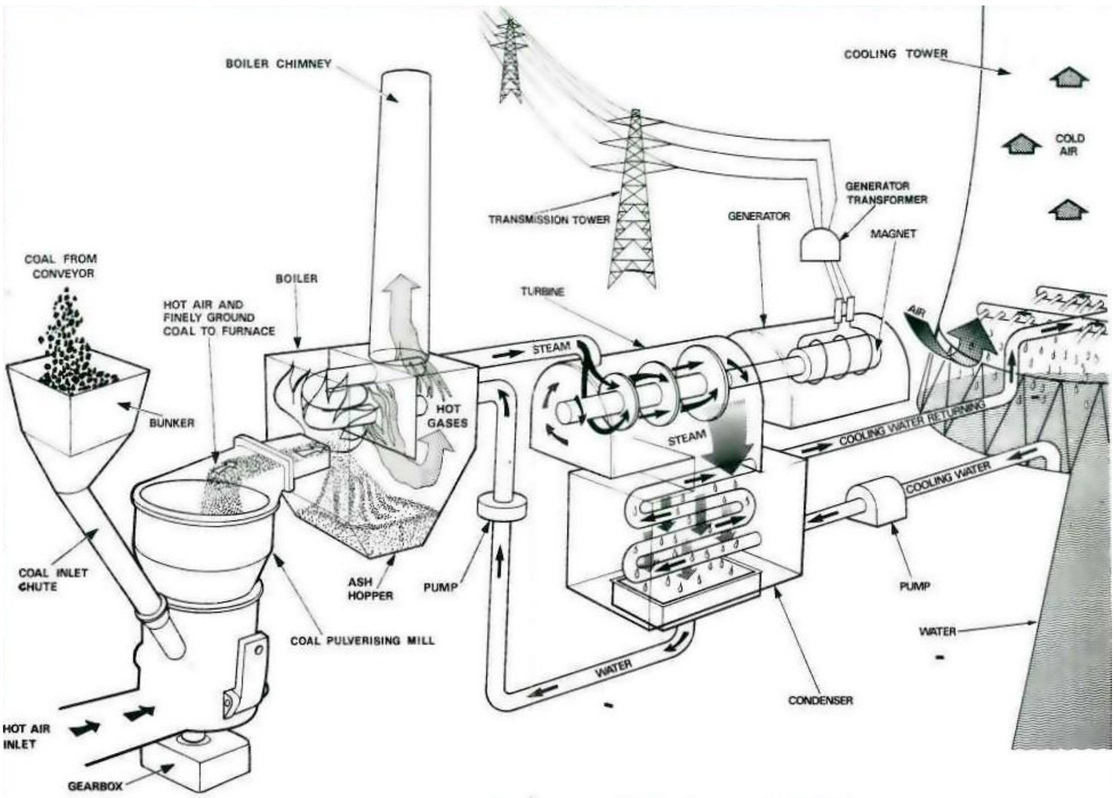
Fuel	Percentage
Gas	45%
Coal	28%
Nuclear	18%
Renewables	7%
Imports	1%
Other fuels	1%

Fossil Fuels

Most of the UK's electricity is produced by burning fossil fuels such as natural gas, coal and oil. Based on 2009 generation, 45% of the UK's electricity was produced from burning natural gas, 28% from coal and <1% from oil. However, these percentages of electricity produced, particularly from burning gas and coal, can change every year depending on fuel prices, e.g. if coal is cheaper than gas the amount of electricity produced from burning coal will increase and the amount produced from gas will decrease.

Fossil fuel power stations convert the chemical energy stored in fossil fuels into thermal energy. The power station then uses rotating machinery to convert the heat energy from combustion into mechanical energy, which then operates an electrical generator. The rotating machinery can be either a steam turbine or a gas turbine. The power stations use the drop between the high pressure and temperature of the combusting fuel or steam and the lower pressure of the atmosphere or condensing vapour to drive the turbine.

In the case of a coal-fired power station (see Figure 2), pulverised coal is burned in a boiler whose walls consist of many kilometres of pipes containing highly purified water. The high temperature produced by the combustion of the coal converts the water inside the pipes to high pressure, high temperature steam. The steam is then forced at high temperature and pressure through a series of turbines which efficiently convert thermal energy into rotational kinetic energy. A metal shaft connects the turbine to a generator which in turn converts the energy into electricity.

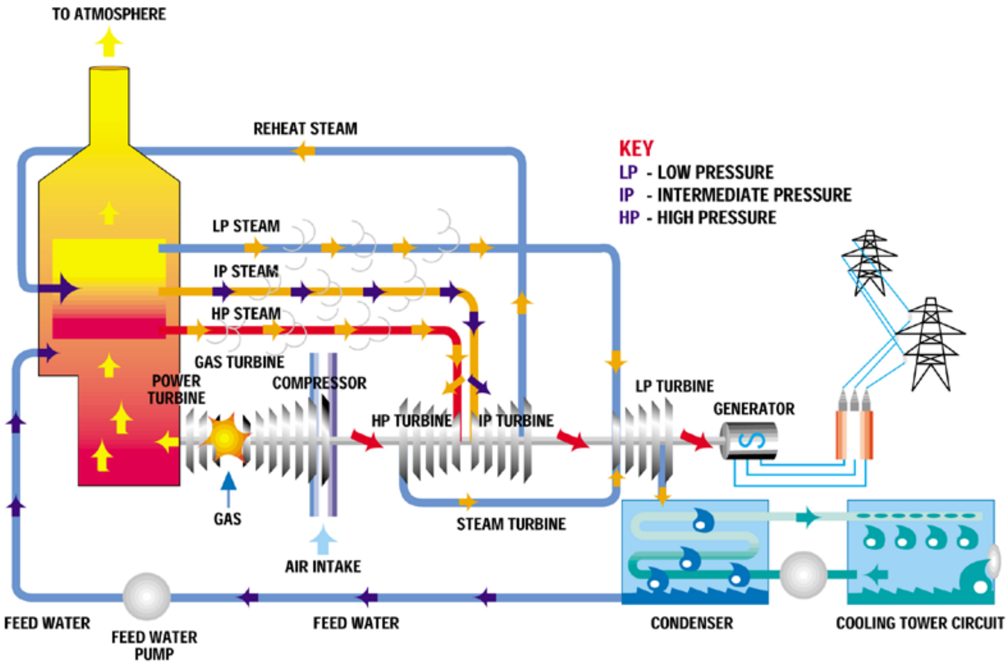


http://en.wikipedia.org/wiki/File:PowerStation2.svg

Figure 2: Schematic of a coal-fired power station

When the steam finally exits the turbines, the steam is cooled and re-condensed by passing the steam through a condenser. The condenser converts the steam back into water, creating a very low pressure that helps draw the steam through the turbines, and the cooled water is pumped back to the boiler to repeat the heating process. The condenser is kept constantly cool by water piped from a local water body such as a river or coastal waters (once-through cooling), or, by using water re-circulating through cooling towers. In the case of once-through cooling, the heat load associated with condenser cooling is discharged to the aquatic environment, while in the case of re-circulating cooling the majority is transferred, via the cooling towers, to the atmosphere. The quality of the cooling water supply (temperature and availability) is an important factor in power plant operation.

In the case of a gas-fired power plant (see Figure 3) , the fuel (natural gas or sometimes a volatile fuel oil) is combusted directly in a gas turbine, producing rotational kinetic energy which is subsequently converted into electricity. In addition, in order to make best use of the heat in the exhaust gases, the latter are generally used to raise steam in a boiler. This high pressure steam is then used to generate further electricity in a similar manner to a coal-fired power plant. Gas-fired stations use either directly-cooled water, cooling towers or air cooled condensers (ACCs) for cooling. Again, cooling water plays an important role in the efficiency of the electricity generation.



http://en.wikipedia.org/wiki/File:PowerStation2.svg

Figure 3: Schematic of a gas turbine power station

By-products of fossil fuel power stations have to be considered in both the design and operation of the plant. As coal burns, it produces emissions of carbon dioxide, nitrogen oxides, sulphur dioxides, particulates and other substances which are released to atmosphere via a tall stack. Large air filters called electrostatic precipitators remove nearly all the fly ash before it can be released into the atmosphere. Other scrubbers and pollution control equipment are used to reduce emissions to air such as Flue-Gas Desulphurisation (FGD) to remove sulphur dioxide from the flue gases and Selective Catalytic Reduction (SCR) to remove nitrogen oxides.

Solid waste or ash is another by-product of burning coal, which is collected in the bottom of the boiler and is removed from the plant. The ash is sold or transported to disposal sites or ash lagoons.

Carbon dioxide and nitrogen dioxide are also produced by gas-fired plant. The latter is controlled by the turbine combustion technology itself or via the injection of water into the combustion chamber.

Nuclear

In 2009, nuclear power stations produced about 18% of the UK's electricity. Power is produced from a nuclear plant by using the heat generated by nuclear reactions to raise steam which then drives turbines in the same manner as for a coal-fired plant. Seven of the eight operational nuclear power stations in the UK are driven by an Advanced Gas-Cooled Reactor (AGR, see Figure 4).

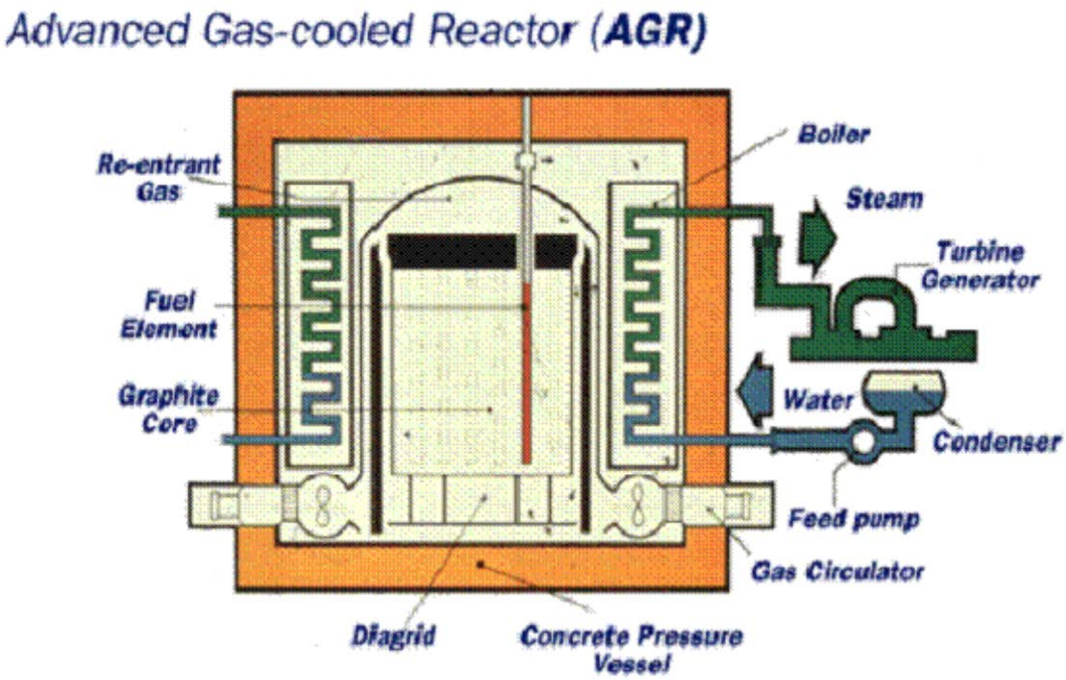


Figure 4: Schematic diagram of an AGR

The most recent nuclear power station built in the UK, Sizewell B, is driven by a Pressurised Water Reactor (PWR, see Figure 5).

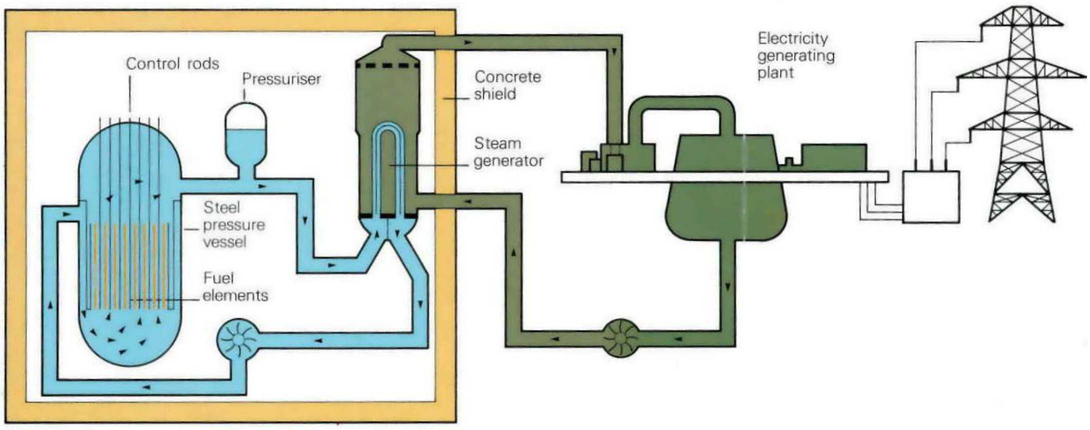


Figure 5: Schematic diagram of a PWR nuclear power station

Nuclear power stations also require the steam to be cooled in a similar way to fossil- fuelled power stations, and the cooling system for the steam cycle is essentially the same as that used by fossil-fuelled power plant. All of the operational stations in the UK are situated in coastal or estuarine locations. Cooling water is abstracted from coastal waters and absorbs excess heat from the circuit before being returned to the sea.

The UK nuclear power stations are reaching the end of their operational lives and will gradually close over the next decade, with all but one expected to cease production by 2025. Several companies have plans to build a new generation of reactors.

3. Business preparedness before Direction to Report was issued

A power station can be thought of as a complex system of interacting components designed to produce electricity (or in the case of a Combined Heat and Power (CHP) plant, heat and electricity). Like any other industrial production process it is dependent on a raw material (fuel and other essential chemicals) delivery infra-structure; water for use in its production process; routes for waste disposal; product route to market; access to services; and also demand from the external market.

The electricity generation sector has made considerable efforts to investigate and assess the sensitivity of power plant in general to weather variability and associated secondary effects as part of the business continuity process. One example of this work is the industry-funded EP2 project, which involved the Met Office and 11 UK electricity companies.

Additional knowledge from literature, climate change studies and projections, climate change scenarios and impacts on businesses from leading climate change research bodies e.g. Intergovernmental Panel on Climate Change (IPCC), UK Climate Impacts Programme (UKCIP), have further fed into the analysis of impacts from climate change and helped to produce a generic Climate Change Impact Register, which summarises potential hazards from climate change to electricity generators. The work underpinning the Register is described in more detail in the next section.

The identified climate change hazards have the potential to generate impacts on the operation of a power plant in a number of ways. For example, delivery of commodities essential for the operation of the power plant such as fuel or particular chemicals could be disrupted or interrupted by weather events such as floods; or water availability might be affected by drought. Operational costs due to changes in efficiency from equipment being used under higher temperatures and modified humidity might increase. The requirement to maintain compliance with environmental regulations and permitting conditions could also constrain operation. Plant itself might be directly damaged by extreme events of increased frequency or greater intensity. The potential consequences for power generators of the hazards identified in the Climate Change Impact Register are discussed in detail in Section 6.

Regulation

The Electricity Act 1989 forms the framework for the regulation of the UK electricity industry. Since privatisation in 1990, changes have occurred to the structure and powers of the regulators. The Utilities Act 2000 has substantially transformed the framework for energy utility regulation. The Act merged the former gas and electricity regulators, replacing the individual regulators for the gas and electricity sectors with a regulatory authority, the Gas and Electricity Markets Authority, supported by the Office for Gas and Electricity Markets (Ofgem). The Act also made changes to the primary duties of the regulator, provided new powers to the regulatory authority and made changes to customer representation in the energy sector (Simmonds, 2002). The Authority is responsible for the statutory responsibilities under the Acts and for developing strategy and policy, whereas Ofgem is responsible for the day-to-day operations and implementing policy.

The Competition Act 1998 and the Fair Trading Act 1973 also apply to the electricity sector and are enforced by Ofgem and the Director General of Fair Trading.

Electricity generating plants also need to comply with the Grid Code. The Grid Code covers all material technical aspects relating to connections to, and the operation and use of, the GB electricity transmission system and it defines the parameters that an electricity generating plant has to meet to ensure proper functioning of the electrical grid. The responsible authority for the Grid Code in the UK is National Grid.

The electricity generating industry is also governed by many environmental regulations via various bodies such as:

- The Department of Environment, Food and Rural Affairs (Defra), which develops regulatory policy related to energy efficiency, climate change and the protection and improvement of air quality.

- The Department of Energy and Climate Change (DECC), which has a major role in promoting renewable sources of electricity and plays a role in planning policy which includes issuing regulations for construction consent for generating stations.

- The Environment Agency (EA), which is the principal environmental regulator in England and Wales. One of its key responsibilities is to enforce the Environmental Permitting Regulations (previously the Integrated Pollution Prevention and Control (IPPC) Regulations). The Environment Agency also sets emission levels for power stations to protect the environment.

- The Scottish Environment Protection Agency (SEPA), which is the principal regulator in Scotland. Its key responsibility is to enforce the IPPC Regulations and, in a similar way to the Environment Agency, it sets emission limit values for power stations to protect the environment.

- The European Commission, which developed the European Union Emissions Trading Scheme (EUETS) for greenhouse gases and the majority of other environmental legislation that is applied in the UK once it has been transposed into UK law.

The Health and Safety Commission and Health and Safety Executive (HSC/HSE) play a significant role for nuclear power stations under the Nuclear Installations Act 1965, making them responsible for nuclear safety and licensing. The Nuclear Safety Directorate of the HSE sets safety standards to be used at nuclear sites in the UK and is responsible for the licensing of nuclear installations. The Office of Nuclear Regulation (ONR), part of the Nuclear Safety Directorate, is responsible for regulating radioactive waste management and decommissioning nuclear licensed sites. In this regard the ONR consults the EA and SEPA to ensure that all regulatory requirements are met in a consistent manner.

Some generation sites also may be regulated under the Control of Major Accident Hazards (COMAH) Regulations 1999 and their amendments 2005, if they store or otherwise handle significant quantities of industrial chemicals of a hazardous nature (e.g. fuel oil). The principal aim of the regulations is to reduce the risks of potential major accidents that are associated with the handling of hazardous substances. The competent authorities and enforcing agencies in the UK are the Health and Safety Executive and either the EA in England and Wales or SEPA in Scotland.

Stakeholders

It is important to co-ordinate plans with key stakeholders when developing an adaptation programme, in order to ensure that a consistent and effective approach is taken. The AEP provides a forum for its members to establish common views and best practices, and to communicate them to stakeholders and decision-makers in the electricity generation industry. This means that the Association interacts with governments, regulators and the media as well as other organisations. The AEP is proactively involved in managing the sector's response to climate change and has recently co-ordinated an assessment of the impact of heat waves, drought and floods on the electricity generation industry via a working group specifically set up for the purpose.

To ensure that power generating companies covered by the Direction to report on Climate Change Adaptation provided consistent information regarding generic climate-related issues that are common to all of them, an AEP Working Group on Resilience and Adaptation was established among the nine generators (Reporting Authorities) in the power sector. In consultation with Defra's Adapting to Climate Change (ACC) Team, DECC and Cranfield University (CU) a two-tiered approach was agreed whereby each company would include generic information (Tier 1) and company-specific information down to power station level (Tier 2). A common structure for the company reports was also agreed to facilitate analysis/review by Defra, CU, DECC and the Adaptation Sub Committee of the Committee on Climate Change. The scope of the adaptation reports was also agreed, as has been presented in Section 1. A common risk assessment methodology was developed and has been applied by all the companies in the electricity generation sector in their reporting of climate change adaptation.

The electricity industry's main stakeholders relevant to the content of this report are:

- Department for Environment, Food and Rural Affairs (DEFRA) – the government department responsible for environmental protection and, therefore, a stakeholder for the electricity generating industry.

- Department of Energy and Climate Change (DECC) – the government department which develops energy policy and climate change mitigation policy that directly affects the electricity generating industry.

- Environment Agency (EA) – the environmental regulators of the industry in England and Wales are key stakeholders because they provide permits on a site-by-site level for activities such as water abstraction, environmental discharges, which might be influenced by climate change, and also flood defence requirements. The EA also produces flood and river level predictions.

- Scottish Environment Protection Agency (SEPA) – the environmental regulators of the industry in Scotland are key stakeholders as they provide permits for operation of the power stations.

- Office of the Gas and Electricity Markets (OFGEM) – OFGEM regulates the industry including protecting consumer interests by promoting competition wherever appropriate and in relation to the reduction of greenhouse gases and the security of electricity supply.

- National Grid plc – National Grid owns and maintains the high-voltage electricity transmission system in England and Wales and operates the system across Great Britain. Power stations reporting under the Direction provide electricity to the transmission system and therefore power company and transmission company assets are inextricably linked.

- HSE Nuclear Safety Directorate – responsible for licensing nuclear installations.

- Water Services Regulation Authority (OFWAT) – the body responsible for economic regulation of the privatised water and sewerage industry in England and Wales.

In addition to these main stakeholders, usually engaged at sector level under the auspices of AEP, direct engagement is expected to take place on a company and site level with those infrastructure operators (e.g. water companies) who have produced adaptation action plans which might be significantly interlinked with each individual company's adaptation strategy.

Business risk management

Existing regulations governing the industry, in particular the Environmental Permitting Regulations, aim to ensure a degree of 'climate change proofing', both in terms of minimising the impact of operating plant on climate (through the requirement to adopt best available techniques (BAT) to maximise energy and resource efficiency) and having adequate measures in place for flood protection. Consideration of climate change impacts is incorporated in the planning of new power stations via adherence to the National Policy Statements (NPS) for the energy industry. The requirement to participate in the EU Emissions Trading Scheme (EUETS) provides a further, economic, incentive to minimise carbon emissions.

All reporting companies have well-developed approaches to risk management and business resilience which are described in detail within the individual company reports. Business Resilience policies ensure that appropriate measures, where cost effective, are in place to ensure that businesses can react appropriately and promptly to unexpected events and continue to operate, without business-threatening disruption. Power stations are pro-actively managing potential specific vulnerabilities to events of extreme weather (e.g. heavy snowfall, river flooding or high tides/tidal surges). Climate change is not considered to introduce any new types of risk to operation, but rather to change the likelihood or severity of risks which are currently managed. These risks are consequently picked up in Business Impact Assessments and Continuity Plans and are already analysed, treated, reported, reviewed, monitored and audited under the existing corporate risk management procedures.

4. Identify risks due to impacts of climate change

In order to present a co-ordinated response to Government, the generating companies with Directions to report have, under the auspices of the AEP's Working Group on Resilience and Adaptation (AEP WGREAD), agreed a common approach for the Climate Change Adaptation Report. Thus each Reporting Authority has addressed the same set of climate change hazards, based on the CCIR, with quantification based on the relevant UKCIP09 High Emissions scenario projections where available, and other agreed sources of information (e.g. the EA for flood risk information) where not. A variety of sources have been drawn on to provide the evidence on which individual company risk assessments have been based.

Climate Change Evidence - UKCIP

The UK Climate Impacts Programme (UKCIP) was established in 1997 to help co-ordinate scientific research into the impacts of climate change, and to help organisations adapt to those impacts.

UKCP09 climate change data represent the latest climate information available for qualitatively and quantitatively assessing specific climate change impacts in the UK. Crucially, UKCP09 produces probabilistic climate projections and allows a measure of the uncertainty in future climate projections to be included.

The UKCP09 projections are accessible by an online User Interface and form the basis for specific impact assessments presented in the companies' reports.

Climate Impact Variables

Most impact variables relevant to generators are covered by UKCP09, and climate change risks can now be assessed directly with UKCP09 data and additional tools such as the Weather Generator and Threshold Detector. However, UKCP09 is not entirely comprehensive and other industry-relevant impact parameters (e.g. river flow) are limited and need to be explored through additional climate data or impact models. Nonetheless, UKCP09 represents a powerful tool to assess climate impacts in the UK and has been used intensively in the assessment of risks from climate change and development of climate change adaptation strategies.

The UKCP09 User Interface allows the probabilistic projections to be visualised and interrogated to produce images (e.g. maps and graphs) or for the data to be downloaded as numerical outputs. Output for several variables and temporal-average periods is available.

UKCP09 Climate Projections over Land

The UKCP09 User Interface offers probabilistic climate projections for land for various weather variables. Impact parameters of particular interest to generators are precipitation and temperature.

Generally, climate projections for land offer:

- Annual, seasonal and monthly climate averages for various climate variables.
- Data for individual 25km grid squares, and for pre-defined aggregated areas (e.g. river basins).
- Data for seven 30 year time periods: 2010-2039, 2020-2049, 2030-2059, 2040-2069, 2050-2079, 2060-2089, 2070-2099.
- Data for three emission scenarios: low, medium and high - defined by the Intergovernmental Panel on Climate Change (IPCC) and reflecting three possible future pathways for greenhouse gas emission levels (Nakicenovic et al 2000).
- Projections reported as absolute values or as changes relative to a 1961–1990 baseline.

UKCP09 Weather Generator and Threshold Detector

For the assessment of some climate impacts, more detailed temporal and spatial data is required than is provided by the UKCP09 probabilistic climate projections. For this reason, UKCIP provides tools such as the Weather Generator (UKCIP-WG) and the Threshold Detector (UKCIP-TD).

UKCIP-WG generates long, synthetic time series at daily and hourly temporal resolutions, and at a spatial resolution of 5 km, that are statistically consistent with a particular average climate. With each run, UKCIP-WG produces two sets of time series, a synthetic daily climate sequence for 1961 to 1990 (the reference period) and a synthetic daily climate sequence for a future 30-year time period. Time series for the reference period are modelled and calibrated based on empirical regression relationships extracted from observations of various weather variables between 1961 and 1995. These empirical relationships are then assumed to be preserved under future conditions and used to generate synthetic time series for future climate that are consistent with the overall statistics of the UKCP09 probabilistic climate projections for the same time period. Based on these time series, a user can assess the likely recurrence interval of particular events, investigate the risk of thresholds being exceeded and test for a variety of weather conditions critical to power plant operation. Although the user can generate extremely long series, e.g. 10,000 years, care must be taken in interpreting these quantities, since they are derived from an imperfect model, which has been fitted using a much shorter observed record. Extreme statistics for return periods longer than ~10 yr should therefore be used with caution

UKCIP-TD is a post-processing tool that can be applied to the output from the UKCIP-WG for daily time series for 30-year duration and a maximum number of 100 samples. For example, users can define conditions for a 'Severe Weather Event' and ask the UKCIP-TD to count the number of occurrences when these conditions are fulfilled in UKCIP-WG runs and to produce a set of summary statistics. Summary statistics include measures of uncertainty in projected number of occurrences of the 'Severe Weather Event'.

For the risk assessments, most reporting companies tested the resilience of plants and sites to standard weather hazards as classified by expert bodies e.g. Absolute Drought as defined by British Meteorological Office (BMO), and to weather hazards specific to plant or site by setting weather indices critical to the specific plant (e.g. via a Tripping Test). These stress tests produced measures of likelihood and uncertainty for the event under investigation by means of the 'mean of average number of event counts' per year during the 30-year period and the standard deviation. Table 2 shows a set of stress tests performed by generators on a site-by-site basis.

A key challenge was, however, to establish well-defined critical thresholds for plant operation, as power stations are designed to continue operation even under extreme weather conditions (with gradually degraded performance) and there are generally no previous incidents which could indicate 'tripping points'.

Table 2: Example stress tests for electricity generators

Title of stress test	Hazard	Generic or specific test	Definition of stress conditions
Tripping test	Extreme high or low temperature causing unit trip	Plant specific (Generators)	Minimum of 1 day on which critical maximum or minimum temperature is exceeded
Flash flood test	Prolonged hot and dry period followed by extreme precipitation causing flash flooding	Generic (UKCIP)	Minimum period of 14 days with less than 1.1mm precipitation per day and maximum daily temperature in excess of 25°C followed by 1 day with at least 40mm rain
Absolute drought test	Prolonged period with no/little rain causing abstraction or discharge issues	Generic (BMO)	Minimum period of 15 days with less than 0.3mm precipitation per day
Dry spell test		Generic (BMO)	Minimum period of 15 days with less than 1.1mm precipitation per day
Days below freezing	Low temperature causing equipment to freeze	Generic / plant specific	Minimum of 1 day with daily minimum temperature below 0°C

UKCP09 Sea Level Projections

UKCP09 offers projections of future changes in relative sea level for 12km coastal grid squares around the UK over the period 1999 to 2099 and for three emissions scenarios plus a high risk, low probability scenario. These projections have fed into generators' site-specific flood risk assessments.

UKCP09 Storm Surge Height Projections

Skew storm surge is the height difference between a predicted astronomical high tide and the nearest (in time) observed or modelled high tide. UKCP09 projections of future changes in skew storm surge around the UK provide the linear trend and 5th and 95th percentiles throughout the 21st Century, for each return period, at each 12km coastal grid square. The statistical consequence of the trend is also indicated. Events with return periods of 2, 10, 20 and 50 year and the UKCP09 medium emissions scenario are available for impact assessments. This data has fed into generators' site-specific flood risk assessments.

Additional UKCP09 technical notes

In January 2011, UKCIP published additional technical notes based on the ensemble of eleven Regional Climate Model (RCM) projections run at 25km resolution. The additional technical notes include snow projections (UKCIP 2011a), wind speed projections (UKCIP 2011b) and projections of future change in lightning (UKCIP 2011c). Snow projections provide future changes of days of snow and snowfall rate. The former is a measure of days when snow could impact on generation and the latter is an indicator for the assessment of intense snowfall on generation. Due to their temporal resolution, wind speed projections are not suitable for assessing high wind events which are of interest to generators. Instead, the UKCP09 storm note (UKCIP 2009a) provides information on future changes in storm frequency and magnitude used by generators for the impact assessment. Additional technical notes based on RCM projections are restricted to fewer future time periods, projection certainty levels and carbon dioxide emission scenarios. As the present analysis is mainly focussed on the potential consequences at individual power stations (without necessarily requiring the use of spatially coherent projections) the auxiliary information offered by the RCM projections is of limited use.

Additionally to UKCP09 climate projections other relevant research and expert bodies have been consulted for the risk assessment. For example, studies and guidelines from the UK's authority on flooding and drought affairs, the Environment Agency (EA), have been applied for all water-related impacts.

EA River Flow Projections

To date, national flow projections based on latest climate projections (UKCP09) have still not been made publicly available. The best available river flow data are still two national studies based on previous climate projections (UKCIP02) commissioned by the UK Water Industry Research (UKWIR 2007) and the EA (EA 2008). The UK's authority on flooding and drought affairs, the EA, states that these studies are fit for qualitative, high-level river flow assessment. Furthermore, in light of significant water flow reductions projected for summer and autumn in both studies, the EA advises Reporting Authorities to investigate site-specific scoping ranges for water availability. For example, EA guidelines recommend carrying out sensitivity tests to find out if there are business-critical thresholds for water availability up to 50% lower than currently available.

Currently, Catchment Abstraction Management Strategies (CAMS), which provide information on how much water is available for households and the industry in the area, do not consider the latest climate projections. However, the EA is now producing the next set of catchment strategies, which incorporate the latest climate change findings and translate the increasing pressures on water availability into regional water abstraction strategies e.g. via time-limited abstraction licences.

UKCIP provides additional tools such as the UKCP09 Weather Generator and Threshold Detector which can be used to perform stress tests for specific sites. For example, users can assess the change of numbers of dry periods for the baseline and a future climate scenario (see Table 2).

EA Flood Projections

The key meteorological driver for flooding is extreme precipitation. There is robust evidence in the latest UKCIP climate projections for precipitation to change significantly across the UK depending on season and location and for snowfall to decrease across the UK thus providing strong evidence that risks driven by these climate stressors will change during this century.

National flood projections are out of the scope of the UKCIP. Instead, climate change is examined for flood impacts by other specialist organisations such as the EA and the Centre for Ecology and Hydrology (CEH). To date, national flood projections based on latest climate projections (UKCP09) have still not been made publicly available.

Site-specific flood risk assessments, especially if climate change is taken into account, are the ideal data source to assess future risk due to flooding. Where no such studies are available or effects from climate change are not considered, EA guidance points to the Flood Risk Zone Map, regional Catchment Flood Management Plans, Strategic Flood Risk Assessments and Shoreline Management Plans as additional sources for the assessment.

The Flood Zone Map is produced by the EA and assesses extreme flood events with return periods from 1 in 100 to 1 in 10,000 years. Regional Catchment Flood Management Plans and Shoreline Management Plans are also produced by the EA and give an overview of the flood risk across each river catchment and large-scale risks associated with coastal processes. Strategic Flood Risk Assessments are produced by Local Authorities and look at flood risk at a strategic level on a local planning authority scale.

Additionally, UKCP09 information discussed earlier in this Section can be extracted to estimate hazards from flash flooding, extreme snow fall, sea level rise and storm surge.

Climate Change Impact Register (CCIR)

A final set of 17 sources of risk was identified for the power sector. For presentational purposes, the climate change impacts in the CCIR have been grouped under four hazard headings: flood and storm surge; extreme high temperature; climate hazards affecting use of water; and other climate change hazards. The identified hazards, the type of plant potentially affected and the potential consequences for plant operation are shown in Table 3:

Table 3: Common list of hazards assessed by reporting companies

No	Climate Change Hazard	Plant type*	Potential consequences for plant
	Flood and storm surge		
1	Flooding of Site	All	Possible generation unit shutdown; water damage to infrastructure on a variety of scales; pipeline fracture due to erosion
2	Flooding of Access Routes to Site	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
3	Flood Events & Extreme High River Flow	All	Higher maintenance
4	Storm Surges	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
	Extreme high temperature		
5	Extreme High Temperature on Steam Turbine	CCGT, Coal	Performance drop / capacity loss
6	Extreme High Temperature on Gas Turbine	CCGT, GT	Performance drop / capacity loss
	Climate hazards affecting water use		
7	Extreme High Temperature on Water Discharge	All	Load reduction to respect discharge limits
8	Drought on Water Availability	All	load reduction, increased water treatment plant usage
9	Drought on Water Discharge (Permitting)	All	Load reduction to respect discharge limits
10	Drought & Change in Water Abstraction Legislation	CCGT, Coal	New permit conditions, additional operational constraints, load restrictions
	Other climate hazards		
11	Extreme Snowfall	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
12	Extreme Low Temperature on Cooling Tower Fans	CCGT	Constraints in performance
13	Extreme Low Temperature on External Systems	All	Additional maintenance / repair; emergency water supply
14	Extreme Low Temperature on Cooling Tower	CCGT, Coal	Ice build-up on unloaded cooling tower and risk of packing collapse
15	Extreme Winds	All	Damage to installations; Health & Safety
16	Weather Conditions Causing Plume Grounding	CCGT, Coal	Hazards and complaints; additional restrictions
17	Subsidence / Landslide	All	Damage to infrastructure and pipelines on a variety of scales

*Note: Plant type is indicative and may not apply to some installations for site-specific reasons

5. Assessing risks

A common methodology to estimate the risk posed by each hazard in the CCIR was developed by AEP WGREAD for use in the Climate Change Adaptation Reports (CCARs). For each risk, the *likelihood* describes, on a six-point scale (ranging from rare to very likely), the estimated probability of occurrence of an event in a specific time-period. The classification scheme, based on annual probability levels, has been complemented with appropriate descriptors to facilitate its interpretation and application in practice. Typically, the evaluation of the current likelihood of hazards to occur is based on site history and qualitative expert judgement, whereas future likelihood is either quantitative, semi-quantitative (where either no critical thresholds or no probabilistic projections are available) or qualitative (where neither critical thresholds nor probabilistic projections are available).

It was agreed within the AEP WGREAD that each reporting company would define and implement its own specific classification of *consequence of risk* according to its own business-related metrics.

An agreed set of ascending numerical values was assigned to each level of likelihood and consequence so that a quantified measure of risk (on a five-point scale from very low to very high risk) could be obtained from the product of likelihood and consequence. The scoring system generally used for the likelihood and the consequence is shown below:

Likelihood of Risk	Score	Consequence of Risk
Very Likely	10	Catastrophic
Likely	9	Major
Possible	7	Serious
Unlikely	5	Moderate
Low Probability	4	Minor
Improbable / Rare	3	Negligible

The diagram below illustrates the final classification of risk obtained from the product of likelihood and consequence scores:

Risk = Score for Likelihood x Score for Consequence

Very high risk	≥ 90
High risk	≤ 50 – 90
Medium risk	≤ 30 – 50
Low risk	≤ 20 – 30
Very low risk	< 20

Uncertainties and assumptions

In addition to the methodological uncertainty and assumptions just described, underlying uncertainties exist in both the projections of climate change and the consequences for generating plant of the occurrence of those climate changes.

As a basic rule, climate models have three sources of uncertainty: natural climate variability, modelling errors and emission scenario uncertainty. For the CCAR assessments, generators generally made assumptions and choices that reduce the chance that uncertainties will render their assessment an underestimate of likely risk. Thus in the case of emissions uncertainty i.e. not knowing the magnitude of future global greenhouse gas emissions, generators have assumed the 'High Emission Scenario', i.e. that causing the highest change in future climate and hence highest impact. In using UKCP09 projections, generators have assessed climate impacts against climate projections which are 'very unlikely' to be exceeded in the reference future time period of 2010-2039 (the 2020s).

A key challenge for generators was to establish critical thresholds for plant operation suitable for assessment against future climate projections. In practice this is not straightforward. Although the response of operating plant to change is well understood for some climatic variations (e.g. gas turbine output variation with temperature), power stations are designed to continue operation under expected weather conditions during their operating life, and there are generally no previous incidents which could indicate tripping points. Where climate variables have gradual effects on plant operation, critical thresholds were also difficult to link to consequences for electricity generation.

6. Addressing current and future risks due to climate change – summary

The adaptation reports from the Directed companies in the power sector have all addressed risks arising from the common list of hazards shown in Table 3, and have used a risk assessment framework based on a common approach (although potentially differing in the way consequence has been assessed, as this needs to tie in with individual corporate risk assessment processes).

In order to facilitate the cross-comparison of the assessments reported by the Directed companies, site-specific risk results have been compiled into weighted company scores (using average site-specific scores weighted by site electrical capacity (MWe) or the highest scores assigned to the assessed fleet, depending on data availability). The results of the risk assessments against the common list of 17 hazards are summarised in Table 4 and Table 5 for the 2020s. When interpreting the variation in risk assessment between companies it must be borne in mind that the consequence scale employed was company-specific, and that this will therefore by itself result in differences in the scoring of risk for a given hazard. Furthermore, some companies focussed on the potential impacts on plant operation alone, while others included other potential issues, such as safety and environmental impacts.

The vast majority of these hazards are assessed to be of 'very low' or 'low' risk in the 2020s (~95% of the scores determined in the risk assessment are in these categories, see Figure 6). A small number are classified as 'medium' risks (~5% of the scores), while no company considers climate change risks in the 2020s to have sufficiently high rating to come into the 'high' or 'very high' risk rating categories.

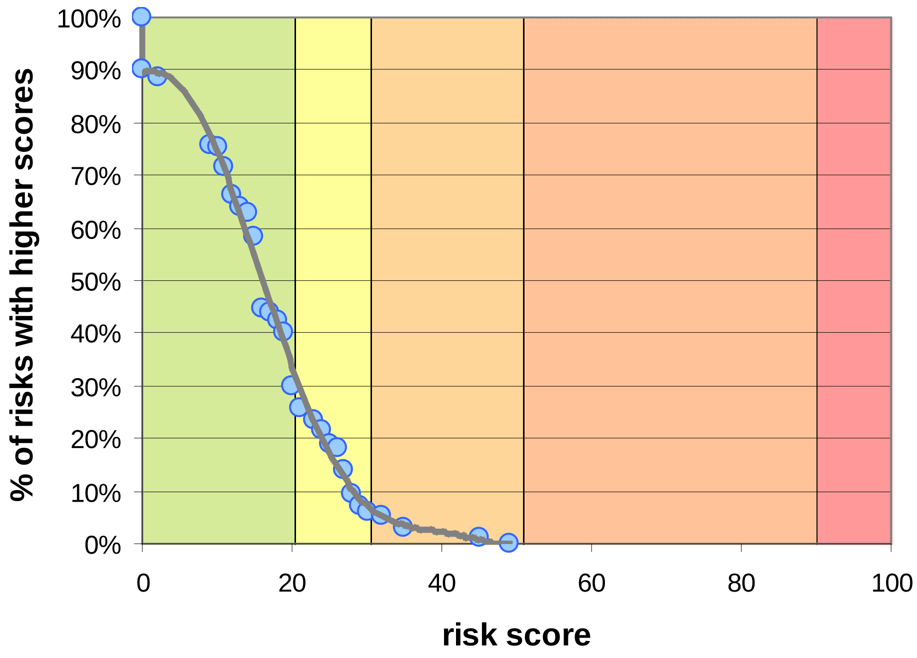


Figure 6: Cumulative distribution of the scores of the individual company risk assessments for the 2020s against the common set of hazards. The colours in the background reflect the classification of risks (see Section 5 or the Legend in Table 4)

As expected, there are site-specific factors evident. Two operators assess storm surge as being a 'medium' risk for coastal power plant, and one assesses the effect of high air temperatures on steam turbine performance also to be a 'medium' risk over this period. One operator assessed the risk from high winds to be a 'medium' risk in the 2020s.

The category of risks which contains the most 'medium' risk assessments is that related to climate hazards affecting future water use, such as drought and high temperature effects on abstraction and discharge of water to rivers.

Table 5 shows the way in which the risk arising from each hazard is calculated to change between the baseline risk assessment, and the assessment for the 2010-2039 period. In broad terms, it may be seen that the flood risk, and risk arising from high air temperatures on turbine performance increase slightly, the issues related to drought on abstraction and discharge to the aquatic environment increase more significantly, and the remaining set of hazards are seen as becoming a reducing risk under the climate change scenario studied.

Table 4: Summary of individual company risk assessments against the common set of hazards

No	Climate Change Risk in the 2020s*	Scottish Power	Int. Power/ Gdf Suez	Centrica	EdF Energy ESCS	EdF Nuclear Gener-ation	InterGen	SSE	E.ON	Drax	RWE npower
1	Flooding of Site	27	27	24	28	20	24	20	27	16	16
2	Flooding of Access Routes to Site	21	14	21	20	28	11	16	19	16	16
3	Flood Events & Extreme High River Flow	28	26	20	9	n/a	11	15	23	16	9
4	Storm Surges	32	12	14	n/a	45	18	16	29	12	20
5	Extreme High Temperature on Steam Turbine	21	25	20	20	45**	27	28	28	15	15
6	Extreme High Temperature on Gas Turbine	20	16	16	n/a	n/a	27	28	29	n/a	15
7	Extreme High Temperature on Water Discharge	21	23	12	25	45	9	20	21	28	16
8	Drought on Water Availability	28	35	24	25	49	30	20	29	16	20
9	Drought on Water Discharge (Permitting)	19	20	9	9	n/a	9	12	35	16	9
10	Drought & Change in Water Abstraction Legislation	27	35	12	25	n/a	9	n/a	n/a	16	49
11	Extreme Snowfall	23	17	13	12	12	9	20	18	16	9
12	Extreme Low Temperature on Cooling Tower Fans	13	16	2	n/a	n/a	9	n/a	15	n/a	9
13	Extreme Low Temperature on External Systems	21	23	16	20	12	13	20	18	16	9
14	Extreme Low Temperature on Cooling Tower	13	11	2	9	n/a	11	16	19	16	9
15	Extreme Winds	29	30	9	16	15	27	35	25	20	9
16	Weather Conditions Causing Plume Grounding	11	11	9	n/a	n/a	15	9	21	n/a	9
17	Subsidence / Landslide	16	10	9	15	12	19	20	16	16	9

* Note: "The 2020s" refers to the period 2010 to 2039.
**Note: Steam turbine not affected, but other plant elements could be.

Legend
very high risk
high risk
medium risk
low risk
very low risk
risk "not applicable"

Table 5: Change in risk rating between 2020s risk and baseline risk ($\Delta R = R_{2020} - R_{baseline}$)

No	Climate Change Risk in the 2020s*	Scottish Power	Int. Power/ GdF Suez	Centrica	EdF Energy ESCS	EdF Nuclear Gener-ation	InterGen	SSE	E.ON	Drax	RWE npower
1	Flooding of Site	7	3	1	7	5	3	0	5	4	0
2	Flooding of Access Routes to Site	2	3	4	5	7	1	0	2	4	0
3	Flood Events & Extreme High River Flow	5	6	3	0	n/a	0	0	4	0	0
4	Storm Surges	11	1	0	n/a	9	3	0	5	0	0
5	Extreme High Temperature on Steam Turbine	-5	3	4	4	25**	0	8	0	0	0
6	Extreme High Temperature on Gas Turbine	3	0	4	n/a	n/a	0	8	0	n/a	0
7	Extreme High Temperature on Water Discharge	5	4	1	5	10	0	5	2	12	4
8	Drought on Water Availability	1	12	4	5	21	1	5	9	0	0
9	Drought on Water Discharge (Permitting)	1	1	0	0	n/a	0	0	10	0	0
10	Drought & Change in Water Abstraction Legislation	5	12	0	5	n/a	0	n/a	n/a	0	n/a
11	Extreme Snowfall	-3	-5	-2	-4	0	0	0	-3	0	0
12	Extreme Low Temperature on Cooling Tower Fans	2	-3	0	n/a	n/a	0	n/a	-6	n/a	0
13	Extreme Low Temperature on External Systems	1	-8	-1	-5	-4	-2	0	-6	0	0
14	Extreme Low Temperature on Cooling Tower	2	-1	0	0	n/a	-2	0	-5	0	0
15	Extreme Winds	2	0	0	0	0	0	0	0	0	0
16	Weather Conditions Causing Plume Grounding	0	-2	0	n/a	n/a	-1	0	0	n/a	0
17	Subsidence / Landslide	2	0	0	0	3	0	4	2	0	0

* Note: "The 2020s" refers to the period 2010 to 2039.

**Note: Steam turbine not affected, but other plant elements could be.

Legend

$\Delta R > 25$
$10 < \Delta R \leq 25$
$0 < \Delta R \leq 10$
$\Delta R = 0$
$\Delta R < 0$
risk "not applicable"

7. Barriers to implementing adaptation programme

In a strongly competitive market, as is the case for the UK electricity market, adaptation measures that are beneficial (from a cost-benefit perspective) are expected to be commercially rewarded and their implementation can therefore be expected to be market-driven, both over the lifespan of an existing fleet, as well as for new plants (with adaptation preferably occurring at the plant design, planning/ consenting and permitting stage). As with any other investment decisions, electricity generating companies derive the optimal timing for the implementation of beneficial adaptation measures by evaluating their net present value (NPV) over different time frames.

A barrier to the timely implementation of adaptive actions might however arise from the high uncertainty intrinsic to the future developments in the energy markets, as well as in the anticipated changes to key weather parameters driven by climate change. The evolution of the electricity market over the next decades, as set out in the Government's White Paper published in July 2011 (DECC 2011), is particularly uncertain, with important parts of the UK's energy policy not yet written into statute.

In England and Wales the Government has made clear that it intends to review the principles of water rights allocation, having regard to climate change. Changes to water availability for thermal power plant due to the consequences of such regulatory developments are much harder to predict than the consequences of weather variability and (imperfectly understood) climate change. Regulatory uncertainty of this kind could pose a barrier to the implementation of appropriate adaptive measures.

Individual generating companies may have resilience, continuity or contingency plans to mitigate the effects, but to quite an extent climate change adaptation for generation is dependent on other sectors and the regulators. A further barrier to implementing adaptation measures lies therefore in the uncertainties about inter-dependencies with other stakeholders and their adaptation plans. Risks to generators from climate change cannot be viewed in isolation from risks to other parts of national and local infrastructure (power distribution, water infrastructure, etc) as many of these risks are regulatory and indirect.

The generation sector is also dependent on Government and regulators for the delivery of the 'state-of-the-art' climate projection data to be used to inform impact assessments. If the data is missing, or available data is deemed expired, then there can be a barrier to the identification of a sufficiently robust mitigation strategy for that risk.

8. Report and Review

One of the main conclusions from the Adaptation Reports is that climate change does not generate sources of risk that are not already analysed, treated, reported, reviewed, monitored and audited under the existing corporate risk management procedures within companies. Consequently, the main value of the CCARs lies in the achievement of a consistent and comprehensive prioritisation of those climate risks with potentially significant impacts over the lifespan of the existing fleet (alongside other business risks).

All of the reporting companies have corporate risk management processes which are covered by company policies and have procedures that are subject to regular internal review and audit, which should not only ensure their delivery, but also capture any change in the risk appetite or altered thresholds that might change the nature of a risk. The decision of whether and when investments should be made to mitigate climate change risks will therefore be an integral part of those companies' risk management processes, ensuring that essential investments are made in a timely manner but also enabling close management of investment appraisals in areas of greater uncertainty. This process will enable a flexible response to changes in risk drivers.

9. Recognising opportunities

As well as the possibility of giving rise to certain hazards, from a corporate perspective there exists the potential for some climate change effects to create beneficial situations. Power station operators participate in a highly competitive market and the identification and evaluation of opportunities is a continuous process. Opportunity identification and evaluation are also an integral part of the corporate risk management procedures, where opportunities are treated and reported in a similar way to risks.

The trend towards warmer average temperatures would offer generators the opportunity of operating under a more even spread of electricity demand over the course of a year and thus to a more evenly-balanced utilisation rate in power stations.

Many complex, multi-faceted factors (social, economic, technological) will have a bearing on the potential of future opportunities. For example, possible opportunities in relation to higher yields of biofuel crops would be subject to future priorities for energy, water and food security. Such considerations strengthen the importance of the constant monitoring and frequent reviewing of identified risks/opportunities to enable more solid decision-making to be made once more accurate data is available.

10. Further comments / information and conclusions

The industry's dependence on, and interconnectedness with, other components of national and local infrastructure is a source of risk. Access to water is one of the key traditional drivers for power station location but there are others (e.g. fuel routeing, transmission capacity, geographic distribution of demand, etc) which may present different potential vulnerabilities and may allow or prevent particular adaptation measures. Climate change over the lifetime of future installations will be taken into account in selecting sites for new power stations.

In the case of proposals for water abstraction rights reform, it is vital to recognise the consequences for thermal plant (both new and existing) and appropriately manage the transition to any new abstraction rights regime respecting the past investment in existing water-dependent infrastructure assets (which include power plant and their associated developments such as transport infrastructure, power distribution networks, etc). The power sector is keen to be engaged in the development of any policy measures that may affect the availability of water to the thermal power plant in areas where there is, or is projected to be, water scarcity and/or drought.

The individual Climate Change Adaptation Reports highlight a number of key considerations and complexities that have a profound bearing on the way the power generation industry in general perceives and manages risks associated with climate change. The key conclusions are:

- Climate change is expected to affect the probability of occurrence and potentially the intensity of forms of risk (generally related to the occurrence of extreme events of a wide range of types and duration) that are already recognised, and consequently already managed/mitigated by Companies – not to introduce any fundamentally novel sources of risk.

- The companies operate in a competitive market subject to national regulatory and policy uncertainties, and market uncertainties, which give rise to risks of greater magnitude than those posed by climate change.

- The probability in any given year that an engineering fault will force a generating unit to stop operating is significantly higher than the additional risks arising from climate change effects over the next two decades.

- Over the lifespan of the operating fleet, short-term variation in weather patterns, such as experienced in the past and present and which are already managed through well-developed risk management systems, will remain more significant as a source of risk than the trend to a changed mean climate.

  Adaptive capacity in the UK electricity generation industry is ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and, in the last decades, electricity generation has demonstrated a consistently high level of resilience to potential disruptions from extreme events. Provided that these key factors are maintained over the next 20 years, this intrinsic ‘robustness’ is not expected to change.

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Appendix B: An overview of electricity generation sector resilience during the extreme weather conditions in Winter 2013/14

Energy UK

The voice of the energy industry

A review of power station resilience over winter 2013/14

8 February 2015

About Energy UK

Energy UK is the Trade Association for the energy industry. Energy UK has over 80 companies as members that together cover the broad range of energy providers and suppliers and include companies of all sizes working in all forms of gas and electricity supply and energy networks. Energy UK members generate more than 90% of UK electricity, provide light and heat to some 26 million homes and invested over £13 billion in the British economy in 2013.

Key points

- The winter of 2013/14 was characterised by an exceptional number of storms, resulting in record levels of rainfall and strong winds throughout.
- Despite the severe winter, there were only three reports of lost production related to weather events at thermal and pumped storage power stations in Great Britain. There was one incident associated with groundwater flooding and two incidents associated with extreme winds.
- Lost production over the period December 2013 through February 2014 is estimated at 193 GWh. This is insignificant (<0.3%) in the context of total thermal and pumped storage generation output for the period, which amounted to 68,300 GWh.
- All the reporting companies operate in a competitive market and have well-developed approaches to risk management and business resilience. Resilience policies ensure that appropriate measures, where cost effective, are in place to ensure that power station operators can react appropriately and promptly to unexpected events and continue to operate without business-threatening disruption.

Sector Background

Electricity generation sits within the UK's Energy Sector alongside the complementary functions of oil and gas production, transmission and distribution system operation and energy supply/customer services. The electricity market in Great Britain is entirely privatised and liberalised, meaning that there is full competition between private companies.

Electricity producers generate electricity using a variety of fuels and technologies. There are many companies in the electricity generation sector, from large multinationals operating a diverse generation portfolio to small, family-owned businesses running a single site. Most electricity is generated 'in bulk' at large power stations connected to the national transmission network. However, electricity can also be generated in smaller scale installations which are connected to the regional distribution networks.
How many power stations are built and of what type is up to companies to decide on the basis of market signals and government policy on issues such as the environment, security of electricity supply and affordability for consumers.

A list of power stations that contributed to this Review is included at Annex 1.

Winter 2013/14 weather – overview

The winter of 2013/14 was characterised by an exceptional number of storms, resulting in record levels of rainfall and strong winds throughout. Due to exceptionally persistent rainfall from 12 December onwards, the ground was saturated for much of the winter, which led to multiple flood events.

The stormy weather resulted in extensive and protracted flooding, caused almost 1 million customers to experience power disruption, inflicted widespread damage to infrastructure and led to major transport disruption.

There were no unprecedented storm events. However, a storm surge on 5-6 December that affected the east coast of England caused notable damage. A similar surge on 3-7 January caused damage along the west coast.

The winter weather events are described fully in a report issued by the Met Office and the Centre for Ecology and Hydrology[1].

Further details on different aspects of the weather and a timeline of significant events are set out in Annex 2.

[1] Met Office and CEH, "The Recent Storms and Floods in the UK", February 2014.

Hazards associated with severe weather

A set of 17 sources of risk was identified for the power sector in a summary[2] of reporting by generating companies under the first round of directions issued under the Adaptation Reporting Power of the Climate Change Act 2008. The full list of hazards is included as Annex 3, but those of relevance to winter 2013/14 are:

1. Flooding of site
2. Flooding of access roads to site
3. Flood events and extreme high river flow
4. Storm surges
5. Extreme winds

Summary of power station performance during severe weather events

The power stations contributing to this review are all either thermal (powered by oil, coal, gas, biomass and nuclear fuels) or pumped storage. The coverage is not comprehensive, but the installed capacity of reporting stations (about 59 GW) represents approximately 87% of the installed thermal and pumped storage capacity (68 GW) for Great Britain.

Flooding

There was only one reported incident of lost generation due to flooding. The power station in question was affected by water ingress through foundations and floor plinths as a result of groundwater flooding. Site operations were suspended on 7 February for a period of 12 weeks.

Elsewhere, river water levels of 1:100 years were experienced, but flood defences were not breached. However, the east coast storm surge in December caused some breaches in flood defences along the River Trent. The consequent fluvial flooding prevented normal access to a power station in the vicinity, but alternative access was gained via the rear of the site in accordance with the operator's flood management plan and no production was lost.

Storm surges

There was no reported incident of lost generation due to storm surges, but there was some disruption to fuel supply chains as a result of damage to east coast ports. For example, the Port of Immingham was not fully functional for two weeks after the 5-6 December storm surge as a result of electrical substations being damaged. One coal-fired power station lost 26 coal trains in that period (approximately 40 ktonnes), but was able to sustain production using stockpiled fuel.

Extreme winds

There were two reported incidents of lost production due to extreme winds. Generation at a power station on the south coast was suspended for a week after flying debris from the roof of a National Grid substation struck power lines. The outage period was extended by the need to carry out safety checks following the rapid shut-down of the plant.

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[2] Association of Electricity Producers, "Climate change risks and adaptation responses for UK electricity generation – a sector overview", October 2011.

On the west coast, two generating units were shut down for several hours on 27 December after windblown sea salt accumulated on an insulator of a grid transformer following a period of high winds and light rain.

Elsewhere, at a power station on the east coast, high winds removed some exterior cladding from the buildings and also caused a fatigue failure of a tuned mass damper at the top of one of the stacks. However, neither of these incidents was serious enough to require the plant to be shut down.

Another power station on the south coast had the power supply to its gas Above Ground Installation blown over by the wind. The same station experienced its main breaker tripping on two occasions as a result of off-site grid problems. No production was lost as a result of either event because the station was not scheduled to run at the time of the incidents.

Conclusions

The exceptional winter weather of 2013/14 (December to February) presented three main potential hazards to electricity generation: flooding; storm surges; and extreme winds. All of these are recognised in generating companies' risk registers.

Electricity generation demonstrated a high level of resilience to potential disruption from weather events. From the 55 power stations (59 GW of installed generating capacity) covered in this report, there were only three reports of lost production caused by incidents connected to severe weather. Estimated lost production over the three months amounted to about 193 GWh.

There were no reported incidents associated with surface water or fluvial flooding. This suggests that current levels of flood protection, agreed at the project design/planning stage are adequate. Production was lost at one power station due to groundwater flooding. In response, the operator is investigating the installation of high volume flood pumps, relocating the flood water release point, sealing cable trenches and installing water level detectors.

There were no reported incidents associated with storm surges. This suggests that coastal defences agreed at the project design/planning stage are adequate. Associated fluvial flooding blocked the main access to one power station, but the flood management plan for the site allowed for an alternative access point. Power stations have an interdependency with ports and rail infrastructure with regard to fuel deliveries. Storm surges caused significant disruption and damage at some ports but, although there was some disruption to fuel deliveries, generators kept sufficient stocks of fuel on site to maintain full production.

There were two reported incidents of lost production due to extreme winds. The most significant one was associated with damage to National Grid assets, which are beyond the control of the power station operator. Transmission system problems were experienced at another site, but no production was lost as the power station was not scheduled to run at the time. A second incident involved the accumulation of wind-blown sea salt on a transformer. The operator is familiar with this hazard and takes appropriate action to minimise its occurrence. Extreme winds caused damage to equipment at two other power stations, but production was not affected. The operators have investigated the cause of the damage and effected repairs, incorporating design changes where appropriate.

Resilience across the electricity sector as a whole is ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and, in the last decades, electricity generation has demonstrated a consistently high level of resilience to potential disruptions from extreme events. This was maintained through the exceptional weather events of winter 2013/14.

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Annex 1. Power stations contributing to this Review

Operator	Station	Capacity (MW)	Fuel	Location
Centrica	South Humber Bank	1260	Gas	East coast, Lincolnshire
Centrica	Killingholme	665	Gas	East Coast, N Lincolnshire
Centrica	Brigg	240	Gas	East Coast, N Lincolnshire
Centrica	Peterborough	405	Gas	Inland, Cambridgeshire
Drax Power	Drax	4000	Coal and biomass	E Yorkshire
EDF Energy	Heysham 1	1155	Nuclear	Lancashire coast
EDF Energy	Heysham 2	1220	Nuclear	Lancashire coast
EDF Energy	Hartlepool	1180	Nuclear	North East coast
EDF Energy	Hunterston	960	Nuclear	North Ayrshire coast
EDF Energy	Torness	1185	Nuclear	East Lothian coast
EDF Energy	Dungeness	1040	Nuclear	Kent coast
EDF Energy	Hinkley Point B	945	Nuclear	Somerset coast
EDF Energy	Sizewell B	1198	Nuclear	Suffolk coast
EDF Energy	Cottam	2000	Coal	Nottinghamshire
EDF Energy	West Burton A	2000	Coal	Nottinghamshire
EDF Energy	West Burton B	1305	Gas	Nottinghamshire
Eggborough Power	Eggborough	2000	Coal	E Yorkshire
E.ON UK	Ratcliffe-on-Soar	2000	Coal	Nottinghamshire
E.ON UK	Ironbridge	450	Biomass	Shropshire
E.ON UK	Grain	1365	Gas	East coast, Kent
E.ON UK	Connah's Quay	1420	Gas	Dee Estuary, N Wales
E.ON UK	Killingholme	900	Gas	East Coast, N Lincolnshire
E.ON UK	Cottam Development Centre	400	Gas	Nottinghamshire
E.ON UK	Enfield	400	Gas	Greater London
GDF SUEZ Energy UK-Turkey	Deeside	515	Gas	Deeside, North Wales
GDF SUEZ Energy UK-Turkey	Rugeley	1000	Coal	Staffordshire
GDF SUEZ Energy UK-Turkey	Saltend	1200	Gas Cogeneration	Hull
GDF SUEZ Energy UK-Turkey	Indian Queens	130	Fuel oil	St Austell, Cornwall
GDF SUEZ Energy UK-Turkey	Ffestiniog	360	Pumped storage	Gwynedd, Wales

GDF SUEZ Energy UK-Turkey	Dinorwig	1700	Pumped storage	Llanberis, Gwynedd, Wales
InterGen	Coryton	779	Gas	Corringham, Essex
InterGen	Rocksavage	748	Gas	Runcorn, Cheshire
InterGen	Spalding	860	Gas	Spalding, Lincolnshire
Lynemouth Power	Lynemouth	420	Coal	Northumberland coast
Marchwood Power	Marchwood	840	Gas	Hampshire coast
RWE Generation UK	Aberthaw	1586	Coal	South Wales coast
RWE Generation UK	Didcot B	1430	Gas	Oxfordshire
RWE Generation UK	Great Yarmouth	420	Gas	Norfolk coast
RWE Generation UK	Little Barford	720	Gas	Bedfordshire
RWE Generation UK	Littlebrook	1370	Oil	Dartford, N Kent coast
RWE Generation UK	Pembroke	2180	Gas	Pembroke, SW Wales coast
RWE Generation UK	Staythorpe	1724	Gas	Nottinghamshire
Scottish Power	Blackburn	60	Gas	Lancashire, North West England
Scottish Power	Rye House	715	Gas	Inland, South East England
Scottish Power	Shoreham	380	Gas	East Sussex
Scottish Power	Damhead Creek	805	Gas	Kent, South East England
Scottish Power	Longannet	2400	Coal	Fife, East Scotland
SSE	Keadby	735	Gas	Keadby, North Lincolnshire
SSE	Burghfield	45	Gas	Burghfield, Berkshire
SSE	Ferrybridge	980	Coal	Knottingley, W Yorkshire
SSE	Fiddlers Ferry	1960	Coal	Warrington, Cheshire
SSE	Medway	688	Gas	Isle of Grain, Rochester, Kent
SSE	Uskmouth	363	Coal	Nash, Newport, Gwent
SSE	Peterhead	1180	Gas	Boddam, Peterhead, Aberdeenshire
VPI Immingham	Immingham CHP	1240	Gas Cogeneration	Immingham, Humber

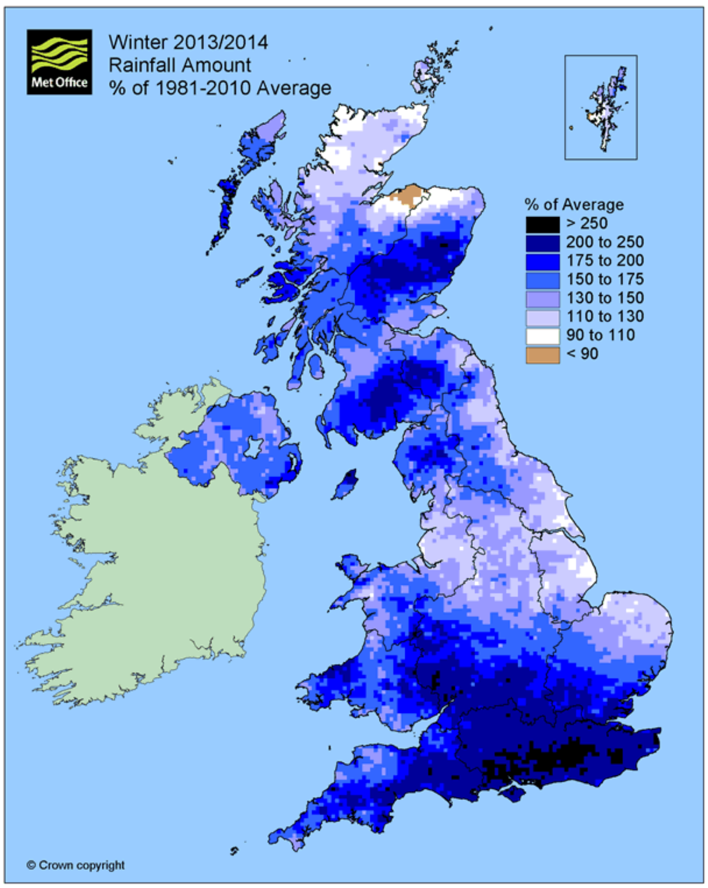
Annex 2. Winter 2013/14 weather – context and events

Rainfall

Winter 2013/14 was the stormiest period of weather for at least 20 years, bringing more days of rain than any other winter since 1961. 545mm of rain fell across the UK, beating the previous record of 485mm set in 1995. England and Wales contributed most significantly to this, as their winter rainfall was the highest since 1766.

December and January were exceptionally wet (see Figure 1), with the UK receiving 156% of December average rainfall and 155% of January average rainfall.

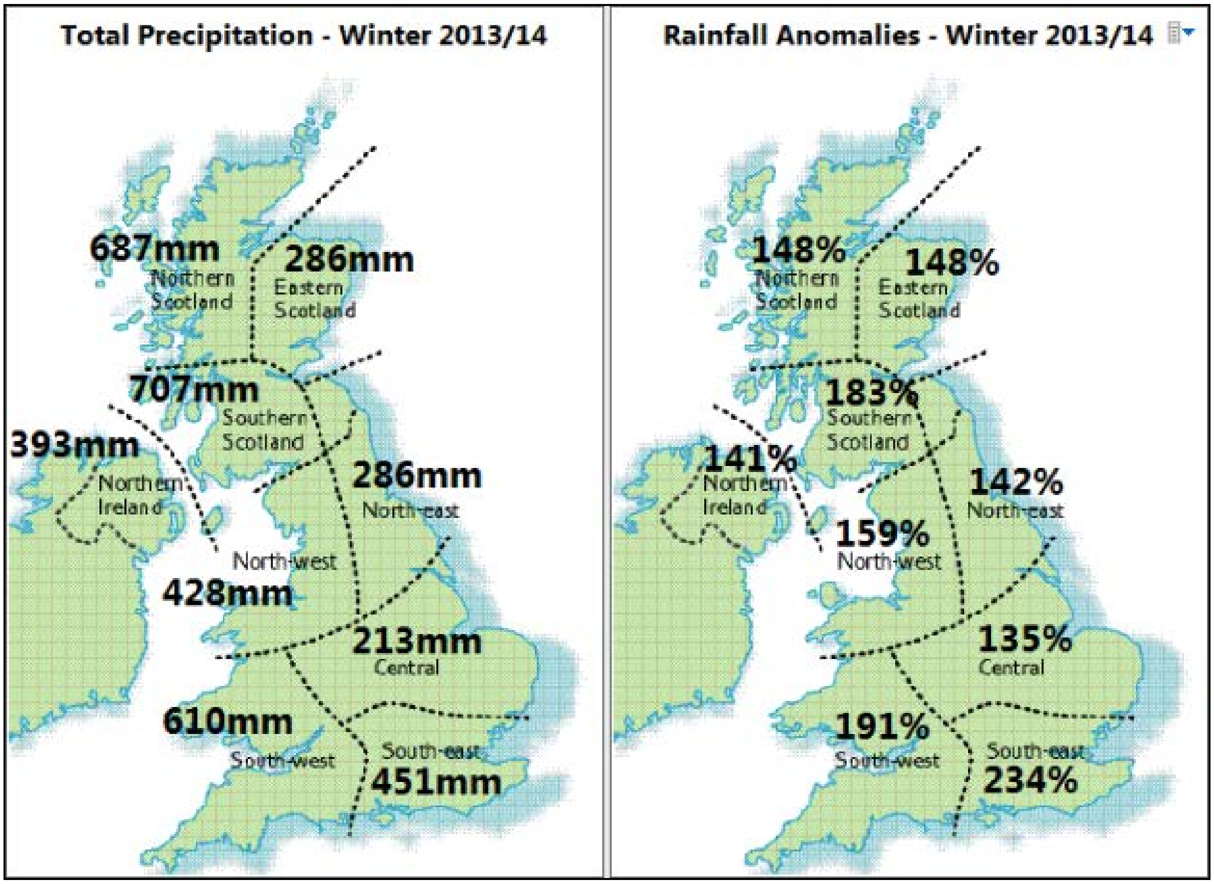
Figure 1. Rainfall for December 2013 and January 2014 from the observational network, showing the distribution of rainfall anomalies as a percentage of the long-term average from 1981-2010 (Met Office, 2014[3]).



Scotland experienced its wettest December since 1910, whilst January was drier. South East England experienced its wettest January since 1910, receiving 451mm of rainfall during the winter, 234% of the 1981-2010 average (see Figure 2).

[3] Met Office, 2014 - http://www.metoffice.gov.uk/media/pdf/n/i/Recent_Storms_Briefing_Final_07023.pdf

Figure 2. UK rainfall statistics, winter 2013/14 (xmetman, 2014[4])



These rainfall events saturated the ground and led to some of the highest river flow rates ever measured for December/January. The Environment Agency raised the Thames Barrier on 13 consecutive occasions in January. For context, in the 2000s there were 75 closures and in the 2010s there were 65 closures (as of March 2014).

Storm surges

The storms that brought extreme weather events to the UK caused a number of storm surges, predominantly along the east, west and south coasts, with severe south-westerly gales resulting in a high level of damage to coastal infrastructure. The east coast had its highest tides for 50 years and the Port of Immingham was not fully functional for two weeks after the 5-6 December storm surge as a result of electrical substations being damaged. The size of depressions in the North Atlantic contributed to the strength of the storm surges; however, their impact on the coastline was exacerbated by the antecedent rainfall, resulting in ground saturation and high river flow rates.

[4] xmetman, 2014 - http://xmetman.wordpress.com/2014/04/13/uk-rainfall-winter-201314/

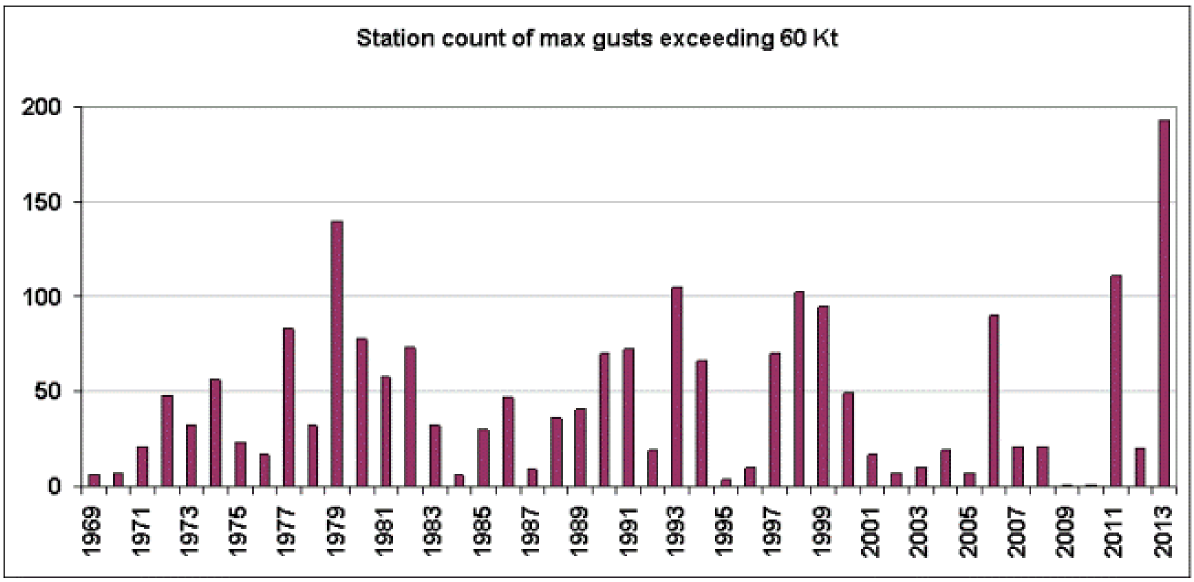
Temperature

The mean temperature for Winter 2013/14 was 5.2°C, 1.5°C above the 1980-2010 average.

Strong winds

Strong winds were experienced throughout the winter. The number of high wind gusts in December 2013 was higher than for any other December back to 1969, and the month was one of the windiest calendar months for the UK since January 1993.

Figure 3. Record of annual wind gusts (Met Office, 2014).



Timeline of major events

5-6 December

Severe storms led to the highest storm surge since the event of January 1953, submerging 6,800 hectares. The effects were felt along the east coast, with Norfolk, Lincolnshire, the Humber region and North Yorkshire particularly affected. The effects of the storms were also felt throughout the UK, in particular Scotland and North Wales. Hundreds of homes were flooded whilst many thousands of residents were evacuated. 100,000 homes lost power in Scotland and there were major effects on transport, including Scotland's rail network and flight cancellations from several major airports.

18-19 December

Western Scotland and Northern Ireland were hit by gale force winds, whilst heavy rain caused localised flooding. Several thousand homes were affected.

23-24 December

Surrey, Dorset and Kent were severely affected by storms, resulting in flash flooding. This event led to one fatality, whilst there were major transport disruptions and extensive power cuts.

26-27 December

Stormy weather and heavy rain throughout the UK cut off more residents from their energy supply and exacerbated transport disruption. Wales and Northern England were particularly affected.

30-31 December

Further rain and gale force winds throughout the UK prolonged interruptions to residents' energy supply and continued to cause transport difficulties.

3-7 January

High tides and strong winds caused flooding in the west of England, along the south coast and across Wales and Scotland. A 1 in a 5-10 year storm surge affected the west coast, with waves measuring up to 8.1m; this event caused extensive damage to coastal areas, exacerbated by antecedent rainfall. The Met Office suggest that in combination with other factors such as high river and groundwater levels this may be a far rarer event.

24-27 January

Heavy rainfall and strong winds affected the northern and eastern parts of the UK, resulting in flooding.

5-6 February

Storms in south west England caused widespread damage, destroying part of the rail line at Dawlish that connects London with the south west, and left approximately 44,000 residents cut off from energy supplies.

10-14 February

Hurricane force winds left nearly 150,000 homes without energy in southern England and caused damage nationwide.

*Note: Plant type is indicative and may not apply to some installations for site-specific reasons

Annex 3. Common list of hazards assessed by reporting companies

No	Climate Change Hazard	Plant type*	Potential consequences for plant
	Flood and storm surge		
1	Flooding of Site	All	Possible generation unit shutdown; water damage to infrastructure on a variety of scales; pipeline fracture due to erosion
2	Flooding of Access Routes to Site	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
3	Flood Events & Extreme High River Flow	All	Higher maintenance
4	Storm Surges	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
	Extreme high temperature		
5	Extreme High Temperature on Steam Turbine	CCGT, Coal	Performance drop / capacity loss
6	Extreme High Temperature on Gas Turbine	CCGT, GT	Performance drop / capacity loss
	Climate hazards affecting water use		
7	Extreme High Temperature on Water Discharge	All	Load reduction to respect discharge limits
8	Drought on Water Availability	All	load reduction, increased water treatment plant usage
9	Drought on Water Discharge (Permitting)	All	Load reduction to respect discharge limits
10	Drought & Change in Water Abstraction Legislation	CCGT, Coal	New permit conditions, additional operational constraints, load restrictions
	Other climate hazards		
11	Extreme Snowfall	All	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
12	Extreme Low Temperature on Cooling Tower Fans	CCGT	Constraints in performance
13	Extreme Low Temperature on External Systems	All	Additional maintenance / repair; emergency water supply
14	Extreme Low Temperature on Cooling Tower	CCGT, Coal	Ice build-up on unloaded cooling tower and risk of packing collapse
15	Extreme Winds	All	Damage to installations; Health & Safety
16	Weather Conditions Causing Plume Grounding	CCGT, Coal	Hazards and complaints; additional restrictions
17	Subsidence / Landslide	All	Damage to infrastructure and pipelines on a variety of scales

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