Energy UK

The voice of the energy industry

A Sector Overview 2021

Climate Change Risks and Adaptation Responses for UK Electricity Generation

About Energy UK

Energy UK is the trade association for the energy industry with over 100 members spanning every aspect of the energy sector – from established FTSE 100 companies right through to new, growing suppliers and generators, which now make up over half of our membership.

We represent the diverse nature of the UK's energy industry with our members delivering over 80% of both the UK's power generation and energy supply for the 28 million UK homes as well as businesses.

The energy industry invests £13bn annually, delivers £31bn in gross value added on top of the £95bn in economic activity through its supply chain and interaction with other sectors, and supports 738,000 jobs in every corner of the country.

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Acronyms and Abbreviations

AC	Adaptation Committee of the CCC (formerly the Adaptation Sub-Committee)
AEP	Association of Electricity Producers
AOD	Above Ordnance Datum
ARP1	Adaptation Reporting Power, Round 1 (2009-2011)
ARP2	Adaptation Reporting Power, Round 2 (2013-2015)
ARP3	Adaptation Reporting Power, Round 3 (2019-2021)
BECCS	Bioenergy with Carbon Capture and Storage
BEIS	Department for Business, Energy and Industrial Strategy
CCAR(1-3)	Climate Change Adaptation Report (for ARP1-3)
CCC	Climate Change Committee (formerly the Committee on Climate Change)
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture Usage and Storage
CHP	Combined Heat and Power
Defra	Department for Environment, Food & Rural Affairs
DCO	Development Consent Order
DNO	Distribution Network Operator
E3C	Energy Emergencies Executive Committee
EIA	Environmental Impact Assessment
ELV	Emission Limit Value
ES	Environmental Statement
FES	(National Grid ESO) Future Energy Scenarios
FFGWL	Future Flows and Groundwater Levels project
GB	Great Britain
GW	Gigawatt
IOAF	Infrastructure Operators Adaptation Forum
IPCC	Intergovernmental Panel on Climate Change
JEP	Joint Environmental Programme
MWe	Megawatt of electrical capacity
MWh	Megawatt hour of electrical output
NAP2	Second National Adaptation Programme (2018)
NDC	Nationally Determined Contribution (under the Paris Agreement)
NGESO	National Grid Electricity System Operator
NGET	National Grid Electricity Transmission
NIC	National Infrastructure Commission
NPPF	National Planning Policy Framework
NSIP	Nationally Significant Infrastructure Project
Ofcom	Office of Communications
Ofgem	Office of Gas and Electricity Markets
Ofwat	The Water Services Regulation Authority
PWS	Public Water Supply
RCP	Representative Concentration Pathway
READ WG	Resilience and Adaptation Working Group
SRES	Special Report on Emissions Scenarios
SWE	Severe Weather Event
TCFD	Task Force on Climate-related Financial Disclosures
TWh	Terawatt hour of electrical output
UKCCRA1	First UK Climate Change Risk Assessment (2012)
UKCCRA3	Third UK Climate Change Risk Assessment (expected 2022)
UKCIP	United Kingdom Climate Impacts Programme
UKCIP-TD	UKCIP Threshold Detector
UKCIP-WG	UKCIP Weather Generator
UKCP09	United Kingdom Climate Projections 2009
UKCP18	United Kingdom Climate Projections 2018
UNFCCC	United Nations Framework Convention on Climate Change

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Foreword

Emma Pinchbeck
Chief Executive, Energy UK

With the 2050 Net Zero target in place and a Government pinning its green colours to the mast ahead of the COP26 meeting later this year, awareness and concern about climate change have never been greater.

While much of the focus is on the efforts we must make, as nations and individuals, to limit rising global temperatures, we are already living in a world where the effects of climate change are becoming increasingly evident. Governments across the world have woken up to the urgency of the situation - which is welcome, if overdue - but however quickly we transform our economies, societies and daily lives in response, adapting to the consequences of rising temperatures will be crucial over the coming decades.

The need to adapt to a new environment is especially important for essential services like energy provision, and thankfully the sector has been somewhat ahead of the curve in thinking about the consequences of the climate crisis. This is our third report detailing how electricity generation is adapting to climate change, and we were pleased to see the recommendations and measures in this report utilised in the Climate Change Committee's official Progress Report this year.

Generation has undergone extraordinary change since we last reported in 2015. Last year, for the first time ever, renewables supplied more of our power than fossil fuels, UK carbon emissions fell to their lowest level since 1879 and we had 180 coal free days, whereas in 2015 coal was still supplying around a quarter of our power.

Our sector will be central to delivering nine of the objectives on the Prime Minister's Ten Point Plan for a Green Industrial Revolution, so our transformation will continue.

We expect huge growth in production and consumption of green electricity, growth in low carbon technologies such as offshore wind, hydrogen, nuclear and carbon capture and storage, and a more flexible system using increased distributed generation, energy storage, and smart technologies and approaches. The pace of change is, of course, dependent on market design and regulatory frameworks that enable investment in this future.

Regular risk assessments and continued investment in their power stations mean that generators have already shown significant resilience in the face of increasingly volatile weather, and extreme weather events. For new energy projects, resilience to potential risks from a changing climate are increasingly embedded in planning and permitting regimes. At a higher level of policy, we have been calling for Government to set a "net zero test" for policy decisions, and are supportive of the proposal in the Energy White Paper to look at national planning policy in light of the need to develop and maintain low carbon infrastructure.

As this report illustrates, generators have responded admirably to the challenges so far but with the demands of meeting Net Zero, and the impacts of climate change now here to stay, the responsibility is more urgent. Energy UK and its members will continue to work closely with Government, Regulators and other key industries to ensure that the power we supply to every home and business in the UK continues to flow – as we look to build a secure, resilient future economy.

"As this report illustrates, generators have responded admirably to the challenges so far but with demand for low carbon electricity multiplying on the path to Net Zero, that responsibility becomes even greater."

Summary

Energy UK has collated information on the progress made in the electricity generation sector in adapting to climate change since its second Climate Change Adaptation Report (CCAR2) was delivered in 2015. This has been undertaken at sector level within Great Britain, on a voluntary basis, in response to a request from Government under the third round of the Adaptation Reporting Power (ARP3) of the Climate Change Act (2008).

As a result of the sector's leading role in the reduction of greenhouse gas emissions, the portfolio of generating technologies in operation and the ownership of particular plant have changed markedly since 2015. Consequently, the scope of this report has been broadened from the large (>100 MWe) thermal and hydroelectric power stations considered in CCAR1 and CCAR2, to include commentaries on smaller (50 MWe to 100 MWe), distributed thermal plant and large (>100 MWe) wind turbine arrays.

In CCAR1 and CCAR2, climate change risks were quantitatively assessed by generating companies (out to 2039, which will encompass the remaining lifetime of most of the existing assets). The analysis relied on the UKCP09 climate projections, available at the time. A review by the Joint Environmental Programme has shown that, for the timeframe of interest, the conclusions of the previous assessment continue to hold under the updated UKCP18 projections, released in November 2018. For new developments, the demonstration of resilience to future climate change, undertaken as part of the planning and environmental permitting processes required for new plant, will use UKCP18.

New regulatory initiatives in the planning and environmental permitting systems since CCAR2 have served to further strengthen consideration and mitigation of climate risks at the development stage of new energy projects. Generating companies are also increasingly embracing voluntary initiatives on climate-related financial disclosure and adoption of new international standards for the management of climate change adaptation.

All adaptation actions identified in CCAR1 by the companies that were directed to report in ARP1 have been progressed and 73 of the 88 agreed actions have now been completed. This has led to a further decrease in risk, albeit from an already low base. 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 ongoing processes and plans are put in place to mitigate potential impacts, thus ensuring a flexible response to future changes in climate risk drivers.

External reviews such as the second UK Climate Change Risk Assessment in 2017 and the Adaptation Committee's progress report to Parliament in 2019 have raised no significant concerns about the adaptation response of electricity generation itself, but better understanding and management of the interdependencies between infrastructure sectors is a recurring theme. Energy UK continues to seek improvements in those areas through participation in multi-sector fora, independent studies, and through close collaboration with regulators. Despite several episodes of extreme weather since 2015, there has been only one significant loss of generating capacity; a combination of events resulted in a major power outage in August 2019. While the interruption to power supply was of relatively short duration (National Grid Electricity System Operator restored the system to normal operation within 45 minutes), the full extent of the disruption was characterised by knock-on impacts on other essential services such as rail transport.

A key area of current engagement and future uncertainty for the sector is the energy/water nexus. Existing thermal power plant will still play a valuable role in supporting the transition to a decarbonised power system and will require continuing access to sufficient water and reliable water rights in order to generate. Furthermore, future water-dependent energy projects e.g. for Carbon Capture Usage and Storage, Bioenergy with Carbon Capture and Storage, and hydrogen production, will also require sufficient, reliable access to water rights to secure future financial investment. An unintended consequence of restricting water abstraction and water rights for the energy sector could be the failure to meet the UK's target of Net Zero greenhouse gas emissions by 2050 in a timely, efficient and resilient way.

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1. Introduction

1.1 History of reporting

Electricity generation sits within the UK's broader Energy Sector alongside the complementary functions of oil and gas production, transmission and distribution system operation and energy supply/customer services. Generating companies operate in a competitive market and have well-developed approaches to risk management and business resilience. It is worth reiterating at the outset that generators have no statutory duty to produce electricity and that the investments they make are not subject to funding approval by economic regulators, as would be the case for transmission and distribution network operators.

Energy UK (and, until 2012, its predecessor the Association of Electricity Producers (AEP)) has maintained engagement with Defra on climate change adaptation over the last decade, ensuring that the sector's approach to adaptation is one which effectively manages the risks posed by climate change and ensures there are plans in place to deal with and mitigate these risks.

This is the third Climate Change Adaptation Report (CCAR) produced for the electricity generation sector under the Adaptation Reporting Power (ARP) provisions in the Climate Change Act 2008. It has been nearly six years since the publication of Energy UK's second CCAR in August 2015. For practical reporting purposes, this report covers activities in the period up to the end of 2020.

For the first round of adaptation reporting (ARP1), which took place from 2009 to 2011, nine electricity generating companies (each with an annual output in excess of 10 TWh) were identified and received Directions under the provisions of the ARP to report to Defra[1]. There was early agreement between generators and Defra that the production of a common approach to risk assessment would be beneficial to the participants. This would cover the core requirements and could be built on further by each company to suit their own needs. All reporting companies therefore adopted a common framework for risk assessment and incorporated any additional site-specific risks in their reports. AEP established a Resilience and Adaptation Working Group (READ WG) to coordinate the work of reporting companies; AEP also produced a voluntary overview of the nine company reports on behalf of the sector.

Under ARP2[2], running from 2013 to 2015, reporting was designed to help Government understand the level of capacity to adapt to climate change risks at the sector level, using the lessons learnt from ARP1. Information provided by generators on a voluntary basis, which was collated and submitted by Energy UK, helped to inform the Government's subsequent Climate Change Risk Assessment published in 2017 and an update of the National Adaptation Programme in 2018. The submission included a report on progress companies had made since their original submissions in ARP1.

Following the decision by Defra not to require mandatory reporting under ARP3, and consistent with the approach taken in ARP2, Energy UK agreed to report voluntarily at sector-level again for ARP3. This approach is considered to give a more meaningful overview of progress as the plant portfolios of the original nine reporting companies in ARP1 have changed significantly since 2011, due either to new plant development or sale or closure of existing assets. It also provides an opportunity to draw on the experiences of a larger number of generating companies.

Electricity generation has also undergone significant changes since the publication of the sector's previous reports; further detail is provided in Section 1.2.

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[1] https://www.gov.uk/government/publications/adaptation-reporting-power-received-reports

[2] Energy UK (2015) Climate change risks and adaptation responses for UK electricity generation: A sector overview 2015. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/478938/clim-adrep-energy-uk-2015.pdf

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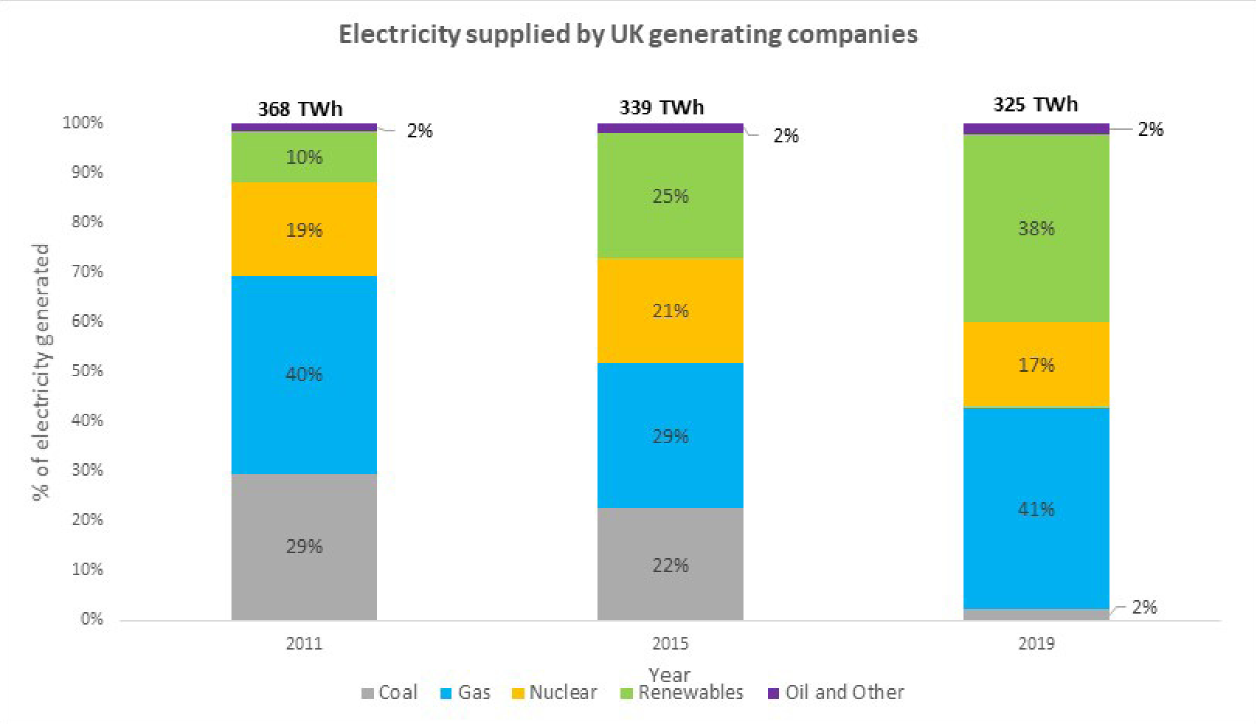
1.2 Sector profile

Electricity generation is currently in the process of an unprecedented transition to a low carbon electricity system and by 2019 the energy sector had reduced its greenhouse gas emissions by 62.8%[3] since 1990. This drive towards decarbonisation has really accelerated over the last three to four years, causing profound changes in the energy sector as a result of sharp declines in the use of some technologies and the emergence of others.

For example, in 1990, coal-fired generation represented 65% of the electricity produced, whereas it only provided 2% in 2019. Conversely, low carbon energy sources like nuclear and renewables accounted for 55% of electricity generation in 2019, up from 22% in 19904. Renewables' share alone reached a record high level of 38% of total UK electricity generation in 2019. The change in generation mix since the sector's first CCAR submitted in 2011 can be seen in Figure 1, below.

Figure1. Electricity supplied by UK generating companies (from BEIS (2020)[5]).



The substantial increase in market penetration of intermittent renewable generation has also increased the need for flexible plant, able to provide electricity on demand (often at short notice), where and when it is required (e.g. at times of low renewable output and high demand). This has driven the deployment of small/medium sized flexible plant, often connected to the regional distribution network and referred to as 'distributed generation' (see Section 3) to complement the larger plant, which are typically connected to the higher voltage transmission network (see Section 2).

These trends are expected to progress following the introduction of the legally-binding UK target of Net Zero greenhouse gas emissions by 2050 into the Climate Change Act in June 2019, strengthening the UK's previous goal to reduce emissions by 80% by 2050.

[3]Department for Business, Energy & Industrial Strategy (2021) 2019 UK Greenhouse Gas Emissions, Final Figures. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957887/2019_Final_greenhouse_gas_emissions_statistical_release.pdf

[4]Department for Business, Energy & Industrial Strategy (2021) 2019 UK Greenhouse Gas Emissions, Final Figures. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957887/2019_Final_greenhouse_gas_emissions_statistical_release.pdf

[5]Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2020

1.3 Scope of the assessment

As noted in Section 1.2, since ARP1 in 2011, there have been substantial changes to the UK's generation mix in terms of the increased presence of renewable technologies and small to medium sized generation assets connected to regional distribution networks (distributed generation) instead of to the national transmission network. To take into account these trends and to deliver a representative report for this latest assessment, it was agreed, following a period of discussion both internally and with Defra, that the scope should be broadened to include not only large thermal and hydroelectric generating plant over 100 MWe capacity at individual site level, but also wind turbine arrays and distributed generation assets.

Given that the UK's total wind generating capacity increased by 19 GW from 5.4 GW in 2010 to 24 GW in 2019[6], wind turbine arrays over 100 MWe capacity, both onshore and offshore, are addressed qualitatively within this report (see Section 4) by detailing the measures and design specifications that ensure adaptation to climate change.

Similarly, by agreement with Defra, the report addresses the increase in generation assets connected to the regional distribution networks. From 2011 to 2019 the GB transmission-connected capacity reduced by approximately 10% (from 78 GW to 69 GW), mainly due to closures of coal-fired and older gas-fired plants, only partially compensated by the increase in transmission-connected renewables capacity. Over the same timeframe, the distribution-connected capacity has, in contrast, more than doubled (from 15 GW to 31 GW), mainly due to the deployment of renewables[7]. This report therefore provides a qualitative explanation of the steps taken by operators of generation plant between 50 MWe and 100 MWe to adapt to the effects of climate change (see Section 3).

It was also agreed not to further consider large combustion plants that have been granted a 'Limited Life Derogation' under the Industrial Emissions Directive (and must therefore close by December 2023), or coal-fired power stations which will not run beyond the UK Government's current coal phase-out deadline of October 2024.

Geographical scope is consistent with previous reporting, covering sites in England, Scotland and Wales which participate in the Great Britain (GB) electricity market, but most of the principles could be applied equally to sites in Northern Ireland.

The chosen timescale for the assessment is based on projections looking out to 2039, as this represents a realistic period for the continued operation of existing plant. For new plant, climate change adaptation and resilience is already embedded in planning and environmental permitting processes (see Section 2.2).

[6]Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020, Chapter 6: statistics on energy from renewable sources. Available at: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

[7]Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020, Chapter 5: statistics on electricity from generation through to sales. Available at: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

2. Large thermal and hydroelectric power of plant (>100 MWe)

2.1 Description of plants

As highlighted in Section 1.2, there have been substantial changes to the UK's generation mix since ARP1 in 2011 and ARP2 in 2015. These changes are set to continue as the transition of the energy system progresses and evolves in ways which cannot always be predicted. This report therefore recognises the increased deployment of renewable technologies and distributed generation and omits those larger thermal plant which have closed, or are due to shut down in the near future. The resulting scope therefore acknowledges in Section 3 the increase in generation assets connected to the regional distribution networks and outlines the steps taken by operators of generation plant between 50 MWe and 100 MWe to adapt to the effects of climate change. Similarly, it encompasses wind turbine arrays, both onshore and offshore, which are addressed in Section 4 by a narrative explanation of the measures and design specifications that are used to accommodate climate change.

This section provides a description of thermal and hydroelectric generating technologies over 100 MWe capacity at individual site level that remain in scope, with the exception of combustion plants that have been granted the 'Limited Life Derogation' under the Industrial Emissions Directive (and must therefore close by December 2023) and coal-fired power stations, which will not run beyond the UK Government's current coal phase-out deadline of October 2025.

Within these parameters, and looking only at plant in GB, this section covers the following technologies at sites equal to, or exceeding, 100 MWe capacity: Combined Cycle Gas Turbine (CCGT), biomass combustion, Combined Heat and Power (CHP), nuclear and hydroelectric power. The combination of these technologies encompasses 16 companies, owning 67 plant and totalling 48.4 GW of capacity which equates to 62% of the UK's total electricity generating capacity (78 GW in 2019[8]).

This large plant category, excluding wind turbine arrays, has been reviewed according to performance against the risk assessment matrices of the sector's CCAR1 and CCAR2, outlining the developments in understanding and mitigation of climate change risks since then. Companies who were not involved in the previous ARP1 and ARP2 reporting rounds but own generating stations above 100 MWe will need to address the risks they face by conducting the same type of risk assessment undertaken in previous rounds.

Thermal power stations are dependent for their operation on delivery infrastructure for fuels, 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 weather and climate conditions on a combination of generation technologies or components: gas turbine, boiler, steam turbine, auxiliary systems and cooling systems.

Hydroelectric power and hydro pumped storage sites are also dependent on climatic factors such as the availability of flowing water as a source of kinetic energy harnessed to create electricity. Seasonal variations in precipitation and long-term changes in precipitation patterns, such as droughts, can have large effects on the performance of hydropower production.

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 weather conditions and climate change for its business. The following descriptions and diagrams illustrate the various components of power stations that could potentially be exposed to climate change risks (as outlined in the list of climate hazards in Table 1, in Section 5.2) and therefore increase the plant's vulnerability to climate change impacts.

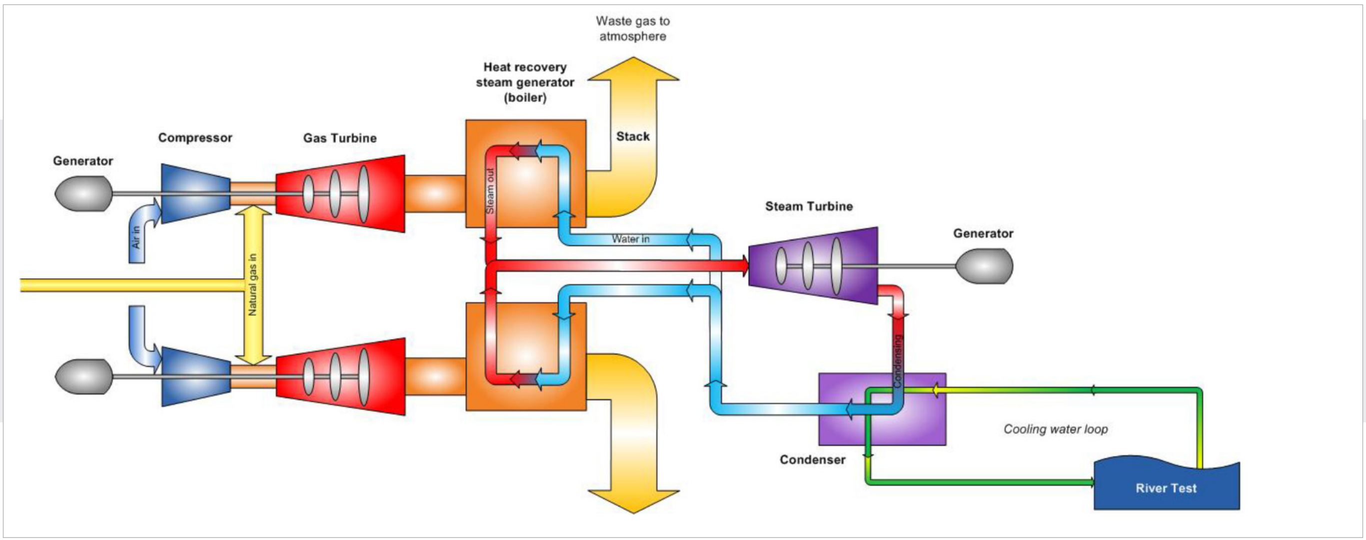
[8]Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/924591/DUKES_2020_MASTER.pdf

Combined Cycle Gas Turbine (CCGT)

In 2019, CCGT stations produced 40.4%[9] of the UK's electricity. In the case of a gas-fired power plant (see Figure 2) 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 order to make best use of the heat in the exhaust gases, the hot gases are generally used to raise steam in a boiler. This high-pressure steam is then used to generate further electricity. For cooling, gas-fired stations rely on once-through (direct) cooling, cooling towers or air-cooled condensers. Cooling water plays an important role in the efficiency of the electricity generation process.

By-products of thermal power stations must be considered in both the design and operation of the plant. Exhaust gases are usually released to atmosphere via tall stacks to aid dispersion.

Figure 2. Schematic of a Combined Cycle Gas Turbine (CCGT) power station.

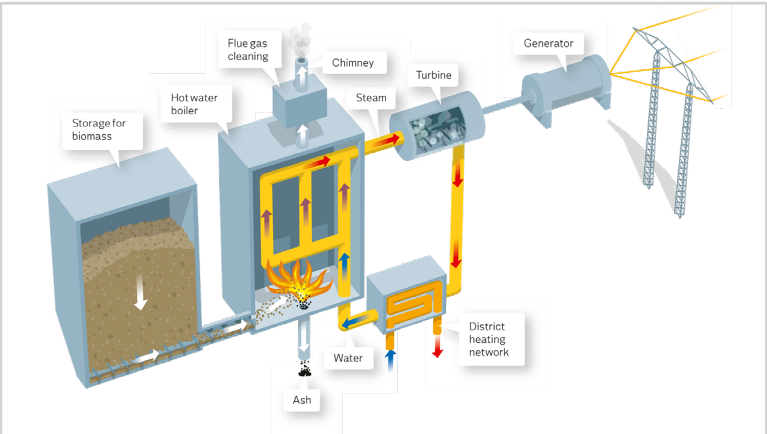


Source: Marchwood Power

Biomass combustion

In 2019, biomass accounted for 7.3%[10] of total UK electricity generation. Biomass is organic material which has stored sunlight in the form of chemical energy. Biomass fuels include wood, wood waste, straw, manure, sugar cane and many other residues from a variety of forestry and agricultural processes. In a biomass power plant, fuel (most commonly woodchips or pellets) is combusted to heat the boiler, the high-pressure steam then drives a turbine which spins a generator to produce electricity. Direct combustion (or 'direct-fired') systems burn biomass in boilers to produce high-pressure steam. To increase the energy-producing efficiency of direct combustion, power plants can also operate cogeneration facilities, where waste heat or 'secondary' steam is captured and used for industrial processes (such as ethanol production or drying of chemical and wood products, also see CHP, Figure 4) or for space heating of buildings.

Figure 3. Schematic of a biomass power plant.



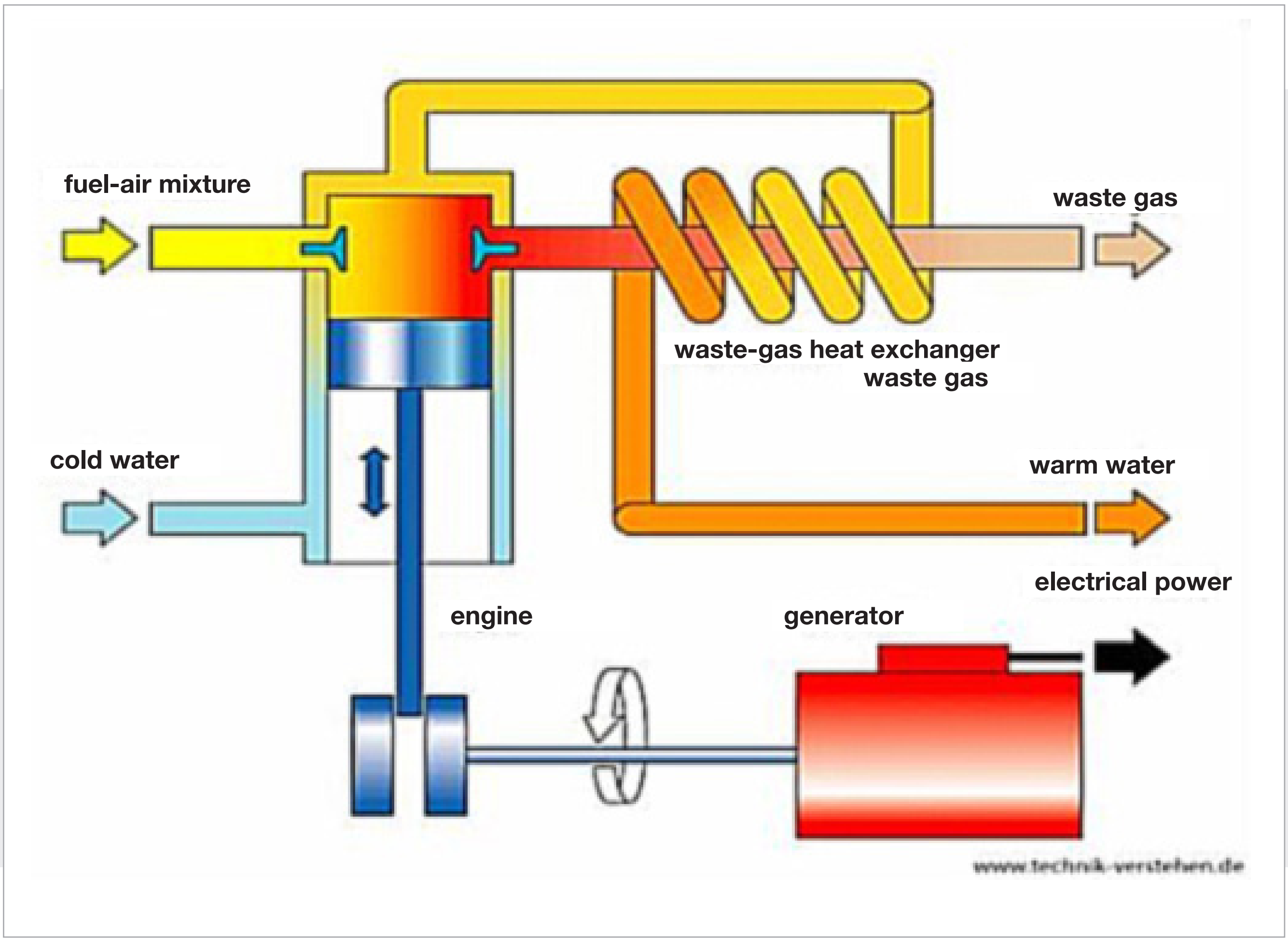
[9] Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/924591/DUKES_2020_MASTER.pdf

[10] Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/924591/DUKES_2020_MASTER.pdf

Combined Heat and Power (CHP)

In 2019, CHPs provided 11.7% of major power producers' thermal electricity generation and 62.2% of thermal autogeneration[11,12]. A CHP plant enables the production of both electricity and usable heat in a single process, as illustrated in Figure 4 below. This process can use a variety of fuels and technologies across a wide range of sizes and applications. The basic elements of a CHP plant comprise one or more of the following: a boiler, a gas turbine, a reciprocating engine, a Rankine Cycle turbine. These all drive electrical generators, with the heat generated in the process captured and put to further productive use such as (depending on the size of the plant) for industrial processes, hot water and space heating or cooling (via absorption chillers).

Figure 4. Schematic of a Combined Heat and Power (CHP) plant process.



Source: Responsible Business- European e-Learning Module

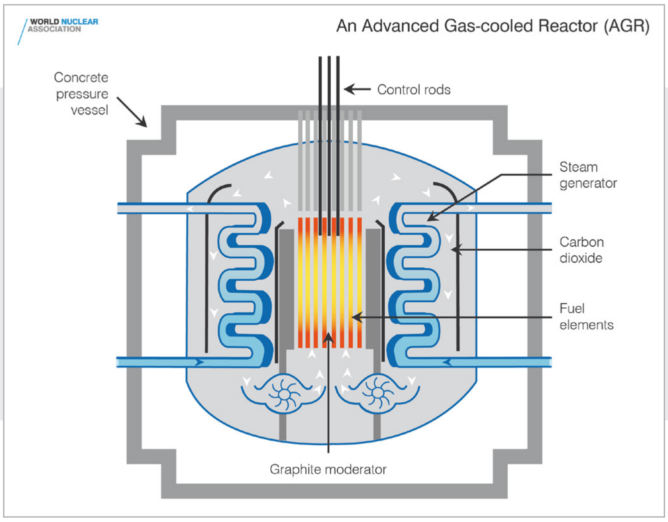
[11] Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020, Chapter 5: statistics on electricity from generation through to sales. Available at: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

[12] Autogenerators produce electricity as part of their manufacturing or other commercial activities, principally for their own use.

Nuclear

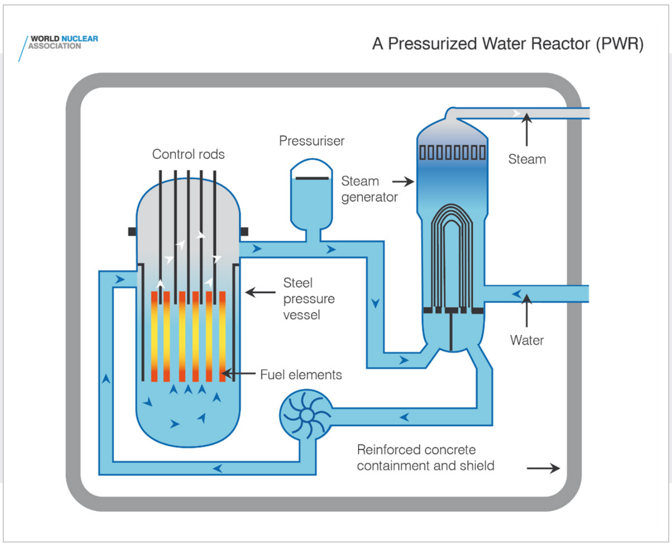
In 2019, nuclear power stations produced 17.3%[13] of the UK's electricity. Power is produced from a nuclear plant by using the heat generated by nuclear reactions to raise steam which then drives a turbine and generator. Seven of the eight operational nuclear power stations in the UK are driven by an Advanced Gas-Cooled Reactor (AGR, see Figure 5).

Figure 5. Schematic diagram of an AGR nuclear power station.



The most recent nuclear power station built in the UK, Sizewell B, and the largest currently under construction, Hinkley Point C, are driven by a Pressurised Water Reactor (PWR, see Figure 6).

Figure 6. Schematic diagram of a PWR nuclear power station.



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

Many UK nuclear power stations are reaching the end of their operational lives and will gradually close over the next few years, with all but one expected to cease production by 2030[14]. Several companies have plans to build a new generation of reactors.

[13] Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020, Chapter 5: statistics on electricity from generation through to sales. Available at: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

[14] https://www.edfenergy.com/energy/nuclear-lifetime-management

Hydropower

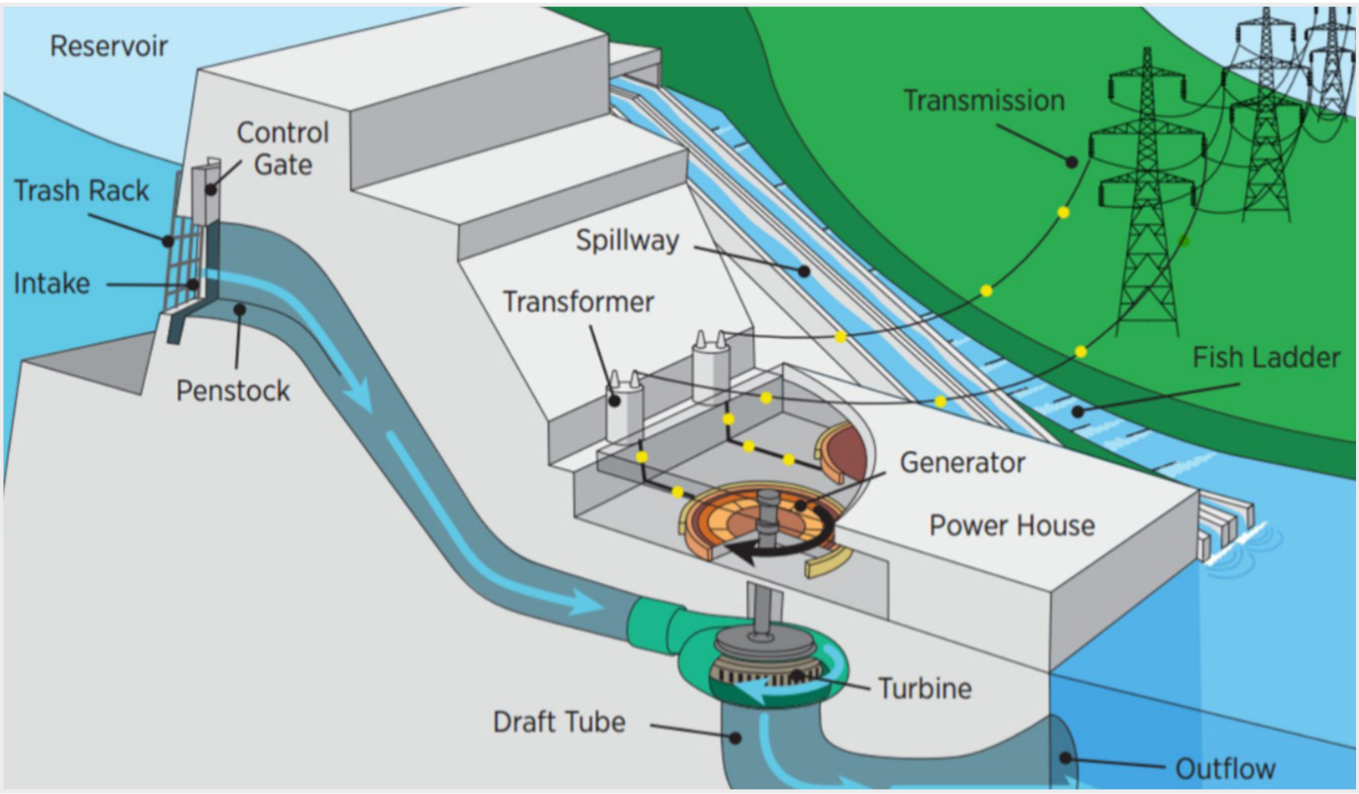
In 2019, hydroelectric power, not including pumped storage, accounted for 4.9% of the UK's total electricity generation15. Hydropower is generated using flowing water; consequently, hydroelectric power plants are usually located on or near a water source. The volume of the water flow and the change in elevation – or fall (often referred to as 'head') – determine the amount of energy that is available for conversion to electricity. In general, the greater the water flow and the higher the head, the more electricity a hydropower plant can produce.

There are four main types of hydropower:

- **Dams** - the most common type of hydroelectric power, using dams to contain and channel the water to drive the turbines (see Figure 7).
- **Pumped storage** - this method requires the moving of water between reservoirs at different elevations and is able to provide electricity 'on-demand' (see Figure 8). Water from a lower reservoir can be pumped to a higher level at times of low demand when electricity is relatively cheap.
- **Run of the river** - typically used for smaller generation, where water flowing downstream is used as it passes. This method relies on a constant supply of water to be effective.
- **Tidal power** - using the predictable movement of tides, large amounts of energy can be created twice a day. Reservoirs here can also be used to generate power during high demand periods.

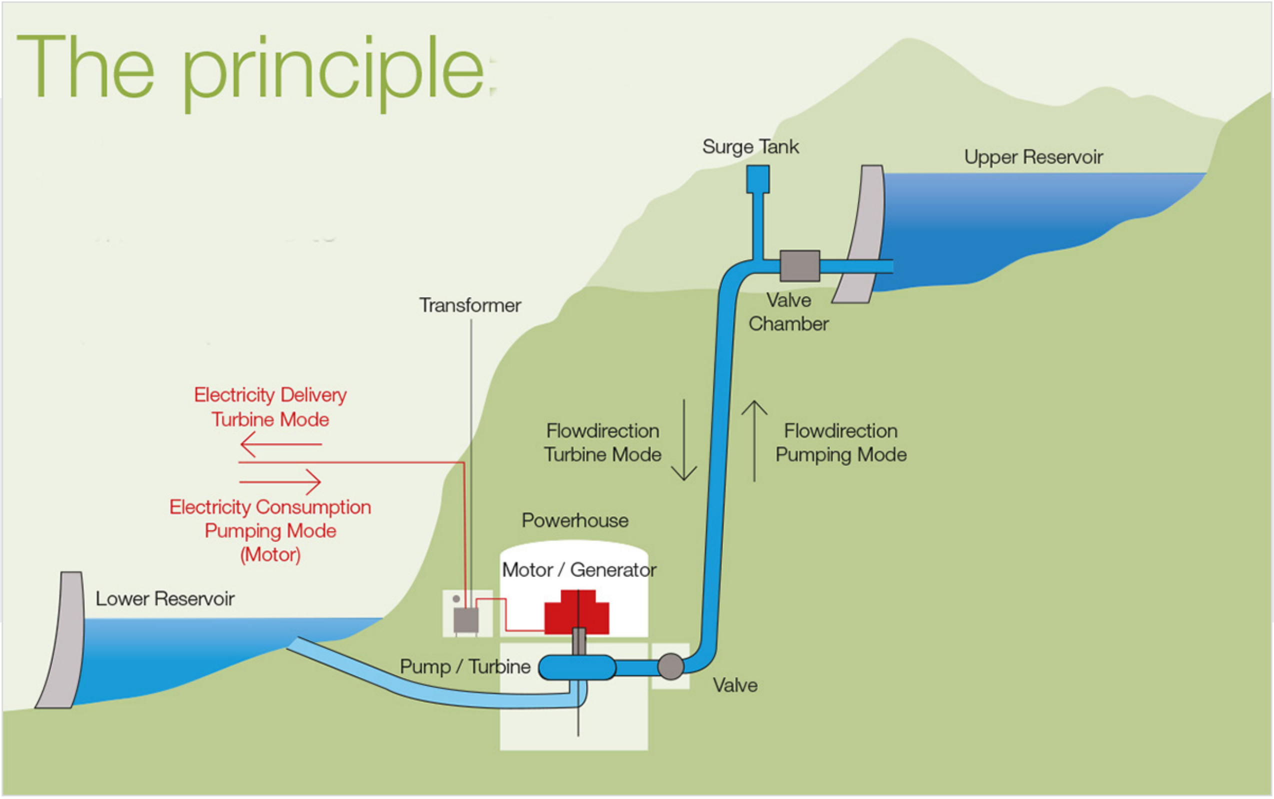
At hydropower plants, water flows through a pipe, or penstock, then pushes against and turns blades in a turbine to spin a generator to produce electricity.

Figure 7. Diagram of a hydroelectric dam.



[15]Department for Business, Energy & Industrial Strategy (2020) Digest of United Kingdom Energy Statistics 2020, Chapter 6: statistics on energy from renewable sources. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904823/DUKES_2020_Chapter_6.pdf

Figure 8. Diagram of a hydro pumped storage process.



2.2 Planning and permitting requirements

It is worth noting that, for a new large installation, or a major upgrade of an existing asset, consideration of climate change impacts is incorporated in the early stages of its development. Since ARP1 and ARP2, there have been several advancements in embedding climate change adaptation via adherence to the National Policy Statements for the energy industry as well as through new rules under the planning system and the Environmental Permitting Regime.

Due to recent changes to Environmental Impact Assessment (EIA) Regulations, energy infrastructure above a certain capacity is required to provide climate change risk assessments to the Planning Inspectorate as part of their planning application. This is covered in more detail in Section 8.3.

Existing regulations governing the sector, 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 to accommodate a changing climate.

In terms of mitigation, the requirement to participate in the EU Emissions Trading Scheme (and, from 1 January 2021, the UK Emissions Trading Scheme, following the UK's exit from the EU) and being subject to the Carbon Price Support tax on fossil fuels for generation since 2013 provide further economic incentives to minimise carbon emissions.

In terms of adaptation, from 1 December 2019, the Environment Agency introduced new procedures and revised its permit application forms and guidance on incorporating climate change adaptation risk assessment into the Environmental Permitting Regime. This is covered in more detail in Section 8.4.

2.3 Corporate risk and Environmental Management Systems

Operators of large plant have well-developed approaches to risk management and business resilience, and are accustomed to using environmental management systems. The International Organisation for Standardisation's (ISO) ISO 14001[16] is the world's most recognised standard that helps companies and organisations to identify and mitigate their impact on the environment. In 2015, ISO 14001 was revised to become a framework to protect the environment and respond to changing environmental conditions in balance with socio-economic needs.

ISO 14001 now requires organisations to consider environmental conditions that are capable of impacting an organisation as much as those impacts an organisation can have on the environment. An organisation needs to determine the risks and opportunities these conditions pose and develop plans to deal with these risks e.g. water shortage or flooding.

Climate change and adapting to climate change are now fundamental parts of a company's management systems and the companies operating large power stations have their environmental management systems certified to ISO 14001:2015.

While this standard has been a long-standing guidance tool employed by the sector in terms of delivering best practice and plans for environmental management, more recently ISO standards have been developed which specifically target climate change adaptation in organisations' business plans. These newer standards, the most notable of which is ISO 14090 'Adaptation to climate change - Principles, requirements and guidelines', and the framework they provide for developing climate adaptation best practice, are covered in more detail in Section 8.5.

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 costly disruption. Among the managed risks, power station operators proactively address potential specific vulnerabilities to extreme weather events (e.g. temperature extremes, 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 already recognised. These risks are consequently identified in Business Impact Assessments and Continuity Plans and are already analysed, treated, reported, reviewed, monitored and audited under existing corporate risk management procedures.

[16] https://www.iso.org/standard/60857.html

3. Smaller thermal plant (50 MWe to 100 MWe)

Section 1 of this document describes the significant changes that have happened to the UK's generation mix as a result of developments in the energy market, the growth of renewables and the need for flexible generation. These in turn have seen the growth of distributed generation, using smaller plants than the conventional large-scale power plants described in Section 2. These smaller plants have not been included in previous rounds of the adaptation reporting process and are included in this report to help to demonstrate the changing nature of the industry and how adaptation is being delivered across the wider sector.

This section covers plants that are connected to the regional distribution networks, which help to provide an additional level of generation to the large-scale power plants feeding the national transmission network. These smaller plants are also located in a number of different regions of the UK, thus providing geographical diversity against localised weather-related events. The combination of centralised generation and distributed generation helps to support the adaptive capacity of the UK electricity generation industry.

For smaller plants, climate change adaptation is factored into the design via the planning process. Section 8.3 provides further details of the planning framework, showing how adaptation to and mitigation of climate change forms one of the core principles underpinning the planning process. The combination of controls, guidance and requirements set out in the planning system ensure that a proactive approach to mitigating and adapting to climate change is included in the selection of the location for developments. Planning requirements therefore influence the design of the proposed installation and new installations have to take into account, where necessary, the long-term implications of factors such as flood risk, coastal change, water supply and rising temperatures.

Case Study

Adaptation by design – protection against flooding at Centrica Brigg Ltd

In 2017, Centrica started construction of a new, fast response, 49.9 MWe gas-fired power generation facility at the Brigg power station site in North Lincolnshire.

Five new high-efficiency gas engines have been installed capable of delivering full power in under two minutes from receiving a signal to commence operation. This flexibility helps to add resilience to the generation industry by being able to respond to sudden changes in generation by intermittent renewables sources or other changes in supply/demand for electricity.

Prior to starting construction, a detailed flood risk assessment for the project was completed. This assessment included allowances for the effects of climate change. Following a detailed evaluation, it was concluded that mitigation measures were required to minimise the risk from flooding. The assessment was included in the planning permission for the development and required the raising of critical infrastructure (such as the engine house) to a minimum level of 4.0 metres AOD. This elevated platform gives protection to the operations now and in the future and is a demonstration of climate change adaptation by design.

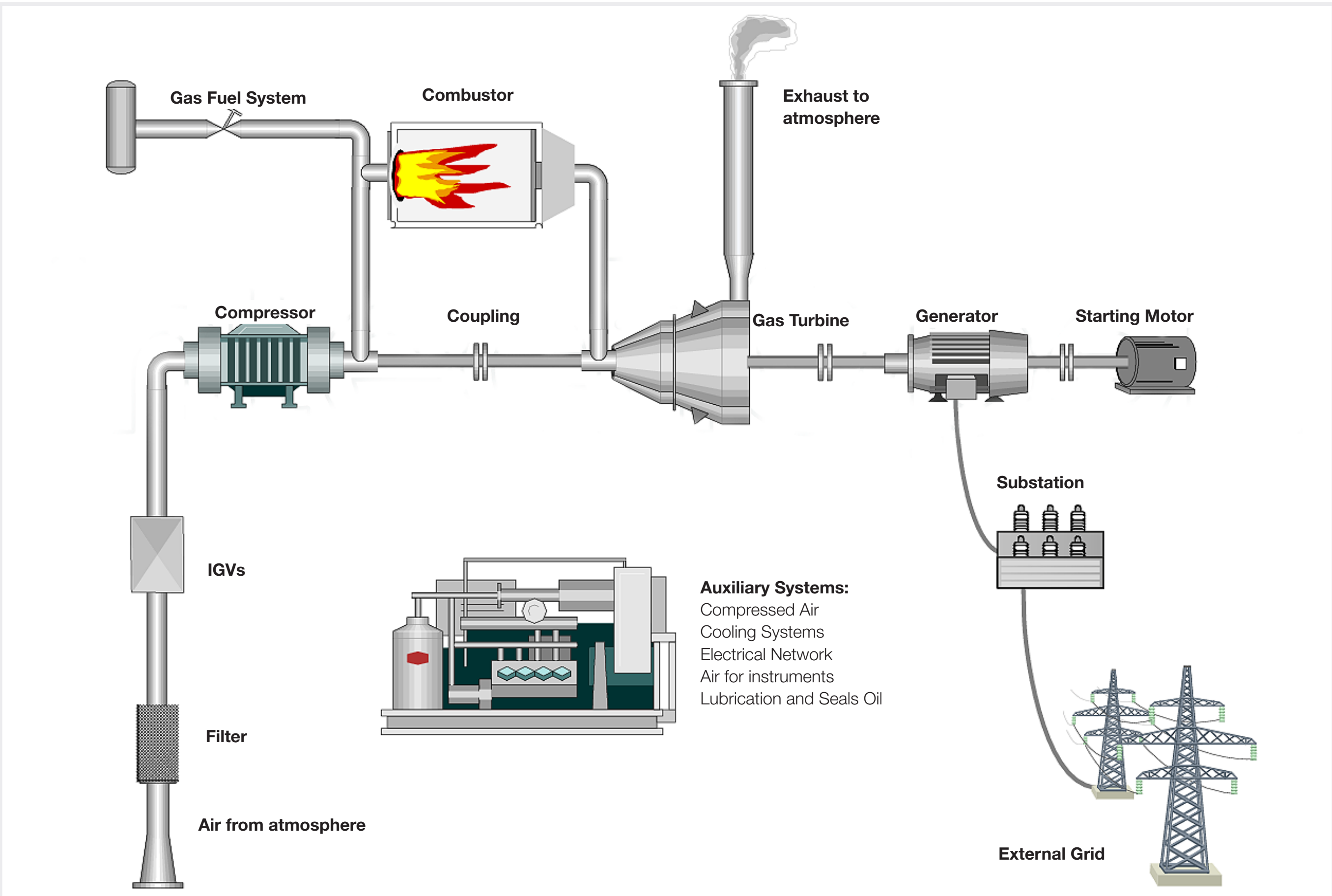
Distributed generation is typically provided by Open Cycle Gas Turbines (OCGT) and reciprocating engines, but this class of plant also covers small-scale Combined Heat and Power (CHP) plants where the plant size has been optimised to match local requirements including heat demand.

Both OCGTs and reciprocating engines can be fired with natural gas or liquid fuel (diesel). These plants typically provide a peaking plant/backup role to supplement other forms of generation and are characterised by the ability to generate at short notice with shorter start-up periods than large-scale plant. It is possible to reach full power within a couple of minutes of receiving a signal to commence generation. The ability for fast start is aided by the fact that these units are single cycle operation without the need for steam cycles, thus reducing the complexity of operation, the cooling water requirements and the associated raw materials.

Open Cycle Gas Turbine (OCGT)

OCGTs in this power output range are typically aeroderivative gas turbines, which are based on jet engines used on aircraft. Industrial gas turbines which are typically larger and heavier can also be used. Air is compressed and burnt with a liquid or gaseous fuel. The resulting hot gases (exhaust) form the working fluid in a gas turbine. This is expanded to produce mechanical power which is used to turn the compressor and drive an electrical generator. The hot exhaust gases from the gas turbine are then discharged to air. This single cycle operation, illustrated in Figure 9 below, enables a faster start, shutdown and load change capability than a CCGT power plant.

Figure 9. Schematic diagram of an Open Cycle Gas Turbine.



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Reciprocating Engine

Reciprocating engines can be fired with natural gas or liquid fuel (diesel). The fuel is combusted with air to produce hot gases that are used to drive a piston up and down. The motion of the pistons is then used to drive a generator and produce electricity. The principle of operation is similar to that of any four-stroke diesel engine in a car. A schematic diagram of a diesel engine is shown below in Figure 10. Multiple single engines are often grouped together to form an installation. An example of an installation consisting of a group of five gas engines is shown in Figure 11 below.

Figure 10. Schematic diagram of a diesel engine plant.

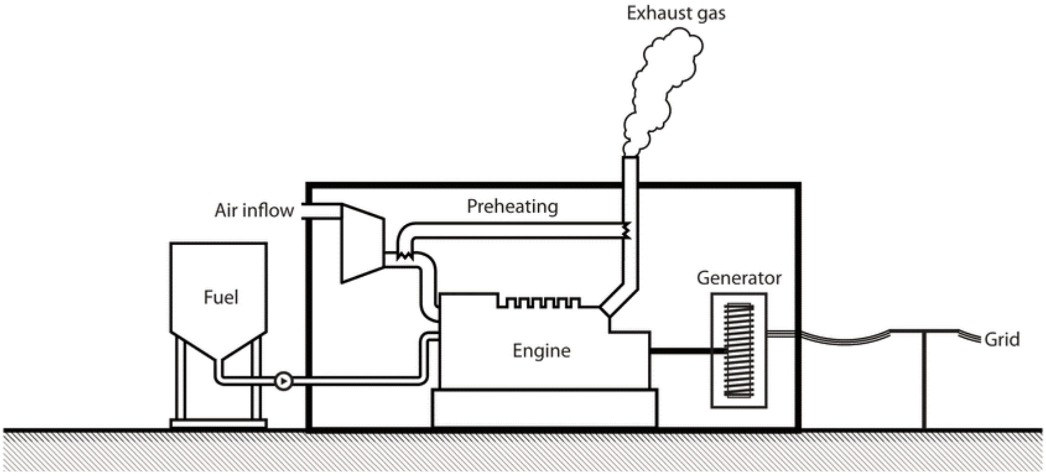
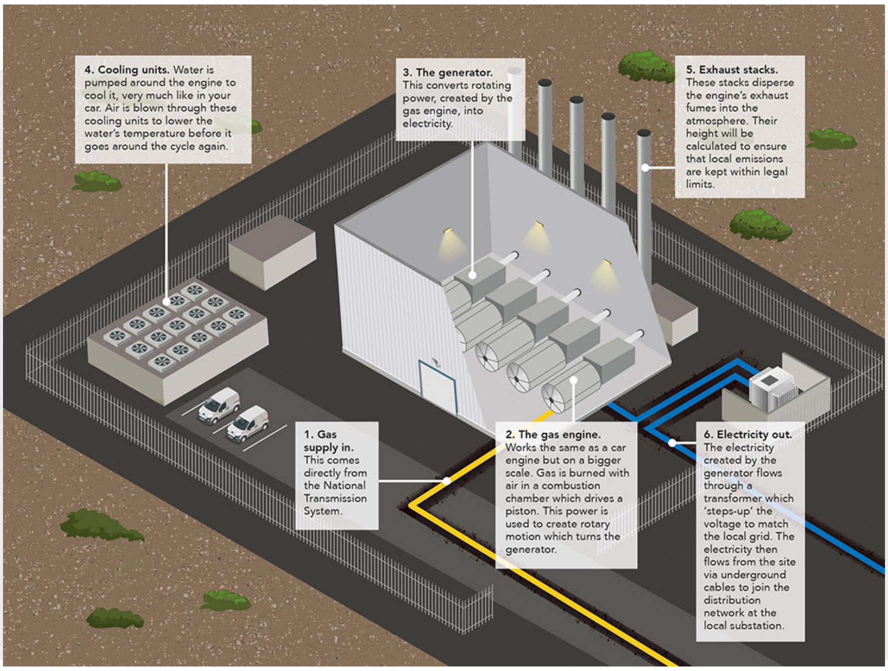


Figure 11. Example of a gas engine distributed generation plant.



Source: Centrica

Combined Heat and Power (CHP)

In addition to OCGTs and reciprocating engines, distributed generation also includes small-scale CHP plants, where the plant size has been optimised to match local requirements including heat demand. As described in Section 2.1, a CHP plant enables the production of both of electricity and usable heat in a single process. This process can use a variety of fuels and technologies across a wide range of sizes and applications. The basic elements of a CHP plant comprise one or more of the following elements: a reciprocating engine, a gas turbine, a Rankine Cycle turbine. These all drive electrical generators, with the heat generated in the process captured and put to further productive use, such as for industrial processes, hot water and space heating or cooling (via absorption chillers).

4. Wind turbine arrays (>100 MWe)

As is the case for the smaller thermal plant described in Section 3, large wind turbine arrays (also commonly referred to as wind farms) are covered in this round of reporting for the first time because they now make a significant and growing contribution to UK electricity production. Energy UK member companies associated with large-scale onshore and offshore wind generation (taken as arrays >100 MWe for this report) design, develop, construct and operate their assets in the knowledge that all wind turbines are subject to external environmental conditions and forces over their lifetime, which may affect their loading, durability and operation.

Wind farms are typically consented for an operational lifetime of 25 years. Given that many of the earlier consented schemes will soon reach the end of their operational life, repowering for such sites is set to be a realistic and viable option to maintain and significantly increase energy output yields from the same locations. The repowering of a site requires a new planning application and EIA, and is subject to the same consultation and application processes, and determinations as that for new wind farm sites. However, the turbine industry has matured significantly over the last 15 years, giving smaller powered sites a real opportunity to upgrade and extend their operational life with vastly increased MWh energy outputs. To ensure optimum longevity and productivity of a wind farm, the wind analysis and modelling outlined below is equally applicable for a new site and the repowering of an existing site.

Wind turbine classes

Wind turbines are designed for specific climatic conditions. IEC 61400 is an International Standard published by the International Electrotechnical Commission, which prescribes a set of design requirements to ensure the structural integrity of wind turbines. In particular, the standard is established to ensure that wind turbines are appropriately engineered to ensure their structural integrity against damage from all hazards within the planned lifetime of the asset. The standard addresses most aspects of the turbine life, from site conditions before construction, to turbine components being tested, assembled and operated.

In accordance with IEC 61400, turbine classes are determined by three parameters: the average wind speed; extreme 50-year gust; and turbulence. During the design and development phases of a new project, extensive on-site meteorological measured data is collated and monitored over two or more years. Extensive scientific and rigorous modelling of this data establishes average annual wind speed, turbulence and extreme 50-year gust (m/s) predictions for the site in question in order to determine the choice of wind turbine class and hence, the definition of blade size suitable for the specific climatic conditions. Data collection and monitoring continues throughout the construction and subsequent operational phases of a project. This investigative and analytical process is also applicable to repowering existing wind farms.

Most commonly, the IEC 61400 standard defines turbines as Class I, II or III. The turbine class is a key consideration when selecting a turbine to ensure longevity and performance e.g. preventing excessive wear at high wind sites by using shorter blades (Class I) or maximising wind energy output from lower wind speed sites with larger/longer blades (Class II and III). All turbines also have a cut-off range where certain wind speed extremes are encountered, preventing excessive turbulence and also prolonging the life of the plant. Given the site specificity of design, there is an extensive range of turbine classes in operation across Energy UK members' sites.

"...the turbine industry has matured significantly over the last 15 years, giving smaller powered sites a real opportunity to upgrade and extend their operational life..."

Other design factors

In addition to the turbine classes discussed above, civil engineering standards and designs factor in the need for resilience to climate conditions. Site tracks and hardstands are typically designed to withstand a minimum of a 1:200 year flood event. Where appropriate, an EIA will include climate change and potential coastal erosion which would, in turn, inform infrastructure design parameter details like cable routing.

Onshore turbine base foundations are below ground and thereby protected from localised surface flooding and potential structural damage. Where appropriate, flood risk assessments are used to understand the potential risk of flooding on site and how it may affect surrounding areas. A risk profile is prepared, which helps to identify any immediate and long-term constraints attributable to flood risk and drainage, and further informs design parameters.

Other design factors continued

Design parameters also take account of the impact on above ground infrastructure and access to site from changing weather conditions, including more frequent storms, increased wind speeds, sustained periods of heavy rainfall and extreme variations in air temperature. Unseasonal and changeable weather conditions also inform the scope and detail of maintenance regimes to minimise climate change impacts.

Offshore installations are subject to enduring dynamic forces such as erosion by the action of the sea. For embedded structures or cabling infrastructure, this erosive action can impact structural integrity if left untreated and is typically prevented by protective measures e.g. concrete rock mattresses on top of cabling laid along the seabed. Given the dynamic nature of operations, an adaptive management regime is an important feature of condition monitoring for engineering integrity, provided in the site's operational monitoring plans. Importantly, monitoring plans extend beyond physical parameters to cover climate change and biodiversity, including contextual monitoring for ecological surveys, which include baseline data as well as short- and longer-term data reviews.

Case Study

Dogger Bank Wind Farm – world-leading offshore development

When it is completed in 2026, Dogger Bank Wind Farm will be the largest offshore development of its kind in the world. With its powerful turbines and efficient transmission links, Dogger Bank will pioneer the latest technology to provide enough renewable electricity for more than 6 million homes, or 5% of the UK's electricity requirements.

The development, which will be located in the North Sea more than 130km from the Yorkshire coast, is being constructed in three phases known as Dogger Bank A, B and C. Dogger Bank A and B are a joint venture between SSE Renewables (40%), Equinor (40%) and Eni (20%). Dogger Bank C is a 50:50 joint venture between Equinor and SSE Renewables. SSE Renewables is the lead operator for the development and construction of Dogger Bank Wind Farm, while Equinor will be lead operator of the wind farm for the duration of its operational phase.

Wind turbines are designed for specific climatic conditions in accordance with IEC 61400, an International Standard published by the International Electrotechnical Commission. The standard prescribes a set of design requirements to ensure that wind turbines are appropriately engineered to provide sufficient structural integrity against damage from all hazards within the planned lifetime of the asset.

Dogger Bank has confirmed GE's 13 MW Haliade-X as the turbine powering the first two phases of the project. Installation of GE's record-breaking machine at Dogger Bank A and B will mark the first time the turbine has been installed anywhere in the world. Meanwhile, GE Renewable Energy has also been confirmed as preferred supplier for Dogger Bank C, with this phase of the development pioneering the upscaled 14 MW Haliade-X turbine. As well as leading the way on installation of these powerful and efficient turbines, the project is introducing new methods of transmission to the UK. Being generated so far from shore, the electricity will be transmitted via High Voltage Direct Current (HVDC) to minimise energy losses, a first for a UK wind farm, and paving the way for more efficient transmission technology for future developments so far from shore.

Onshore construction work for the first two phases of Dogger Bank began in early 2020 and will pick up pace throughout 2021 as the team puts the foundations in place over the next five years to support the transition to a Net Zero world.

Image supplied by GE Renewable Energy: an artist's impression of a Haliade-X turbine

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5. The consequences of updated UK Climate Projections for risk assessments

5.1 Introduction

The assessment of risks and opportunities of climate change undertaken by companies in the sector for ARP1 and ARP2 were presented in CCAR1 and CCAR2 respectively. The assessments were based on the UK Climate Projections 2009 (UKCP09), the best information available at the time.

Although the main hazards for electricity producers still remain the same as the ones identified in CCAR1, understanding of climate change amongst the science community has significantly increased since 2011. Greater computational resources have become available and significant improvements have been made to climate change ensemble models. In particular, from late 2018, the UKCP09 projections used to inform CCAR1 and CCAR2 were superseded by the UK Climate Projections 2018 (UKCP18). Section 4 ('*Notable differences between UKCP09 and UKCP18')* of the UKCP18 Science Overview Report[17] (Lowe *et al.* 2019) offers an initial overview and comparison of results obtained, over land, under both projections. The analysis reveals a considerable overlap between the two sets of projections and indicates a generally high degree of consistency between them. However, it recommends users who have previously applied UKCP09 results to re-examine the consequences of using UKCP18.

The aim of this section is to determine how differences between the future climate projected by the newer UKCP18 model ensemble and the now superseded UKCP09 projections might affect the conclusions from CCAR1, and whether any of these conclusions might be invalidated by UKCP18.

The review reported in this section was provided by members of the Joint Environmental Programme (JEP, a programme of research into the environmental impacts of electricity generation funded by leading electricity producers in the UK).

[17] Lowe, J.A., Bernie, D., Bett, P., Bricheno, L., Brown, S., Calvert, D., Clark, R., Eagle, K., Edwards, T., Fosser, G., Fung, F., Gohar, L., Good, P., Gregory, J., Harris, G., Howard, T., Kaye, N., Kendon, E., Krijnen, J., Maisey, P., McDonald, R., McInnes, R., McSweeney, C., Mitchell, J.F.B., Murphy, J., Palmer, M., Roberts, C., Rostron, J., Sexton, D., Thornton, H., Tinker, J., Tucker, S., Yamazaki, K., and Belcher, S. (2019) ***UKCP18 Science Overview Report***. Met Office Hadley Centre, Exeter, UK. Available at: https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf

5.2 Identification of climate change risks

As already noted in the previous CCARs, power stations have been routinely managing potential vulnerabilities to events of extreme weather (of a wide range of types and duration) and inter-sectoral dependencies. Climate change is therefore not considered to introduce a novel source of risk, but rather to affect the likelihood and severity of hazards which are currently recognised, managed, reported, reviewed, monitored and audited under existing corporate risk management procedures. In a continuing process, risks are therefore reassessed, as new information is released, and the responses updated, as appropriate.

The hazards identified and considered in the previous CCARs and the potential consequences for plant operation are briefly summarised in Table 1.

No	Hazard	Potential Consequences
	Flood and storm surge	
1	Flooding of site	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	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown
3	Flood Events and Extreme High River Flow	River water quality reduced by high levels of suspended solids, water inlets blocked by floating debris; higher maintenance
4	Storm Surges	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	Degradation of plant efficiency / net output
6	… and on Gas Turbine	Potential for 'unit trips' at extreme high temperatures
	Climate hazards affecting water use	
7	Extreme High Temperature on Water Discharge	Operational limitations to guarantee compliance with permit conditions
8	Drought and low river flow on Water Availability	Low river flows are more frequent than droughts and both may result in operational limitations due to (physical inability, water quality) or regulatory restrictions (tier / hands-off conditions in the abstraction licence).
9	Drought and low river flow on Water Discharge (Permitting)	Operational limitations to guarantee compliance with permit conditions
10	Drought and Change in Water Abstraction Legislation	New permit conditions, additional operational constraints, load restrictions. Potential pressure for changes in policy regarding resource allocation to prioritise public water supply.

Continued on next page

Table 1. List of climate hazards considered in the first CCARs (AEP 2011[18]).

<table>
<tr><th></th><th colspan="2">Other climate hazards</th></tr>
<tr><td>11</td><td>Extreme Snowfall</td><td rowspan="4">Operational limitations due to block of access routes to a site or disruption of local traffic systems which, in turn, hinder or limit access (reduced staffing levels and supply chain disruption of critical products)

Operational limitations, constraints in performance</td></tr>
<tr><td>12</td><td>Extreme Low Temperature on Cooling Tower Fans</td></tr>
<tr><td>13</td><td>Extreme Low Temperature on External Systems</td></tr>
<tr><td>14</td><td>Extreme Low Temperature on Cooling Tower</td></tr>
<tr><td>15</td><td>Extreme Winds</td><td>High wind speeds can cause parts of site equipment and structures to break loose and flying debris can then damage additional parts of the site and create a health and safety risk</td></tr>
<tr><td>16</td><td>Weather Conditions Causing Plume Grounding</td><td>'ground fogging' can then lead to hazards and complaints (mainly in relation with low level arrays of mechanical draft cooling towers)</td></tr>
<tr><td>17</td><td>Subsidence / Landslide</td><td>Damage of assets and infrastructure and pipelines on a variety of scales</td></tr>
</table>

In CCAR1, electricity generators approached their risk assessment on the timescale of relevance for the continued operation of existing assets and by making conservative assumptions and choices. UKCP09 provided climate projections for the three emissions scenarios set out in the Special Report on Emissions Scenarios (SRES) and explored in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report[19]. In CCAR1, it was decided to assess risks against the 'High Greenhouse Gases Emission Scenario - A1FI', i.e. the SRES scenario with the highest impacts on future climate and considered 'very unlikely' to be exceeded in the future.

UKCP18 uses the new set of emissions scenarios explored in the IPCC's 5th Assessment Report[20]. These scenarios, called Representative Concentration Pathways (RCPs), specify the concentrations of greenhouse gases that would result in target amounts of radiative forcing at the top of the atmosphere by 2100, relative to pre-industrial levels. The changes in the underlying emissions scenarios (from SRES to RCPs) make a direct comparison of UKCP18 with the earlier UKCP09 challenging. To analyse the potential consequences of these changes, probabilistic climate projections of both SRES scenarios and RCPs, using a single consistent framework, were undertaken by Rogelj et al. (2012)[21].

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

[19] Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team]. IPCC, Geneva, Switzerland, 104 pp.

[20] Intergovernmental Panel on Climate Change (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. ISBN 978-1-906360-03-0.

[21] Rogelj, J., Meinshausen, M. and Knutti, R. (2012) Global warming under old and new scenarios using IPCC climate sensitivity range estimates. Nature Climate Change 2, 248–253. Available at: https://doi.org/10.1038/nclimate1385

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The analysis noted that, although the RCP scenarios were not developed to mimic specific SRES scenarios, scenario pairs with similar impacts on the temperature projected over the 21st century can be found between the two sets. This is summarised in Table 2, extracted from the UKCP18 Guidance 'UKCP18 for UKCP09 users' by Fung and Gawith (2018)[22].

The UKCP09 'high emissions - A1FI' scenario used in CCAR1 would therefore yield temperature projections that are close to those of the UKCP18 scenario with highest emissions (RCP8.5). Consequently, the UKCP18 RCP8.5 scenario has been selected for the comparison of the UKCP09 and UKCP18 results. It is worth noting that the high emissions scenarios (RCP8.5 and SRES A1FI) are intended to represent a world where temperatures rise by circa 4°C by the end of the century. Under current energy and greenhouse-gas-emissions mitigation policies and international agreements, they represent therefore an extreme 'worst-case' scenario, see e.g. Hausfather and Peters (2020)[23].

Table 2. UKCP18 Emissions Scenarios, from Fung and Gawith (2018).

UKCP18 scenario	Increase in global mean surface temperature (°C) by 2081 – 2100	Most similar UKCP09 scenario (in terms of temperature)
RCP4.5	2.4 (1.7 – 3.2)	SRES B1 (low emissions scenario in UKCP09)
RCP6.0	2.8 (2.0 - 3.7)	SRES B2 (between low and medium emissions scenario in UKCP09)
RCP8.5	4.3 (3.2 – 5.4)	SRES A1FI (high emissions scenario in UKCP09)

For consistency with CCAR1, the results are cross-checked using the '2020s' (the 30 years from 2010 to 2039) as the most representative (UKCP09) timeframe for the lifespan of existing generation assets. For new build assets, the climate risk will be informed by the latest available scientific evidence and technical knowledge and managed in the environmental permit application process (see Section 8.4).

A further difference affecting a direct comparison between the two projections is the absence of the Weather Generator (UKCIP-WG) and the Threshold Detector (UKCIP-TD) tools from UKCP18. In CCAR1, these two post-processing tools were used to quantify likelihoods, under UKCP09, of Severe Weather Events (SWEs). Fung and Gawith (2018) explain that, rather than the statistical approach of UKCIP-WG/TD, UKCP18 chose to provide data from a physically-based modelling system (as this can be better evaluated against real world observations).

The use of the UKCP18 2.2km sub-daily regional projections over UK, along with the daily data provided by the UKCP18 global (60km) and regional (12km) climate model projections, are therefore suggested as replacements for the UKCIP-WG/TD.

This change in the overall approach makes more difficult a like-for-like comparison of the risk of SWEs and the assessment of how the conclusions of the previous CCARs, based on UKCP09 and the use of the UKCIP-WG/TD, might be affected by UKCP18. A detailed comparison of the UKCP09 (UKCIP-WG/TD) and UKCP18 (regional projections) is outside the scope of this analysis and only results of an initial screening are presented and discussed in this section.

The screening exercise is based on the interpretation of the tails of the UKCP09 and UKCP18 probabilistic projections (i.e. >90th percentile and <10th percentile – for temperature, precipitation, etc.) as reasonable proxies for SWEs. More appropriate assessments of the likelihoods and impacts of SWEs on existing assets, based on site-specific time series representative of the UKCP18 regional climate model projections, are left to be undertaken by the individual operators.

[22] Fung, F. and Gawith, M. (2018) UKCP18 for UKCP09 Users. UKCP18 Guidance. Met Office Hadley Centre, Exeter.
[23] Hausfather, Z. and Peters, G.P. (2020) Emissions – the 'business as usual' story is misleading. Nature Vol 577, 30 January 2020, pp 618-620.

In summary, to compare like-for-like data within the two models, common emissions scenarios, scales, time slices and baselines were selected as follows:

- UKCP09 SRES A1FI and UKCP18 RCP8.5 'high' emissions scenarios
- 25km probabilistic projections output as cumulative distribution function and compared graphically and numerically
- 2010 to 2039 (2020s) time slice
- 1961 to 1990 baseline

An analysis was undertaken for six 25km grid squares, selectively chosen to include large power generation plant and to represent the geographical extent of the UK. For simplicity, only the results associated with four of these locations are illustrated in this section, as representative of North (Scotland), West (Wales), East and South locations in the UK.

5.3 Air temperature

There is well established evidence in climate projections for an upward trend in UK air temperatures during this century. Ambient air temperature affects the electricity generation process in many ways (see Table 1). For example:

- Ambient atmospheric conditions (mainly temperature) affect the performance of steam turbines, gas turbines, auxiliary systems and cooling systems
- Extreme high summer temperature (of air and river water) can constrain plant operation in order to respect permit limits (e.g. permitted temperature at water discharge outlet)
- Extreme winter temperature and extreme snowfalls can affect performance and hinder or limit access to sites.

The increase in temperatures is therefore generally expected to have an adverse impact on electricity generation in summer due to degradation in plant performance, whereas electricity generation in winter could show some benefits due to anti-icing systems being required less frequently. The risk analysis in AEP's CCAR1 sector overview focused on the degradation in performance, using the 'hottest monthly mean of daily maximum temperatures' as the relevant metric (UKCP09 baseline, based on July – the hottest month). This section provides a comparison of the daily maximum air temperature difference (represented as a cumulative probability distribution) during the summer (months June, July and August) projected under UKCP09 and UKCP18, in the 2020s (2010 to 2039).

Figure 12. Comparison of the Cumulative Distribution Functions for the anomaly (with respect to the 1961-1990 baseline) in the daily maximum temperature (in Summer) projected in the 2020s (the 30 years 2010-2039), under UKCP09 (dotted lines) and UKCP18 (full lines), high emission scenarios/RCP8.5. The results are illustrated at each of the four selected representative sites in the North (blue), West (green), East (grey) and South (yellow) of the UK. A 'normal probability' (nonlinear) x-axis has been used, to better visualise the results at extremely high (or low) percentiles.

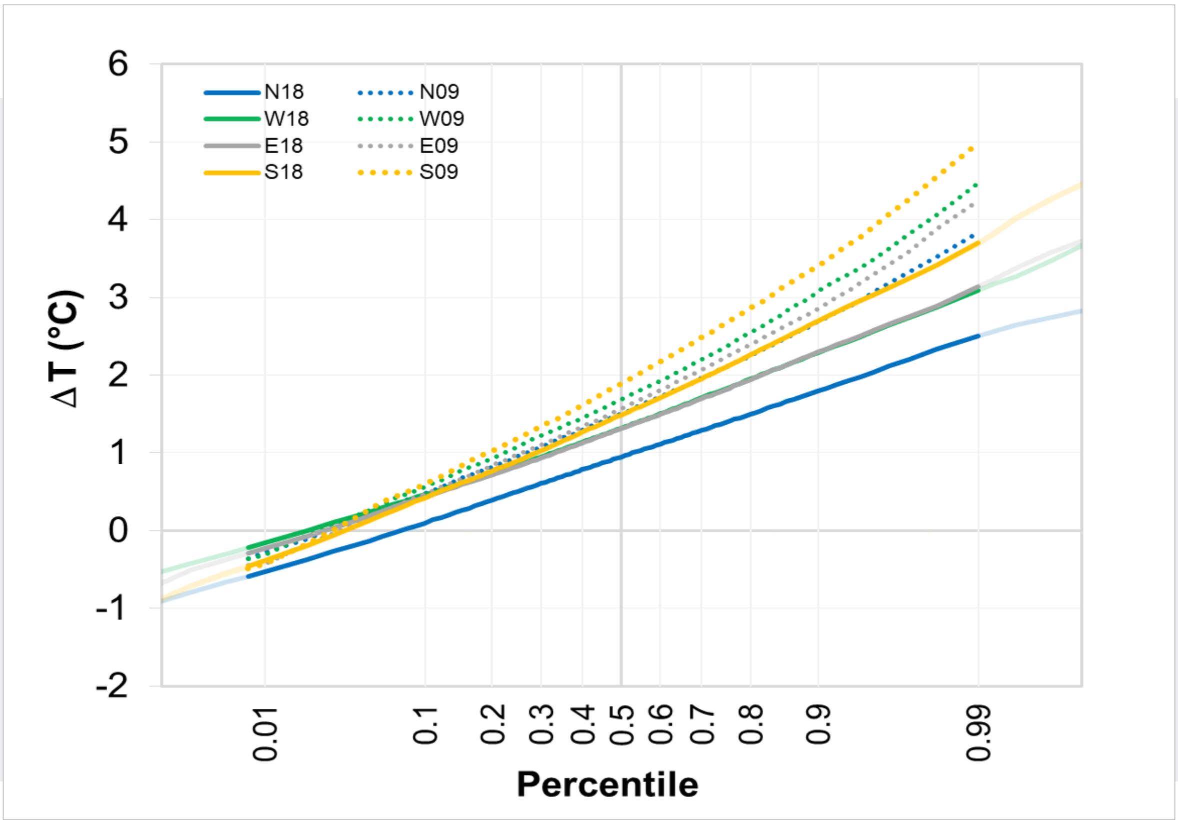

Figure 12 shows that (especially for the highest percentiles) the climate change driven increase in the maximum summer daily temperature projected under the UKCP09 'high emission scenarios' was higher than the one projected under the UKCP18 updated projections. The findings of the previous analysis of power station resilience to climate change driven increases in air temperature (which was based on UKCP09) therefore remains robust (as resilience will be better with the smaller temperature increase projected by UKCP18).

In addition to the direct influence of air temperature on power plant operation, as noted in Table 1, extreme high air temperatures might also limit operation due to restrictions on water discharge in the environmental permit. However, water temperatures generally tend to vary less throughout the seasons than air temperatures and can be expected to reflect air temperature. UKCP18 does not provide projections for the change in marine water temperature and so it is necessary to assume UKCP09 provides the best estimate for climate change in marine and coastal water temperature. AEP (2011) supported the view that, for most of the time, temperatures in estuarine/coastal waters would continue to be within the range currently experienced (although occasional high temperatures beyond those currently experienced would be expected to become apparent in the coming decades).

No significant variations in operational constraints were therefore expected over the lifespan of the considered direct-cooled marine sites, with little scope for mitigation other than an eventual load reduction under the most challenging combinations of within-season 'natural' variations. This conclusion still holds under the updated projections.

5.4 Sea level rise

As well as improved climate models and scenarios, UKCP18 refines the treatment of ice dynamics (compared to UKCP09). The improved modelling results in systematically larger values for sea level rise (than presented in UKCP09), see Palmer *et al*. (2018)[24].

Palmer et al (2018) also reports on the output of the surge model (when driven directly from a single global climate model, selected because it predicted an increase in winter storm track intensity). Storm surge can increase the rise of flood due to a short-term increase in sea level. The projected rate of change in sea level due to storm surge is however reported to be an order of magnitude less than the rate of mean sea level rise (with different models predicting either an increase or a decrease in storm surge). Palmer et al (2018) also notes that the UKCP18 study shows a reduction in mean Significant Wave Height projected across all UK seas (with the exception of a slight increase to the North of Scotland).

As the projected change in extreme coastal still water levels are dominated by time-mean sea level increase, the comparison between the two projections focused on this variable, see Figure 13.

Figure 13. Projected mean sea level rise (against the 1990 baseline), using the same notation as in Figure 12.

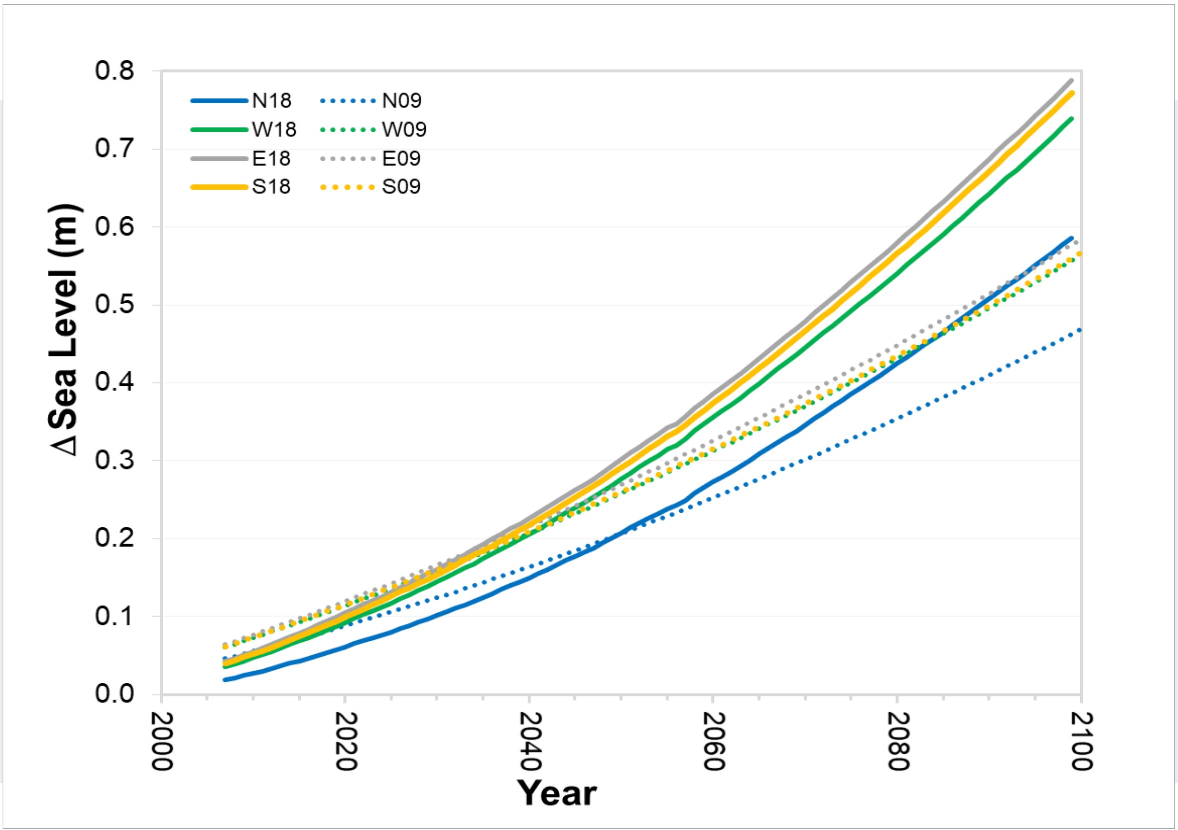

Figure 13 clearly shows the expected north-south gradient, which is a combination of response to the proximity of the Greenland ice sheet and glacial isostatic adjustment. Both UKCP09 and UKCP18 project a greater rise in mean sea level to be experienced in the South than in the North UK. The figure also shows a small difference between the two data sets, for the mean sea levels at 2007 (due to the underlying differences in the modelling). The authors of the UKCP18 marine report state that the UKCP18 modelling is better able to reproduce the observed changes in mean sea level than were the previous models and is therefore more reliable. The difference between UKCP09 and UKCP18 reduces until about the mid-2030s, after which the sea level rise is projected to be greater under UKCP18 than UKCP09 with the difference increasing significantly towards the end of the 21st century.

[24] Palmer, M., Howard, T., Tinker, J., Lowe, J., Bricheno, L., Calvert, D., Edwards, T., Gregory, J., Harris, G., Krijnen, J. and Pickering, M. (2018) UKCP18 marine report.

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For the 2020s (2010 to 2039), the results show that the latest projections of mean sea level rise are slightly lower than or similar to those from UKCP09 (with sea level rise higher in the south than in the north). The conclusions derived from the assessment of impacts associated with sea level rise and storm surge on existing assets, undertaken for CCAR1 based on UKCP09, should therefore still hold under UKCP18 (due to the limited lifespan of existing assets).

It should however be noted that the revised projections might have a significant impact on a longer timescale. Similarly, low probability-high consequence events such as the H++ storm surge scenario of UKCP09 (still considered a useful plausible but unlikely high-end sea level pathway for decision making under UKCP18), although not relevant for the lifetime of existing power stations, should be relevant on longer timescales. The assessment of climate change risks on new build projects (managed in the environmental permit application process) should therefore be informed by the latest scientific evidence.

5.5 Precipitation change

Although average annual rainfall has not significantly changed since records began in the 18th century, in the last 50 years more winter rainfall has fallen in heavy events (although the picture is less clear for summer rainfall), Watts and Anderson (2016)[25]. This trend is expected to continue and Watts and Anderson (2016) predict, for the future:

- more frequent and more severe floods, particularly during winter
- summer flash flooding may become more common.

Changes in precipitation also affect river flows (the topic of Section 5.6) and the risks associated with storm surges (discussed in Section 5.4).

In the context of the initial CCARs and the climate hazards in Table 1, the main focus is:

- on risks arising from decreased precipitation, particularly in summer. This might have an impact on riverine power plant, since there are sectors, including power generation, which currently do not have access to significant inter-year or even inter-seasonal storage and are exposed to low river flow risk (as well as drought), with low flow risk being much more frequent than drought (droughts are discussed further in Section 8.6)

- on risks arising from increased and extreme precipitation. This might lead to operational constraints (e.g. cooling water inlets blocked by debris) or result in flooding of sites and their access routes (limiting supply distributions, staff access, etc.).

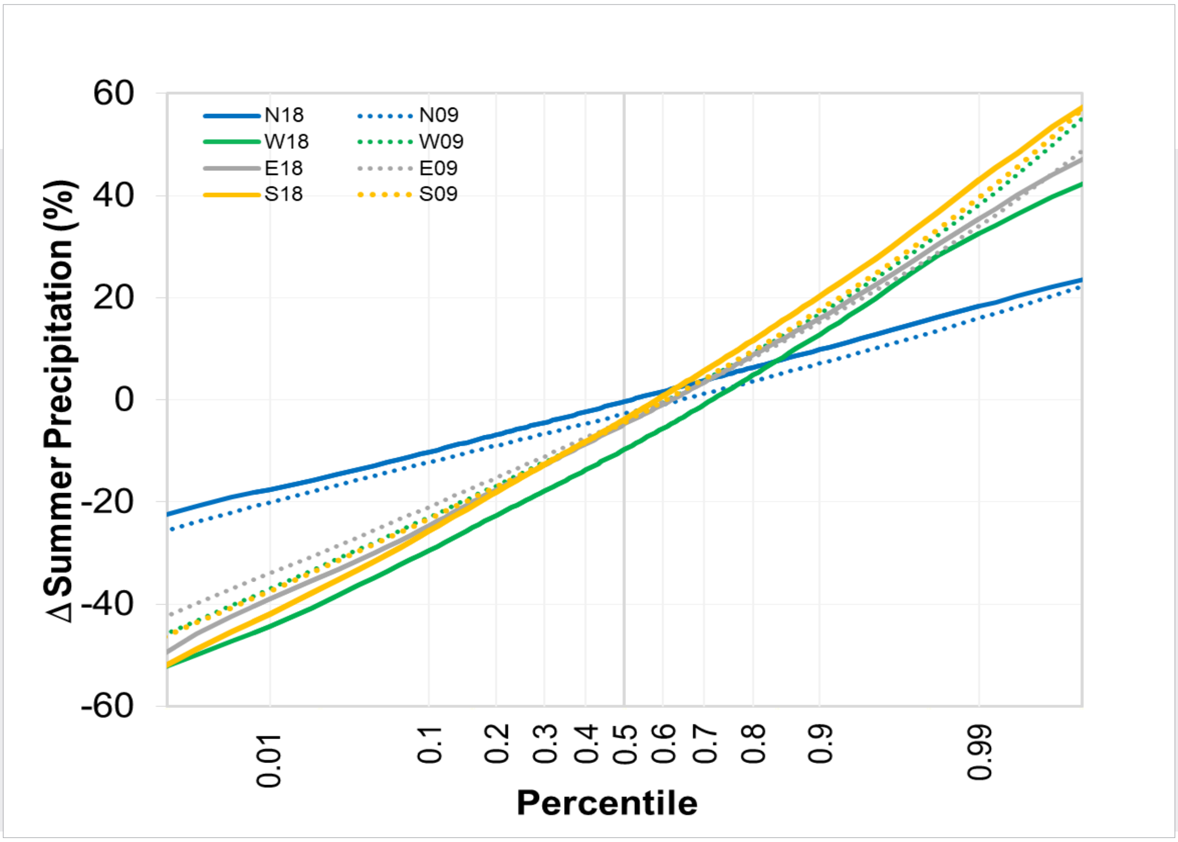
This section provides an assessment, which is based on the analysis of the cumulative distribution functions for changes in seasonal precipitation, as projected under UKCP09 and UKCP18 – for summer (June, July and August) and winter (December, January and February), see Figure 14 on page 31 (top and bottom chart, respectively). The focus is again on the 2020s (with 1961 to 1990 as baseline). Changes in seasonal precipitation has been identified as the most suitable among the available metrics. This is because:

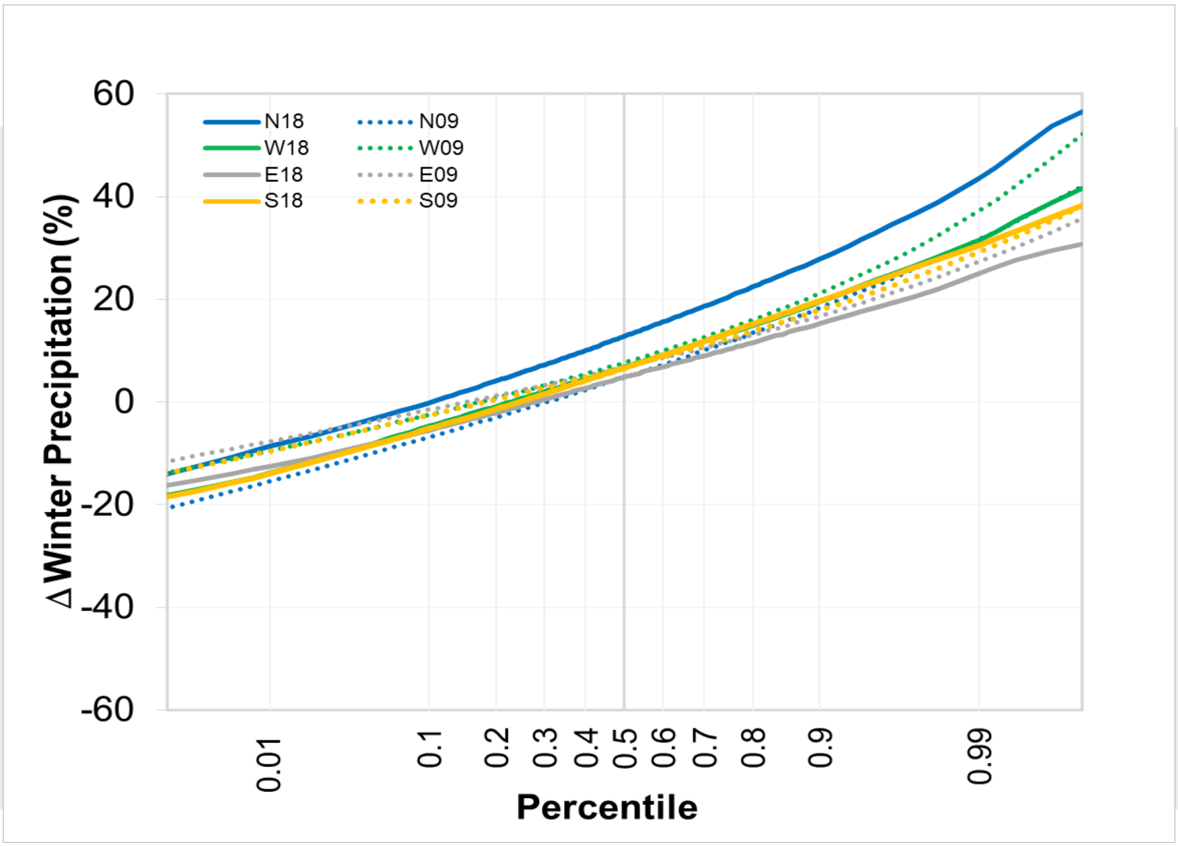
- its response for very low percentiles might be interpreted as a proxy for the occurrence of extreme events of prolonged low precipitation; and

- its behaviour at very high percentiles might instead be useful to screen impacts associated with events of extremely heavy and prolonged precipitation.

[25] Watts, G. and Anderson, M. (eds.) (2016) Water climate change impacts report card 2016 edition. Living With Environmental Change. Available at: https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards/water/

Figure 14. Same as Figure 12, but for the percentage changes in summer (top figure) and winter (bottom figure) precipitations.





A visual inspection of the charts in Figure 14 shows considerable consistency between the results obtained from UKCP18 and the ones associated with the previous UKCP09 projections, more specifically:

- Figure 14 (top) shows that the response of summer precipitation in the 2020s is still uncertain (although a decrease in precipitation, with respect to the 1961 to 1990 baseline, is slightly more probable than an increase)
- Figure 14 (bottom) shows instead the general tendency towards increased winter precipitation
- Overall the most recent projections of precipitation change in UKCP18 are generally similar in direction and magnitude for summer and winter precipitation change, with some exceptions
- The occurrences of extremely high seasonal precipitations, at the upper end of the cumulative distribution functions (high percentiles), are also comparable under the two projections. A notable exception is however the projections for the representative site in the North of the UK (Scotland), shown by the blue lines in Figure 14 (bottom), which show a larger increase in winter precipitation under UKCP18 than UKCP09.

As already mentioned in Section 5.2, the findings of the risk analysis undertaken in the framework of CCAR1 were based on the use of the UKCIP Weather Generator and Threshold Detector. The results outlined above, tend however to support the conclusions that (possibly with the exclusion of Northern UK) resilience to precipitation related impacts is unlikely to be significantly affected under UKCP18, given the generally good agreement between the output of UKCP09 and UKCP18. It reasonably follows that the conclusions of the ARP1 CCAR can be expected to still hold.

5.6 River flows

The impacts of climate change on future river flows are of particular concern to the energy industry because of possible increases in the frequency and magnitude of floods, low river water levels and droughts but also the impact of changes in the flow regime on river water quality, erosion, morphology, and ecology (Kay et al. 2019)[26].

High flows and flooding are expected to increase over the 21st century because of increased rainfall, particularly in winter (see Section 5.5) and studies tend to agree on a trend towards similar or increased average winter flows and reduced average summer flows, with mixed patterns in spring and autumn. Watts and Anderson (2016) underline how the projections of future river flow are uncertain because of uncertainties in both future rainfall and evapotranspiration.

At the time of CCAR1, the best available river flow data were two national studies based on previous climate projections (UKCIP02, Hulme *et al*. 2002[27]).The Future Flows and Groundwater Levels project (FFGWL), which incorporated the latest projections from the UK Climate Impacts Programme (UKCIP) (including the UKCP09 probabilistic projections), Prudhomme *et al*. (2012)[28], became available later. Due to large variation in the model output, the use of the FFGWL project was judged to be of limited value in a risk analysis, and it was not considered appropriate to update the risk assessments based on this new information within the subsequent report for CCAR2.

CCAR1 noted that national flood projections were also out of the scope of the UKCIP and 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, Environment Agency 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. Updated national flood projections were not provided by UKCP18 and, if required, site-specific risk assessments would be undertaken using the existing published data (Flood Risk Map, Catchment Management Plans, etc.) as was recommended by the previous CCARs.

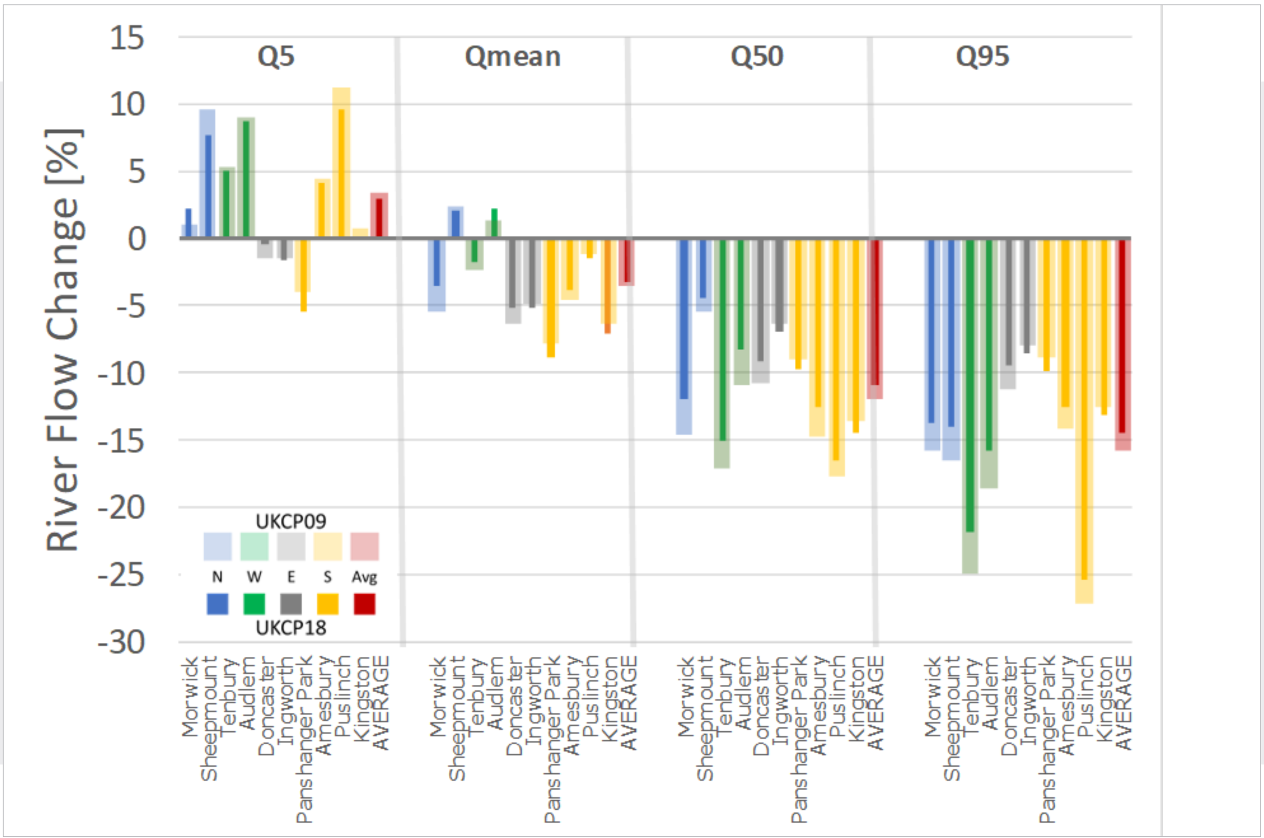
[26] Kay, A.L., Watts, G., Wells, S.C. and Allen, S. (2019) The impact of climate change on UK river flows: a preliminary comparison of two generations of probabilistic climate projections. Hydrological Processes.

[27] Hulme, M., Jenkins, G.J., Lu, X. and Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M. and Hassell, D. (2002) Climate change scenarios for the United Kingdom: the UKCIP02 scientific report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

[28] Prudhomme, C., Crooks, S., Jackson, C., Kelvin, J. and Young, A. (2012) Future Flows and Groundwater Levels, Final Technical Report. Centre for Ecology and Hydrology, Science Report/Project Note SC090016/PN9, October 2012.

An initial analysis of the consequences of the release of UKCP18 on river flows projected under a climate changed future was undertaken in a recent study by the UK Centre for Ecology & Hydrology, Kay et al. (2019). In this modelling exercise, the probabilistic projections from UKCP18 and UKCP09 were alternatively applied to drive an identical hydrological model for 10 representative hydrological catchments, across England. The resulting outputs were then cross-compared. The analysis considered changes in mean and median flow (Q_{mean} and Q_{50}), as well as changes in measures of high and low flow (Q_5 and Q_{95}, the flows exceeded 5% and 95% of the time, respectively). The study used a 30-year time slice (2050s), considering the changes from the 1961 to 1990 baseline period, using the common A1B emissions scenario from both UKCP09 and UKCP18. The resulting median changes are illustrated in Figure 15.

Figure 15. Median changes (in the 2050s, from the 1961-1990 baseline period) in the measure of high flow (Q5), mean and median flow (Qmean, Q50) and low flow (Q95), modelled (under the common A1B emissions scenario) in each of the 10 representative hydrological catchments. The larger semi-transparent bars report the results for UKCP09, while the narrower solid-filled bars report the equivalent results but for UKCP18. Although all the modelled catchments are in England, for illustrative purposes, a colour scheme similar to the one used in the previous figures has been applied: North (blue), West (green), East (grey) and South (yellow). Averages over all the modelled catchments are also reported (red bars).



A visual inspection of Figure 15 shows considerable consistency between the flows obtained under UKCP09 and UKCP18. A more detailed comparison is reported in Kay et al. (2019), which concludes that 'the results suggest that existing assessments of hydrological impacts remain relevant though it will be necessary to evaluate sensitive decisions using the latest projections'.

More specifically, the fact that in the low flow regime (Q95) the typical flow decreases projected for the 2050s are shown to be slightly smaller using UKCP18, means that a risk assessment based on UKCP09 tends to be more conservative with regard to drought and low river flows impacting water availability and water quality. It is therefore expected that previously derived conclusions remain broadly the same and do not change greatly with the UKCP18 projections.

With respect to the assessment of the impacts of low river flows and droughts, it is also worth noting that individual power companies and Energy UK are active in regional water resource planning initiatives, with Energy UK also participating in the Water Resources National Framework (see Section 8.7). Part of the work of regional water planning requires prediction of future rainfall, river flows, groundwater levels, etc., in order that Public Water Supply (PWS) options can be developed to deliver the necessary PWS resilience (1:500-year drought).

In order that the risks to non-PWS sectors such as power/energy are properly evaluated within climate change adaptation strategies, it is necessary to develop tools which will indicate statistics of future river flows (outside of severe drought events) as well as developing libraries of drought events (for PWS and general use). The development and the application of these tools in the regional water resource planning initiatives should offer the involved sectors a reassessment of the climate change risks. It is likely that adopting a cross-sector approach to individual sector risk management will provide a more efficient means of developing societal climate change adaptation than adopting a silo-sector approach.

5.7 Conclusions

The release of UKCP18 provides electricity generators with a valuable set of tools to assess the impacts of climate change on assets. It also provides the opportunity to reassess the results of the risk analysis undertaken by individual companies, for existing assets, in CCAR1 in 2011.

This section has presented the results of a screening analysis for the potential impacts of the updated UKCP18 climate projections on the conclusions of the first (UKCP09-based) CCAR for the main risks identified for the electricity sector, and its subsequent update in Energy UK's CCAR2 in 2015. The screening is generally based on a cross-comparison of probability distributions of relevant climate variables, as released under UKCP09 (underpinning the previous CCARs) and updated by UKCP18. Extreme percentiles are used as a proxy for SWEs.

The screening is based on the comparison of like-for-like data within the two projections. Common emissions scenarios, scales, time slices and baselines were selected as follows:

- UKCP09 SRES A1FI and UKCP18 RCP8.5 'high' emissions scenarios
- 25km probabilistic projections output as cumulative distribution function and compared graphically and numerically
- 2010 to 2039 (2020s) time slice
- 1961 to 1990 baseline

The 'high' emission scenarios were used for consistency with the previous assessment. It is worth noting that, due to energy and greenhouse-gas-emissions mitigation policies and international agreements made in the time intervening the two projections, the 'high' emission scenario tends now to be considered to represent a much more conservative 'worst-case' baseline than at the time of the first assessment. However, because the UKCP09 and UKCP18 climate change forecasts are being compared in the relatively near future (the 2020s) the predictions are less sensitive to the choice of pathways than they are later in the 21st century.

The analysis shows a reasonable level of consistency between the UKCP18 and UKCP09 probability distributions with regard to all the main climatic parameters of interest (air temperature, precipitation change, sea level rise, etc.), especially over the timescale of interest for existing assets. Where the datasets do diverge, this tends to support the UKCP09 assessment being more precautionary with regards to potential impacts on assets.

The main conclusion is that, fundamentally, the assessments undertaken by participating companies in CCAR1 in 2011 and its subsequent update in CCAR2 in 2015 still hold true, and the key conclusions reached therein still apply:

- Climate change mainly affects 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 and mitigated by operators – it does not introduce any fundamentally novel sources of risk;

- Over the lifespan of the operating fleet, natural 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.

- The additional risks arising from climate change in the near future are relatively small compared to the operational risks that generators currently manage.

Differences between UKCP18 and UKCP09 might however become more significant over longer timescales, in particular with respect to the projected sea level rise and coastal or riverine flood risk. More accurate analyses, based on the use of relevant time series extracted from the UKCP18 regional projections, are left to be undertaken by individual companies to evaluate sensitive decisions concerning their assets, using the latest projections. Similarly, the assessment of climate change risks on new build assets (managed in the environmental permit application process) should be informed by the latest scientific evidence.

6. Reviews of progress

6.1 Progress on actions identified previously by reporting companies

In ARP1, those sector companies that were directed to report developed action plans to address identified risks resulting from future changes to certain climate change hazards. These were site- or company-specific actions.

For the purposes of the CCAR2, 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 and progress on each action was categorised as 'completed', 'in progress', or 'not started'. The assessed success in mitigating a risk was categorised as 'mitigated', 'partially mitigated', 'not mitigated', or 'not yet evaluated'.

That process was repeated for the purposes of this report and the results are shown in Table 4.
The colour key is shown in Table 3.

Table 3. Colour key to Table 4.

Progress Key		Mitigation Key	
Complete	(yellow-green)	Mitigated	(yellow-green)
In progress	(teal)	Partial	(teal)
Not started	(orange)	Not mitigated	(orange)
		Not yet evaluated	(dark grey)

Table 4 shows that substantial progress has been made by generating companies in completing actions identified in their CCAR1 reports. Importantly, actions have continued to be progressed since Energy UK's CCAR2 report across a range of underlying climate change hazards including flooding of site, extreme high temperature on water discharge, extreme low temperature on cooling tower, drought on water availability and subsidence/landslide.

All actions have been progressed and 73 of the 88 agreed actions have now been completed. This has led to a further decrease in risk, albeit from an already low risk base.

Table 4. Summary of sector progress with mitigation actions since CCAR1 – See page 37.

6.1 Progress on actions identified previously by reporting companies (continued)

Table 4. Summary of sector progress with mitigation actions since CCAR1

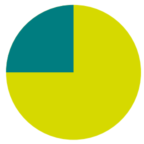
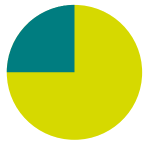
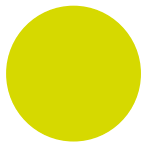
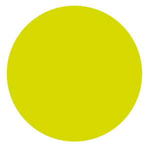
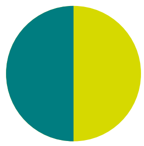
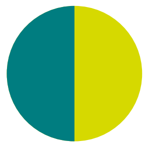
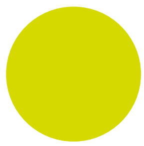
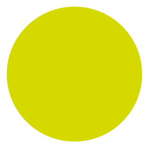
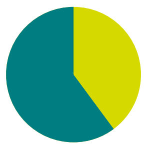
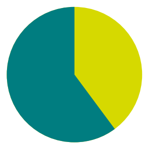
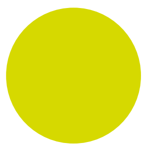
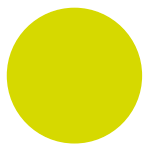
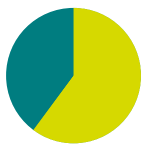
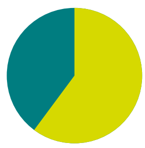
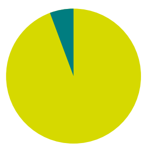
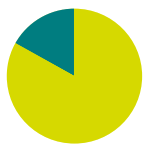
Underlying Climate Change Hazard	Number of Actions	Progress on implementation	Degree of risk mitigation achieved
1. Flooding of site	20		
2. Flooding of Access Routes to Site	6		
3. Flood Events & Extreme High River Flow	2		
4. Storm Surges	4		
5. Extreme High Temperature on Steam	5		
6. Extreme High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

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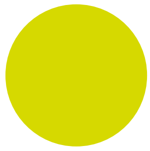
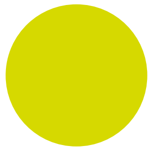
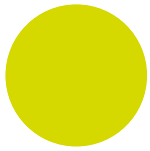
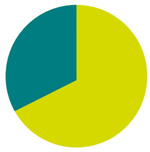
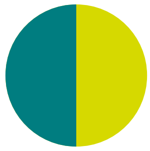
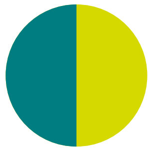
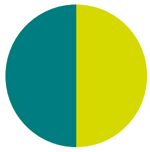
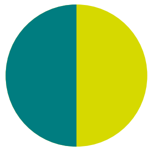
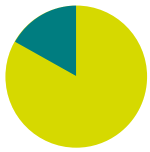
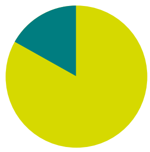
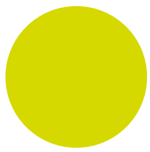
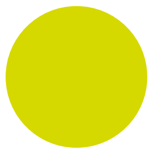
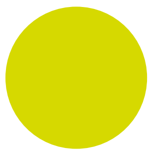
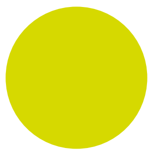
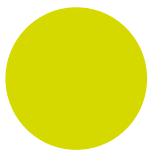
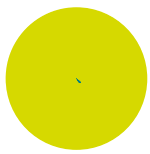
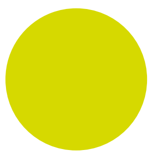
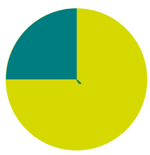
Table 4 continued. Summary of sector progress with mitigation actions since CCAR1

Underlying Climate Change Hazard	Number of Actions	Progress on implementation	Degree of risk mitigation achieved
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	3		
15. Extreme Winds	4		
16. Weather Conditions Causing Plume Grounding	1		
17. Subsidence / Landslide	4		

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6.2 Second UK Climate Change Risk Assessment (UKCCRA2, 2017) and Second National Adaptation Programme (NAP2, 2018)

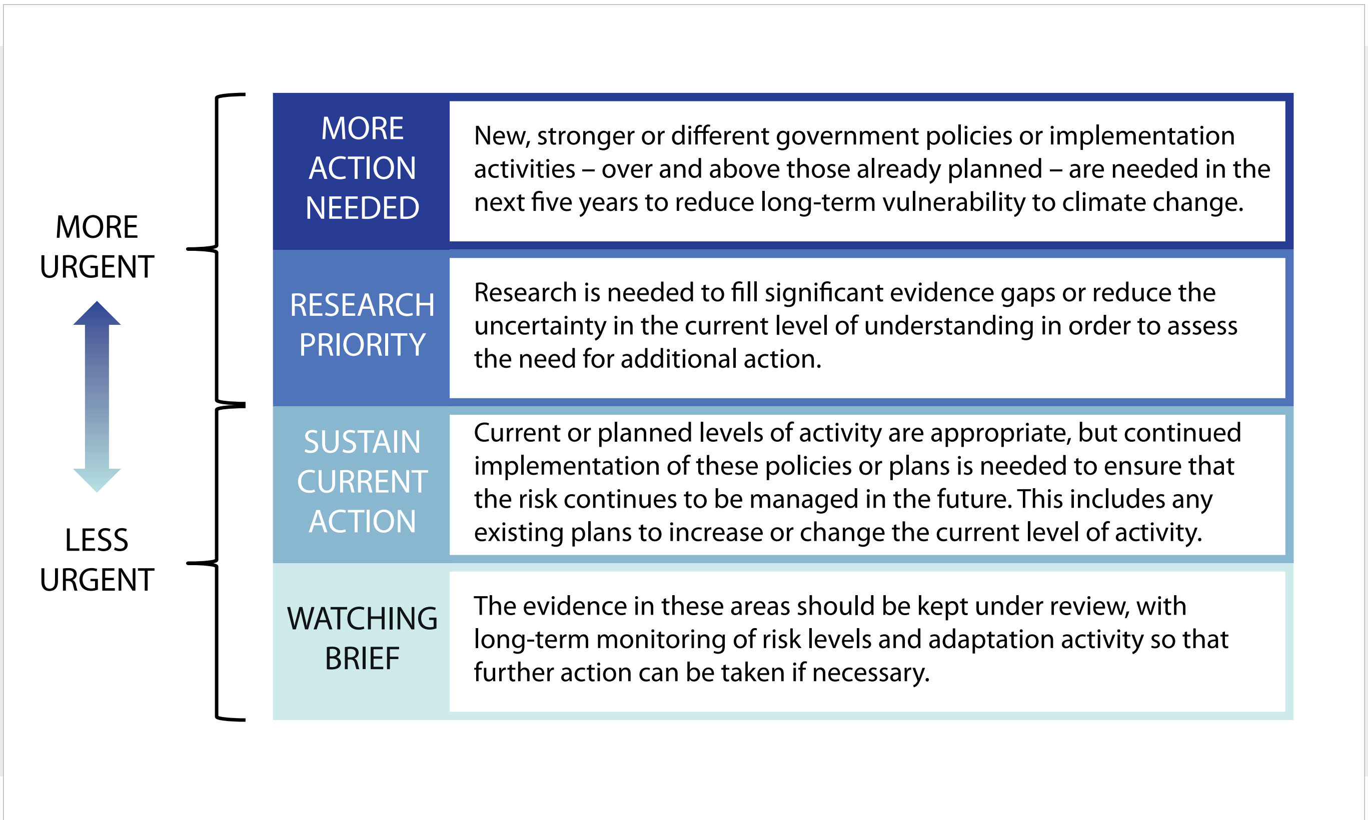
The Climate Change Act (2008) requires the UK Government every five years to publish an assessment of the risks for the United Kingdom of the current and projected impact of climate change. The first UK Climate Change Risk Assessment (UKCCRA1) was presented to Parliament in January 2012. It set out the main priorities for adaptation in the UK under five key themes, which had been identified in the associated UKCCRA1 Evidence Report. It also described the policy context, and actions already in place to tackle some of these risks.

For UKCCRA2, Defra asked the Climate Change Committee to prepare the independent Evidence Report setting out the latest evidence on the risks and opportunities to the UK from climate change and updating the evidence base from UKCCRA1.

The UKCCRA2 Evidence Report[29] considered a smaller list of 56 priority risks and opportunities highlighted by the Government, focusing on the urgency of further action rather than the size of the different risks and opportunities. The Government again followed the publication of the UKCCRA2 Evidence Report with the UKCCRA2 report, which was released in January 2017. This summarised the main risks, opportunities and priorities for action.

Each of the main risks and opportunities identified were separated into four urgency categories described in figure 16 below.

Figure 16. UKCCRA2 urgency categories.



Source: Committee on Climate Change (2016)

[29]Committee on Climate Change (2016) UK Climate Change Risk Assessment 2017 Synthesis Report: priorities for the next five years. Available at: www.theccc.org.uk/uk-climate-change-risk-assessment-2017/synthesis-report/

The 14 individual risks related to UKCCRA2 Chapter 4: Infrastructure, some of which are relevant to the electricity generation sector, and their associated urgency category, are shown in Table 5 below.

Table 5. UKCCRA2 infrastructure risks.

MORE ACTION NEEDED	RESEARCH PRIORITY	SUSTAIN CURRENT ACTION	WATCHING BRIEF
In1: Risks of cascading infrastructure failures across interdependent networks	In5: Risks to bridges and pipelines from high river flows/erosion	In13: Extreme heat risks to rail, road, ICT and energy infrastructure	In7: Low/high river flow risks to hydroelectric generation
In2: Risks to infrastructure from river, surface/ groundwater flooding	In11: Risks to energy, transport & ICT from high winds & lightning	In14: Benefits for infrastructure from reduced extreme cold event	In8: Subsidence risks to buried/ surface infrastructure
In3: Risks to infrastructure from coastal flooding & erosion	In12: Risks to offshore infrastructure from storms and high waves		In10: Risks to electricity generation from drought and low flows
In4: Risks of sewer flooding due to heavy rainfall			
In6: Risks to transport networks from embankment failure			
In9: Risks to public water supplies from drought and low river flows			

Source: Adapted from Committee on Climate Change (2016).

The key risks outlined above, requiring action in the next five years (2017 to 2022), were grouped into six categories:

1. Flooding and coastal change risks to communities, businesses and infrastructure
2. Risks to health, well-being and productivity from high temperatures
3. Risks of shortages in the public water supply for agriculture, energy generation and industry
4. Risks to natural capital including terrestrial, coastal, marine and freshwater ecosystems, soils and biodiversity
5. Risks to domestic and international food production and trade
6. New and emerging pests and diseases and invasive non-native species affecting people, plants and animals

The electricity generation sector's response to issues highlighted in UKCCRA2 are covered in this report as follows:

1. In1: Risks of cascading infrastructure failures across interdependent networks (More Action Needed) – the important role of interdependencies was recognised in Energy UK's CCAR2 report and activities since then are described in Section 7
1. In7: Risks to hydroelectric generation from low or high river flows (Watching Brief) – this is not considered a major issue in the sector and the CCC's Adaptation Committee concluded in its 2019 Report to Parliament that "impacts of increased or reduced hydropower generation can be managed using normal operation procedures on the national grid"
2. In10: Risks to electricity generation from drought and low river flows (Watching Brief) – a joint project between Energy UK, the Environment Agency, National Grid, BEIS and Defra was completed in February 2018 (see Section 8.6). Energy UK and its members also represent the energy sector in the regional water resource planning process (see Section 8.7)
3. In12: Risks to offshore infrastructure from storms and high waves (Research Priority) – offshore arrays of wind turbines are included in the scope of this report for the first time (see Section 4).

The UKCCRA2 provided a summary of each risk area and the Government's general approach. Detailed responses and actions were taken through to the second National Adaptation Programme (NAP2) which was published in 2018. NAP2 set out the Government's response to UKCCRA2 showing the actions it had taken and would be taking to address the risks and opportunities posed by a changing climate. These actions are included in the detailed actions log shown in Annex 2 of NAP2. The actions include the significant risks to infrastructure identified by the UKCCRA2 due to flooding, rising sea levels and increases in the frequency and severity of extreme weather.

NAP2 also notes that "The electricity sector has a well-developed understanding of the risk faced by flooding and a high level of mitigation is in place, and gas and electricity companies will again be completing ARP reports for the sector". The comment on flooding should have come as no surprise as the electricity generation sector was not identified as deficient in its response to resilience by the National Flood Resilience Review published by the Cabinet Office and Defra in September 2016[30].

In 2020, Defra reviewed its Action Tracker which contained all adaptation actions from NAP2, as well as new actions to reflect additional cross-government activity addressing the priority risks of UKCCRA2. There were no actions from NAP2 that were directly allocated to the electricity generation sector, so there were therefore no updates to submit.

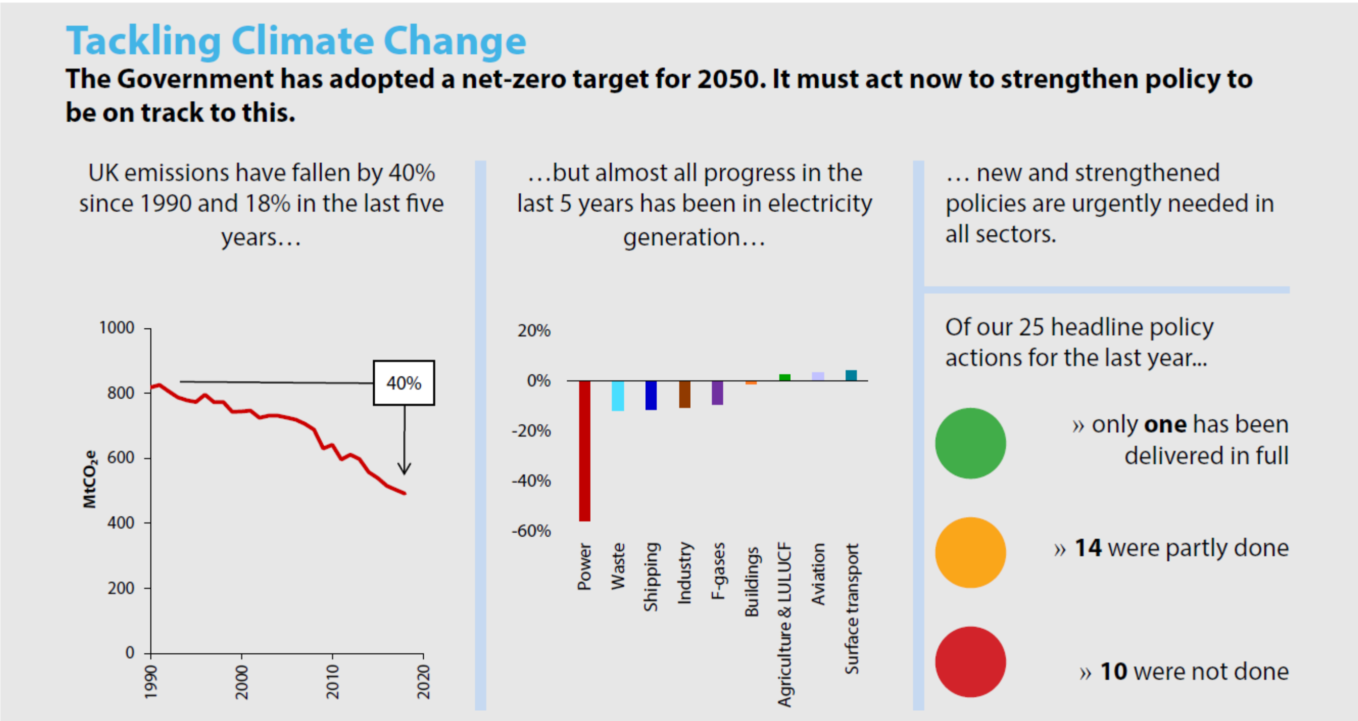
[30] HM Government (2016) National Flood Resilience Review. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/551137/national-flood-resilience-review.pdf

6.3 CCC Adaptation Committee Report to Parliament (2019)

In July 2019, the Adaptation Committee (AC) reported to Parliament on its latest assessment of progress in preparing for climate change in England and provided a first evaluation of the Government's NAP2 published in July 2018.

The report[31] recognised the dominant contribution the electricity generation sector has made to the UK's climate change mitigation efforts, reducing its carbon emissions by over 55% (since 1990), illustrated in Figure 17 below.

Figure 17. Progress in tackling climate change.



Source: Committee on Climate Change (2016)

There were two actions related to energy sector infrastructure within the AC's report:

1. Ongoing work to further cross sector understanding of the energy interdependencies as part of resilience planning and risk management Strategies – with next steps being considered by the Infrastructure, Resilience and Security Working Group, a sub-group of the National Security Council, and

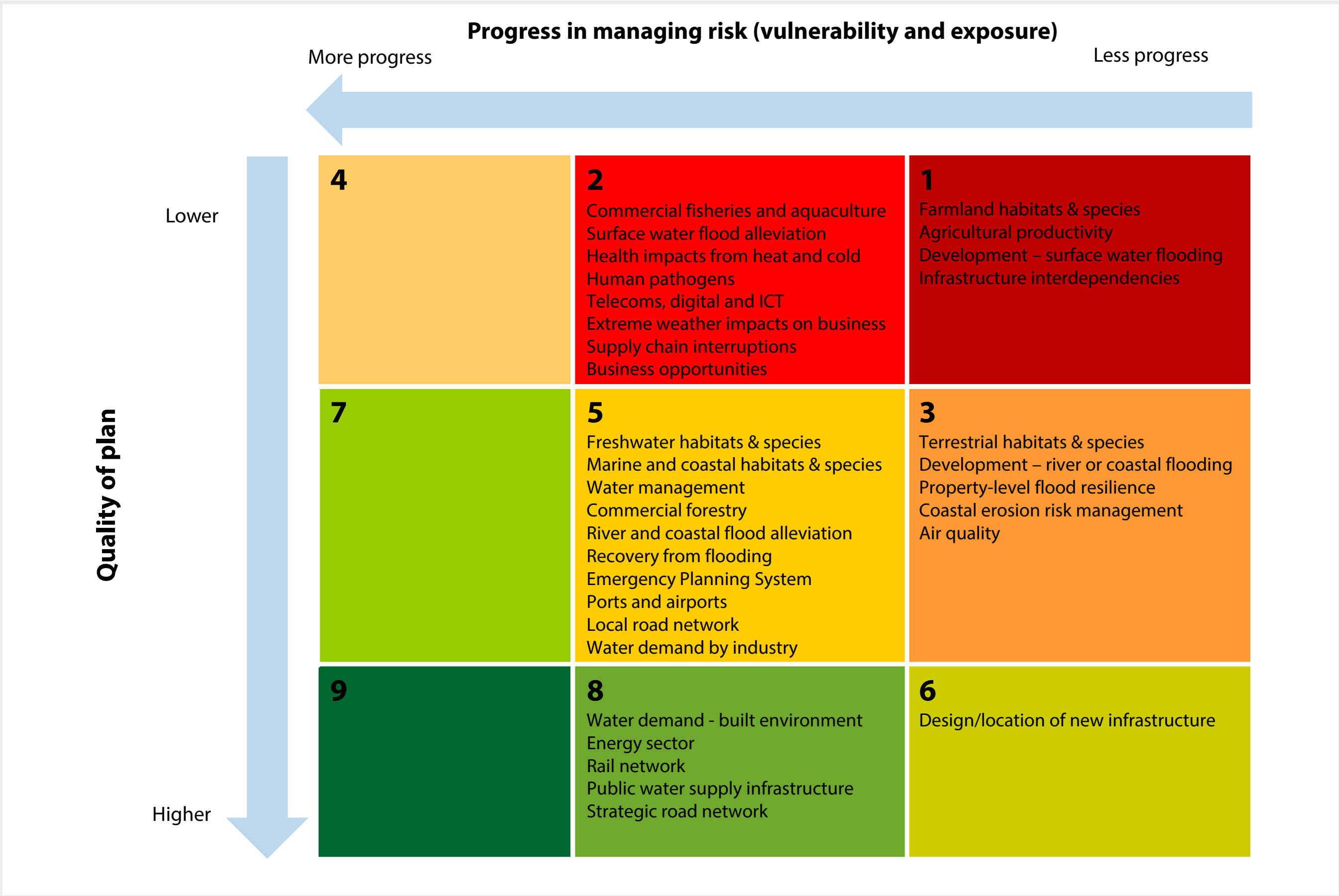
2. Increase the resilience of energy infrastructure from all forms of flooding – relating specifically to electricity networks and substations, which are being addressed through the Energy Networks Association's Flooding Resilience Working Group (ETR138).

The two actions relate to broader energy sector interdependencies rather that electricity generation itself. However, Energy UK remains actively engaged in the consideration of interdependencies, as described in Section 7.

[31] Committee on Climate Change (2019) Progress in preparing for climate change: 2019 Report to Parliament'. Available at: https://www.theccc.org.uk/publication/progress-in-preparing-for-climate-change-2019-progress-report-to-parliament/

The AC's scoring of adaptation priorities for the energy sector was Green (8 out of 9), and Red (1 out of 9) for infrastructure interdependencies, as illustrated in Figure 18 below.

Figure 18. The Adaptation Committee's scoring of adaptation priorities.



The AC also noted that:

- Energy infrastructure should be sited appropriately for managing future drought and low river flows
- Further research is needed to understand whether the climate risks to existing and planned offshore renewable energy infrastructure have been included into designs effectively
- Impacts of increased or reduced hydropower generation can be managed using normal operation procedures on the national grid
- Reporting organisations should ensure that ARP3 reports include actions to mitigate interdependent risk

Addressing those four points in order:

- Energy UK and its member companies are closely involved in discussions around future water resource planning and the effect that will have on the siting of power stations and future projects for Carbon Capture Use and Storage (CCUS) and for the production of hydrogen (see Section 8.7)
- Offshore arrays of wind turbines are included in the scope of this report for the first time and Section 4 provides some background on the standards to which they are designed and built
- Energy UK agrees that impacts of increased or reduced hydropower generation can be managed using normal operation procedures on the national grid and that, as the GB electricity generation market is fully competitive, management of the financial risks to individual sites that may be affected by fluctuations in flows is a matter for the individual operator/developer
- This CCAR3 report outlines the work carried out by Energy UK and its members to mitigate interdependent risk (see Section 7).

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7. Addressing interdependencies

7.1 Engagement with other infrastructure sectors

The need to understand and work to mitigate interdependent risks was recognised in Energy UK's CCAR2 report in 2015 and highlighted again in the AC's progress report to Parliament in 2019 (see Section 6.3).

The electricity generation sector is one on which almost all other sectors depend heavily for their operation and smooth functioning. At the same time, electricity producers can be affected by failures in other sectors (e.g. gas and water supply systems or communication and transportation networks). A major incident at a piece of critical infrastructure in one sector and one location can therefore cascade rapidly to other sectors and locations. Dependencies and interdependencies across sectors have therefore been the subject of much discussion in recent years, but have not always been well understood.

Energy UK therefore considers it is important that, outside of its internal groups, the generation sector makes representations at multi-industry groups and feeds into research projects on climate resilience and adaptation to identify any key pinch points where an event (e.g. a failure or disruption) in one sector might cause a secondary impact on another sector. Through mapping and discussing these risks in a cross-sectoral forum, various infrastructure operators are able to share best practice, identify common issues and find solutions. An example of the multi-sector groups that Energy UK has contributed to is the Infrastructure Operators Adaptation Forum.

Infrastructure Operators Adaptation Forum (IOAF)

The IOAF was established under the Environment Agency's Climate Ready programme in 2012, which subsequently closed in 2015. It is a multi-sector group which enables its members to discuss and share information relating to resilience and climate change adaptation with a vision "for our assets and services to be resilient to today's natural hazards and prepared for the future climate". As a result, Forum members are encouraged to learn from each other and work together.

Forum membership is drawn from infrastructure operators, regulators, government, trade associations, academics and professional bodies from the energy, water, transport, ICT and waste sectors. IOAF is a wide group which represents £billions worth of infrastructure including water, transport and energy and therefore provides a valuable cross-sectoral space to learn and build relationships with infrastructure leads. The Forum fosters sharing of knowledge and practice of adaptation planning, action, reporting and regulation. This collaboration offers the potential to reduce vulnerability to, and realise opportunities offered by, points of dependence on other systems.

One of the main benefits of the group is to the operators involved, providing them with a link to policy makers and researchers. This provides the opportunity to learn of existing and new approaches to weather resilience and adaptation from other members through sharing experience and learning and also provides access to knowledge and information in support of adaptation, including that required to support reporting under the Adaptation Reporting Power of the Climate Change Act (2008). A practical example of this happened in November 2019, when Energy UK presented to a workshop run by a fellow member of the IOAF, the Airport Operators Association, to brief them on the electricity generation sector's work on adaptation and resilience broadly, but also specifically in relation to the ARP3 process. This then led to a broader discussion on adaptation interdependencies.

Another benefit of the Forum is that there are good links to Defra, CCC and the AC as well as support for national, devolved administration and local government policy on infrastructure and adaptation, including the NAP. This channel for dialogue with Government bodies, regulators and stakeholders allows members to inform and support adaptation actions and policy. The cross-sectoral representation of the Forum also enables a more integrated and evidence-based approach for supporting national, devolved administration and local government policy on infrastructure and adaptation. It also provides the opportunity to engage with key research projects and to learn of relevant research and innovation results.

Energy UK's membership of the IOAF is one of the many vehicles used to ensure that the interdependent relationships between electricity generation and other sectors are consistently understood and considered. As such, both energy operators and other individual sectors can plan their adaptation strategies taking into account the points of vulnerability arising from interdependencies with other sectors. The water sector is one on which the energy sector is reliant for electricity production from large thermal plant and is therefore one with which Energy UK has endeavoured to forge a strong strategic engagement. Section 8.7 of this report outlines how, since 2015, the energy sector has taken a very proactive role in water resource management planning, so as to ensure that the water sector appropriately accounts for the water needs of the power sector, as it continues to play a major role in the drive towards the UK's target of net zero greenhouse gas emissions by 2050.

7.2 Engagement with researchers and reviews

WSP work on interdependencies and cascading failures

UKCCRA2 highlighted that there was a gap in knowledge around interacting climate change risks and their impacts on various parts of society and the economy. Such climate change risks are not discrete and can affect multiple assets and sectors at the same time, causing the impact to 'cascade' from one to several other sectors, infrastructure and natural environment. The cascades are made possible by the multiple interdependencies which exist (e.g. functional, physical, geographic, economic and financial, policy and social) and are further exacerbated by climate change.

As part of UKCCRA3, the CCC commissioned consultants WSP to undertake a research project to look at the interacting risks between the built environment, the natural environment and infrastructure. A specific climate change impact (e.g. a flood) has knock-on effects that run through infrastructure, built and natural environments. These effects are generally hard to quantify in a consistent way.

As part of the research project process, Energy UK was invited to participate in the stakeholder group and joined a series of virtual workshops over 2019. During these workshops, stakeholders were able to learn about and sense-check WSP's proposed method, identify missing data, studies or information, and impart lessons learnt from sectoral experience.

The final report, 'Interacting Risks in Infrastructure and the Built and Natural Environments'32 provides additional analysis for use in the technical chapters of the UKCCRA3 Evidence Report about how different risks interact and what these interactions mean for the overall level of risk. It informs the detailed climate risk evidence report, prepared by a consortium of experts, and in turn will inform the CCC's final assessment.

Using a combination of dependency modelling and systems mapping, the research project showed how flooding, high summer temperatures, sea level rise, extreme rainfall and drought will lead to increasingly significant interactions of impacts in the future as they transfer or cascade through the considered environments: infrastructure, built, and natural.

Further still, the study found that, in terms of affecting the overall level of risk, pathways which cascade within the same environment (infrastructure, built or natural) are more important than those which cascade from one to another. The report also showed that, due to its greater ability to recover from events, impacts on the natural environment are generally of lower magnitude than those on infrastructure and the built environment.

However, the analysis of future climate projections has shown that the increase in severity associated with the cascading nature of impacts from single events is small relative to the increase in severity driven by the increased frequency and severity of climate change hazards. As such, more frequent hazards (e.g. coastal flooding) result in larger overall impacts than the total damages caused by the cascading impacts from said hazardous event (e.g. coastal flooding leading to loss of power supplies, causing IT/communications to be disrupted).

[32]WSP (2020) Interacting Risks in Infrastructure and the Built and Natural Environments. Research for the Committee on Climate Change in support of the UK's Third Climate Change Risk Assessment Evidence Report. Available at: https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Interacting-Risks_WSP.pd

The most noteworthy point for the power sector from this activity was that, out of all the different possible dependencies, an interrupted power supply had the greatest number of knock-on impacts (or 'downstream connections') to other sectors; most of these were to the infrastructure sector followed by the built environment. In other words, this means that risks to power supply also have the greatest potential to cascade down to other sectors, due to the great number of potential risk pathways.

This further strengthens the argument for ensuring the resilience of the electricity generation sector to the impacts of climate change, so that the potential for a situation whereby it exposes the vulnerability of the various other sectors who interact with or are dependent on it is minimised. A recent example is set out in Section 7.3 below.

National Infrastructure Commission

The work undertaken by WSP was one of the first steps in mapping the interacting risks between the built environment, the natural environment and infrastructure. Running in parallel, and following a request from Government in the 2018 Budget, the National Infrastructure Commission (NIC) undertook a study on the resilience of the nation's economic infrastructure. Energy UK contributed to the study via an expert interview. In May 2020, the NIC published its report 'Anticipate, React, Recover: Resilient infrastructure systems'[33], which proposed a new framework for delivering resilient infrastructure with a number of recommendations across operators, Government and the regulators.

Many of the report's recommendations were directed at the regulators of the various infrastructure operators (Ofgem, Ofwat and Ofcom), with the NIC's headline recommendation being to introduce a resilience duty on these regulators and potentially on the rail and road sectors. It was also advised that regulators should factor in meeting short- and long-term resilience standards when making their determinations in future price reviews. The report also suggested that from 2022, Secretaries of State should be required to publish resilience standards every five years accompanied by assessments of changes required to support the delivery of these standards.

For the infrastructure operators themselves, the NIC report recommended that operators develop and maintain long-term resilience strategies. It also recommended that operators undertake regular and proportionate stress tests as a means of assessing their infrastructure against the requirements within the Government's new resilience standards, taking actions to address any vulnerabilities.

Alongside these recommendations was a recognition of the importance of interdependencies, with the 9 August 2019 power outage event, as outlined in Section 7.3 of this report below, cited as an example. The report referred to a pilot study[34] with Oxford University, which used modelling to try to understand the impact of dependencies and interdependencies on resilience and to demonstrate how failures could cascade through the cross-sector system. As the power sector recognises its position as the infrastructure provider upon which all other sectors have a degree of dependency, it will need to not only maintain its own high level of resilience but also remain involved in future work looking at and addressing interdependencies as potential solutions and actions come forward.

[33] National Infrastructure Commission (2020) Anticipate, React, Recover: Resilient infrastructure systems. Available at: https://nic.org.uk/app/uploads/Anticipate-React-Recover-28-May-2020.pdf

[34] Pant, R., Russell, T., Zorn, C., Oughton, E. and Hall, J.W. (2020) Resilience study research for NIC – Systems analysis of interdependent network vulnerabilities. Environmental Change Institute, University of Oxford, UK. Available at: https://nic.org.uk/app/uploads/Infrastructure-network-analysis.pdf

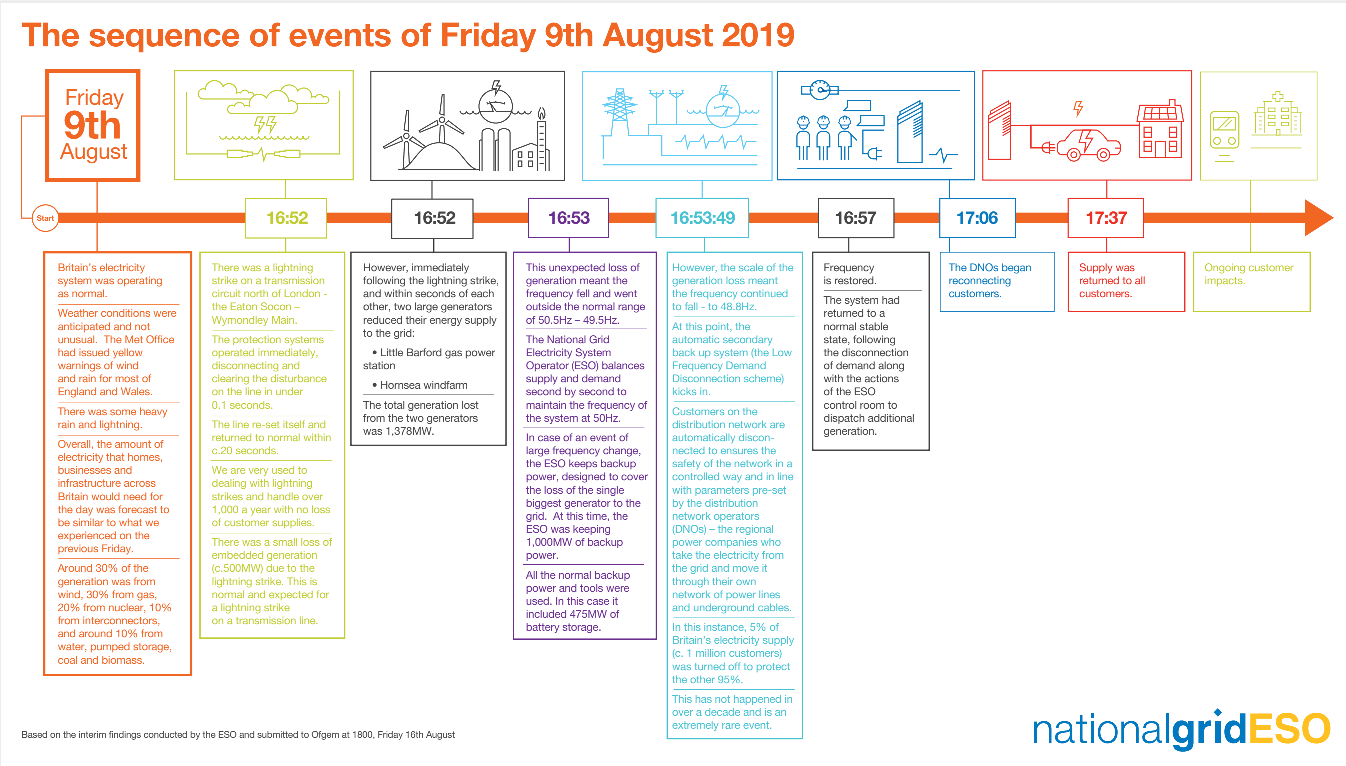
7.3 August 2019 power outage

As highlighted in Section 7.2, an interrupted power supply has the potential to cascade risks down to other sectors. When a power outage occurs, several other power-dependent sectors are in turn disrupted. Often these ‘downstream’ disruptions propagate over larger distances, continue to persist even when the power supply is restored and result in impacts that are more significant than the ones directly relatable to the primary power loss.

A clear example of this is the power outage event which took place on Friday 9 August 2019. The event resulted in a loss of power for just under an hour in the affected regions, but the impacts were felt by essential services for an extended period and across a wider region.

In the aftermath of this short loss of supply, several investigations and associated reports[35,36,37] identified the cause and chain of events which led to the power outage, as well as the secondary impacts on other sectors. These reports concluded that the significant impact caused by the event was more as a result of the lack of resilience of the downstream connections from the power sector, than from the brief loss of supply itself. By learning from these incidents and implementing any recommendations, network resilience should be improved.

Figure 19. Timeline of events on Friday 9 August 2019 (Source: National Grid ESO[38]).



As outlined in Figure 19, a lightning strike caused a fault on the transmission system and resulted in a number of small distributed generators automatically disconnecting in accordance with their protection settings. This was compounded by two large generators experiencing faults at the same time and being unable to continue providing power to the system after the lightning strike. The combined loss of these two transmission-connected generators and the distributed generators caused the system frequency to fall rapidly, and further distributed generation then disconnected in line with their protection mechanisms. Selected demand in specific regions across GB then had to be disconnected in order to protect the system due to the combined power losses exceeding the reserve held by the National Grid Electricity System Operator (NGESO).

[35]Department for Business, Energy & Industrial Strategy (2019) GB power system disruption 9 August. Energy Emergencies Executive Committee: Interim Report. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/836626/20191003_E3C_Interim_Report_into_GB_Power_Disruption.pdf

[36]National Grid ESO (2019) Interim report into the Low Frequency Demand Disconnection (LFDD) following generator trips and frequency excursion on 9 Aug 2019. Available at: https://www.nationalgrideso.com/document/151081/download

[37]National Grid ESO (2019) Technical Report on the events of 9 August 2019. Available at: https://www.nationalgrideso.com/document/152346/download

[38] https://www.nationalgrideso.com/document/151061/download

NGESO took a series of steps to limit the falling frequency and restore the power supply. Within 45 minutes the system had been fully restored to normal operation and electricity supply had been reconnected to all households. While this interruption to power supply caused a disruption directly to consumers for a relatively short duration, it was the secondary impacts of the interruption on essential services such as trains which characterised the full extent of the disruption.

The investigations following the incident highlighted that there were systems within essential service infrastructure which led to the varying levels of disruption experienced, in some cases far beyond the period of interrupted power. These were as a result of individual automatic safety systems or business continuity measures and their duration could not be directly attributed to power disconnection.

Such an event provides a real-life example of the level of interdependencies and therefore the potential for failures to cascade between sectors in GB. It also provides a strong rationale for work on mapping and fully understanding these interactions to minimise the extent to which an incident can cascade onto its downstream connections. Some work has already been undertaken to look at these cross-sector dependencies, for example the National Infrastructure Commission's study on resilient infrastructure systems and the WSP project, both published in 2020 and described in Section 7.2. Both set out the need for further, more detailed work to devise material actions which can be taken to manage interdependencies and reduce the occurrence of cascade failures.

In January 2020, a final report[39] by the Energy Emergencies Executive Committee (E3C) (in which Energy UK participates) put forward a list of recommendations to enhance the security of the network, and to prevent and manage further power disruption events. The resulting actions, in alignment with those from Ofgem's independent investigation[40] are being taken forward through the E3C and its various Task Groups which will ensure that Government, the Regulator and industry (including NGESO and individual electricity generators) take the necessary action to avoid similar occurrences in the future.

7.4 Work to support Black Start permit conditions

NGESO manages the GB electricity transmission network, which transmits high voltage electricity from where it is produced to where it is needed, and is therefore responsible for ensuring the stable and secure operation of the transmission system. Using the infrastructure owned by the three Transmission Operators (National Grid Electricity Transmission, Scottish Hydro Electric Transmission and SP Energy Networks), high voltage electricity is passed on to one of the 14 DNOs across the country. The DNOs own the local networks and convert the electricity to a lower voltage that is suitable for delivery to homes and businesses.

There may be circumstances in which there is a significant partial or total failure of the electricity supply system across GB (far more significant than the August 2019 outage described in Section 7.3), noting that the system in Northern Ireland is separate, and recovery from these failures is known as a Black Start Event. Such a total or partial shutdown could potentially be triggered by the impact of a weather event or equipment failure.

A recent survey of major power system blackouts across the world from 2011 to 2019[41] showed that 50% of the recorded instances were caused by abnormal weather conditions such as severe winds and heavy storms, and trees falling on to transmission lines as a consequence. Black Start Events are very rare but can have significant consequences in terms of health and safety, e.g. loss of power (heating, lighting, traffic signalling and refrigeration), economics (loss of power to industrial and commercial premises) and the environment (operation of large numbers of high emission back-up generators). Some international examples are provided in a report produced by DGA Consulting for the Australian Energy Market Commission in 2016[42].

[39] Department for Business, Energy & Industrial Strategy (2020) ***GB power system disruption 9 August***. Energy Emergencies Executive Committee: Final Report. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/855767/e3c-gb-power-disruption-9-august-2019-final-report.pdf

[40] Ofgem (2020) 9 August 2019 power outage report. Available at: https://www.ofgem.gov.uk/sites/default/files/docs/2020/01/9_august_2019_power_outage_report.pdf

[41] Alhelou, H.H., Hamedani-Golshan, M.E., Njenda, T.C. and Siano, P. (2019) A survey on power system blackout and cascading events: research motivations and challenges. Energies 2019, 12, 682.

[42] DGA Consulting (2016) International comparison of major blackouts and restoration. Available at: https://www.aemc.gov.au/sites/default/files/content/144f4579-f61f-41ea-803f-2048e2eb695d/DGA-Consulting-_International-comparison-of-major-blackouts-and-restorat.pdf

During a Black Start Event, NGESO would issue instructions to operate (Black Start Instructions) to a selection of power generation plants such as large power stations and smaller OCGTs in order to re-establish and stabilise the electrical grid system. These plants have been previously designated and contracted by NGESO as Black Start Units, based on their established capability to start without an external electricity supply.

During such a Black Start Event, contracted Black Start Units would be under the instruction of NGESO and would be required to operate to enable other power plants to start and stabilise the transmission system. As a result, plants (that is Black Start Units as well as other plants that are enabled to start by virtue of the Black Start Units) may be called upon to operate in a mode that is not optimised and, for plants fitted with abatement equipment, the plant may be operated in such a way that not all abatement equipment is operational or effective. It is therefore possible that, when operating under instruction from NGESO, plants may exceed the Emission Limit Values (ELVs) specified in their environmental permit. Black Start permit conditions are specified to allow non-optimised operation of plants during a Black Start Event such that emissions during this period are not used for compliance assessment purposes.

The JEP commissioned an assessment of the potential air quality impacts associated with short and long duration Black Start Events for a range of different power station technologies[43], which was accepted by the Environmental Regulators and BEIS in June 2020. The results demonstrate that, under all circumstances, the environmental impact associated with Black Start Events is inconsequential and does not need to be considered further unless the plant emissions are significantly higher than those assumed in the generic study.

The Environmental Regulators in GB, i.e. the Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency, need to ensure that the environmental impact of Black Start operation is minimised as far as is practicable. Consequently, a permit Improvement Condition was included in the permits issued as part of a wide-ranging permit review in 2019/20, which took into account the results of the JEP assessment. This Improvement Condition requires the Operator to provide a Black Start Response Plan, which sets out what the Operator will do during a Black Start Event. The plan should include an impact assessment to demonstrate that there is no significant risk associated with Black Start Events and shall propose methodologies to: i) minimise the associated environmental impact; ii) notify the Environmental Regulator of the Black Start Instruction and its duration; and iii) exclude emissions that are in excess of the ELV from reporting. The latter point reflects a practical approach to avoid a breach of permit conditions during a Black Start Event, given that such temporary breaches have been demonstrated to have inconsequential environmental impacts.

Building on the successful outcome of the generic air quality impact assessment, JEP continued to work with the regulators to formulate a generic Black Start Response Plan to satisfy the permit Improvement Condition, which was agreed in September 2020[44]. Power stations now have a clear and enduring regulatory framework within which to operate should a Black Start Event ever arise. This will add to the resilience of the electricity supply system in GB.

Although Black Start is currently a transmission-led service using large fossil-fuelled generators, NGESO and partners are engaged in a project (Distributed ReStart[45], January 2019 to March 2022) exploring how distributed energy resources such as solar, wind and hydropower can be used to restore power to the transmission network in the unlikely event of a blackout.

[43] Whitwell, I. and Griffiths, S. (2020) Air quality impacts associated with black start operation. Joint Environmental Programme, Report ENV/656/2020 Revision 1. Available at https://www.energy-uk.org.uk/publication.html?task=file.download&id=7674

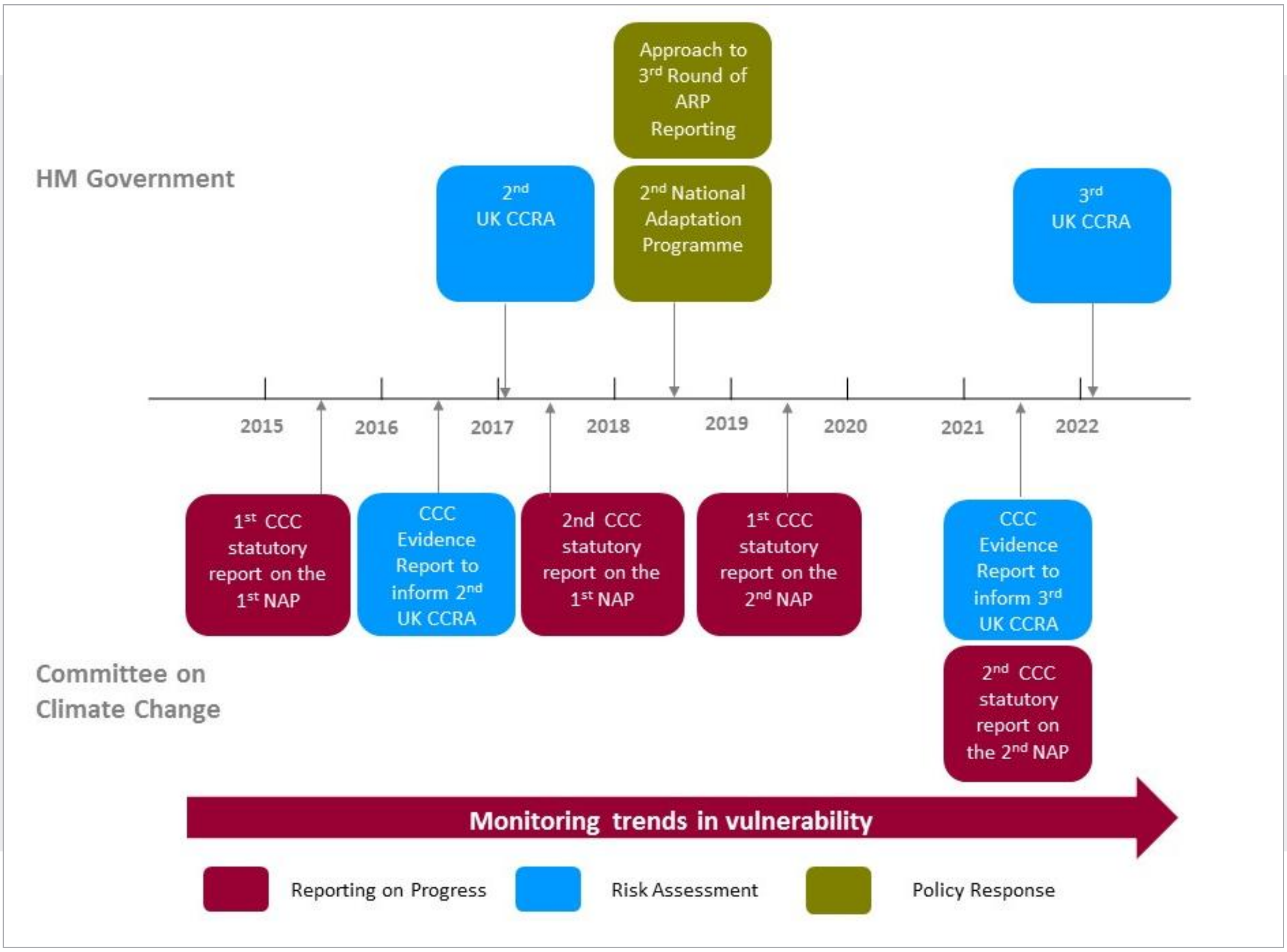
[44] Graham, D. P. and Salway, G. (2021) JEP IED Compliance Protocol (LCP BREF Update) Report UTG/20/ERG/CT/789/R. Appendix G. Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7905

[45] https://www.nationalgrideso.com/future-energy/projects/distributed-restart

8. New initiatives since ARP2 (2015)

8.1 Timeline 2015-2020

It has been over five years since the publication of Energy UK's CCAR2 in August 2015. Figure 20 below (courtesy of the CCC) gives an overview of the UK climate adaptation policy cycle and shows the key publications that have emerged since 2015 and those yet to come to complete the current adaptation reporting cycle.



Since 2015, there have been a number of other key policy announcements, publications and events, and the following Table 6 highlights those of relevance to the electricity generation sector.

Table 6. Key publications and events (December 2015 to December 2020).

DATE	PUBLICATION/EVENT	RELEVANCE TO SECTOR
December 2015	UK signed the Paris Agreement, which aims to keep the global temperature increase to well below 2°C above pre-industrial levels by the end of this century, whilst pursuing efforts to avoid more than a 1.5°C increase.	Electricity generation is at the forefront of reducing greenhouse gas emissions in the UK.
December 2015	Task Force on Climate-related Financial Disclosures established.	Some electricity generators have signed on to the TCFD (see Section 8.2).
December 2015	Record rainfall and extreme flood events across wide areas of the country resulting from Storm Desmond.	Electricity generation not significantly affected.
July 2016	UK Climate Change Risk Assessment 2017 Evidence Report (CCC Adaptation Sub-Committee).	Set priorities for the next five years. 'Risk of shortages in the public water supply, and for agriculture, energy generation and industry' was ranked third in the priority list for 'More Action Required'. Individual risks identified included (see Section 6.2): • In1: Risks of cascading infrastructure failures across interdependent networks (More Action Needed) • In7: Risks to hydroelectric generation from low or high river flows (Watching Brief) • In10: Risks to electricity generation from drought and low river flows (Watching Brief) • In12: Risks to offshore infrastructure from storms and high waves (Research Priority)

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Table 6. Key publications and events (December 2015 to December 2020) continued

February 2018	Environment Agency completed a project with Energy UK, National Grid, BEIS and Defra to consider the impact on England and Wales thermal electricity generation output capability from drought conditions.	The project (see Section 8.6) concluded that the modelled severe (1 in 200) or extreme (1 in 500) drought conditions represented no significant increased risk in National Grid's ability to meet GB electricity customers' demand.
February 2018	'Beast from the East' and Storm Emma weather events, 26 February to 3 March 2018. Freezing temperatures, blizzards and high winds prompted a Red alert from the Met Office.	Electricity generation responded to these significant events and was able to meet GB demand without being significantly affected.
June – July 2018	Exceptionally dry and warm weather (second warmest June on record for the UK).	Electricity generation not significantly affected.
July 2018	National Infrastructure Assessment (first report by the National Infrastructure Commission).	Recognised the need for infrastructure to adapt to the effects of climate change. Proposals included half of the UK's power to be produced from renewables by 2030 and ensuring resilience to extreme drought.
July 2018	National Adaptation Programme (2018-2023) and the third strategy for climate change adaptation reporting.	Endorsed the risks and priorities identified in the July 2016 UKCCRA2 Evidence Report. Government undertook to work with Energy UK to agree detailed scope of generator participation in ARP3, in view of the changes to the generation fleet and the regulatory framework within which it operates.
November 2018	Publication of UK Climate Projections 2018 (UKCP18) looking out to 2100.	Provides a set of analysis tools and the most up-to-date assessment of how the UK climate may change in the future (see Section 5). Concluded that there will be a greater chance of warmer, wetter winters and hotter, drier summers.
November 2018	Energy UK formally invited to provide an ARP3 report by Defra Minister David Rutley MP.	Energy UK responded positively, undertaking to provide a voluntary ARP3 report at sector level.
June 2019	The Climate Change Act 2008 (2050 Target Amendment) Order 2019	UK's greenhouse gas reduction target changed from 80% to 100% against a 1990 baseline, giving a Net Zero target for 2050. Electricity generation expected to decarbonise further and faster.

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Table 6. Key publications and events (December 2015 to December 2020) (continued)

July 2019	2019 Report to Parliament – Progress in preparing for climate change (CCC Adaptation Committee's first report on the second National Adaptation Programme published in July 2018).	The scoring of adaptation priorities was Green 8/9 for the energy sector and Red 1/9 for infrastructure interdependencies (see Section 6.3). Noted that: • Energy infrastructure should be sited appropriately for managing future drought and low river flows • Further research is needed to understand whether the climate risks to existing and planned offshore renewable energy infrastructure have been included into designs effectively • Impacts of increased or reduced hydropower generation can be managed using normal operation procedures on the national grid • Reporting organisations should ensure that ARP3 reports include actions to mitigate interdependent risk
August 2019	On 9 August 2019, over 1 million customers were affected by a major power disruption that occurred across England and Wales and some parts of Scotland.	Though the power disconnection itself was relatively short lived – all customers were restored within 45 minutes - the knock-on impacts to other services were significant (see Section 7.3).
February 2020	Storms Ciara and Dennis brought very strong winds and heavy rain in one of the wettest months ever recorded.	Electricity generation not significantly affected.
March 2020	COVID-19 pandemic caused national lockdown.	Generators worked closely with Government, through Energy UK, to ensure that electricity production could continue safely and securely.
May 2020	'Anticipate, React, Recover: Resilient infrastructure systems' (National Infrastructure Commission).	Calls on economic regulators to introduce new obligations on infrastructure operators to meet resilience standards and undertake regular stress tests. Highlights the cascade failure associated with the August 2019 power cut (see sections 7.2 and 7.3).
June 2020	Reducing UK emissions: 2020 Progress Report to Parliament (CCC annual report, including advice on recovery from the COVID-19 pandemic. Recommendations on emissions reduction are joined with recommendations on adaptation and advice is grouped by Government department for the first time).	Recent falls in UK emissions are dominated by policy-driven progress in the power sector (down 67% from 2008 to 2019). Progress in adaptation across Government remains significantly off track to build climate resilience. No particular recommendations for action on adaptation in electricity generation beyond those identified in July 2019.

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Table 6. Key publications and events (December 2015 to December 2020) (continued)

July 2020	AC Chair letter to BEIS Secretary of State on Adaptation in the UK's Nationally Determined Contribution.	As adaptation is one of the five themes for COP26 in 2021, Baroness Brown recommends that Government should use the opportunity of the UK's NDC to set out ambitious plans for adaptation.
November 2020	The Ten Point Plan for a Green Industrial Revolution (BEIS).	The Prime Minister set out how the economy could 'build back better' after the COVID-19 pandemic and invest to make the UK a global leader in green technologies. Offshore wind, low carbon hydrogen, new nuclear and CCUS were all allocated a 'Point'.
December 2020	Sixth Carbon Budget (CCC)	CCC's recommended pathway requires a 78% reduction in UK territorial emissions between 1990 and 2035, in effect bringing forward the previous 80% target by nearly 15 years. Electricity production is zero carbon by 2035. Electricity demand is expected to increase by a half over the next 15 years and double or even treble by 2050. The potential exposure of energy generation to risks from reduced water availability was noted.
December 2020	The UK's Nationally Determined Contribution under the Paris Agreement (BEIS). Formal submission of the UK's NDC to the UNFCCC.	The NDC commits the UK to reducing economy-wide greenhouse gas emissions by at least 68% by 2030, compared to 1990 levels.
December 2020	The UK's Adaptation Communication to the United Nations Framework Convention on Climate Change (UNFCCC) 2020 (UK Government).	The Communication complements the UK's NDC, describing the policy and legal framework for adaptation and progress to date.
December 2020	Energy White Paper: Powering our Net Zero Future (BEIS).	Puts in place a strategy for the wider energy system that transforms energy, supports a green recovery and creates a fair deal for consumers. Refers briefly to delivering actions in NAP2 and the commitment of electricity generation to report under ARP3.

The following sections highlight some of the initiatives related to adaptation in which Energy UK and its members have engaged since 2015.

8.2 Task Force on Climate-related Financial Disclosures

The Task Force on Climate-related Financial Disclosures (TCFD) is a globally-recognised best practice disclosure initiative and is a high priority signal for investors of a company's commitment to the low carbon future. The TCFD was set up to provide a framework for consistent, climate-related financial risk disclosures by companies to provide information to investors, lenders, insurers, and other stakeholders. It was established by the G20 Financial Stability Board (chaired at the time by Mark Carney, former Governor of the Bank of England) in 2015. At its heart is the idea that financial markets should be able to effectively "price climate change risk in order to support informed, efficient capital-allocation decisions".46 The Task Force illustrates that the impacts of climate change on companies do not necessarily manifest themselves only in the long term. Impacts can also be noted in the short and medium terms too, including: potential greenhouse gas reduction policy impacting on business capital and generation potential; decreased availability of water in drought periods; and the requirement to invest in new technology to meet stretching national regulations.

The G20 Financial Stability Board established the TCFD to identify the information needed by investors and lenders to appropriately assess and price climate-related risks. In its 2017 report, the TCFD set out its recommendations for disclosures that should be included in public annual financial filings. The key disclosures are structured around four areas:

- **Governance;** describing the organisation's governance around climate-related risks and opportunities, including Board oversight
- **Strategy;** the actual and potential impacts of climate-related risks and opportunities on the organisation's businesses, strategy and financial planning, including long-term scenario analysis
- **Risk Management;** describe the process used by the organisation to identify, assess and manage climate-related risks
- **Metrics and targets;** used to assess and manage relevant climate-related risks and opportunities, including greenhouse gas targets.

Organisations expressing their support for the TCFD recommendations join a cohort of leading companies taking action against climate change, including assessing and disclosing how climate change will impact their businesses. Several Energy UK member companies are signed up to the TCFD, including Centrica, Drax Power, EDF Energy UK, SSE and Uniper. A critical element of the TCFD framework is that it asks boards to understand and integrate climate-related risks and opportunities into their strategic and financial decisions, and to link information on climate change with financial information and other key business metrics. The initiative also ensures that climate risks and opportunities are considered within board and executive-level managers' decision making.

The TCFD is seen by many as one of the leading benchmarks of a company's commitment to the climate agenda. It is no surprise that 477 investors representing more than US$34 trillion in assets under management signed a letter calling upon G20 leaders to support the TCFD recommendations. Details of the recommendations and the supporting disclosures are shown in Figure 21 below:

[46] Task Force on Climate-related Financial Disclosures (2017) Recommendations of the Task Force on Climate-related Financial Disclosures: Final Report. Available at: https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf

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Figure 21. Extract from Task Force on Climate-related Financial Disclosures (2017).

Recommendations and Supporting Recommended Disclosures

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities.	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.
Recommended Disclosures	**Recommended Disclosures**	**Recommended Disclosures**	**Recommended Disclosures**
a) Describe the board's oversight of climate-related risks and opportunities.	a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term.	a) Describe the organization's processes for identifying and assessing climate-related risks.	a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process.
b) Describe management's role in assessing and managing climate-related risks and opportunities.	b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning.	b) Describe the organization's processes for managing climate-related risks.	b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.
	c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario.	c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management.	c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets.

In its Green Finance Strategy[47], published in 2019, the Government set out a series of ambitions to enhance the UK's leadership in tackling climate challenges. The ambitions include an expectation for all listed companies and large asset owners to disclose in line with the TCFD recommendations by 2022 and the establishment of a joint taskforce with UK regulators, to look at the most effective ways to approach climate disclosure.

8.3 Climate Change Adaptation in the Planning System

This section seeks to demonstrate that, from the intent set out in wider planning policy across the Devolved Administrations down to the practical application of EIAs within risk assessments, the Planning System provides a critical point at which climate change resilience and adaptation are considered in response to potential climate impacts, thus enabling deployed energy infrastructure to be suitably resilient to the climate change impacts projected in the coming decades.

While operators take the necessary steps in their projects' lifespan to analyse, address, report, review, monitor and audit the risks of climate change under existing corporate risk management procedures, in recent years, processes within the Planning System have been put in place to ensure a baseline level of preparedness before a project has even been built. In May 2017, a distinct change was made to the planning process which recognised the need for EIAs to analyse the impacts of climate change on potential developments. This ensured that, before consent had been granted, the proposed project or, in this case, energy infrastructure development had considered and could demonstrate resilience against the effects of the most-up-to date climate projections.

[47] HM Government (2019) Green Finance Strategy: Transforming finance for a greener future. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/820284/190716_BEIS_Green_Finance_Strategy_Accessible_Final.pdf

Given that this report outlines the climate change resilience and adaptation of electricity generation infrastructure across GB (i.e. Scotland, Wales and England), it is important to clarify the varying roles of each of the Devolved Administrations in planning policy and therefore the different regimes that potential developments are subject to, according to their geographical location and size. Table 7 below outlines to what extent planning is a devolved power for some administrations and not others. Planning legislation defines the capacity of generating stations in terms of 'megawatts'; custom and practice is to use megawatts of electrical capacity in planning applications, so the abbreviation 'MW' in this section can be read as 'MWe'

Table 7. Planning governance in England, Scotland and Wales.

<table>
<tr><th>Planning/consents</th><th>England</th><th>Scotland</th><th>Wales</th></tr>
<tr><td>Planning policy and Framework</td><td>The National Planning Policy Framework (NPPF)[48]</td><td>The National Planning Framework (NPF)[49]</td><td>Planning Policy Wales (2018)[50]

National Development Framework (NDF)[51]</td></tr>
<tr><td>Nationally significant infrastructure</td><td>Over 50 MW covered by the NSIP Regime under the Planning Act 2008 (except onshore wind)</td><td>Over 50 MW covered by Scottish Ministers under the Planning (Scotland) Act 2019</td><td>Over 350 MW covered by UK Govt the NSIP Regime under the Planning Act 2008

10 MW-350 MW - are the responsibility of the Welsh Government under the Developments of National Significance (DNS) regime of the Planning (Wales) Act 2015[52]</td></tr>
<tr><td>Planning applications from electricity generators up to 10 MW</td><td rowspan="2">Town and Country Planning Act 1990</td><td rowspan="2">Town and Country Planning (Scotland) Act 1997</td><td>Town and Country Planning Act 1990</td></tr>
<tr><td>Planning applications from major electricity generators from 10 MW – 50 MW</td><td rowspan="2">Welsh Govt under the Developments of National Significance (DNS) regime</td></tr>
<tr><td>Planning applications from major electricity generators from 50 MW – 350 MW (including offshore up to 12 nautical mile limit)</td><td rowspan="2">NSIP Regime under the Planning Act 2008 (excluding onshore wind)</td><td rowspan="2">Scottish Ministers under Section 36 of Electricity Act 1989</td></tr>
<tr><td>Planning applications from major electricity generators over 350 MW (including offshore up to 12 nautical mile limit)</td><td>NSIP Regime under the Planning Act 2008</td></tr>
</table>

Source: Adapted from the CCC – https://www.theccc.org.uk/wp-content/uploads/2015/06/Annex-7-Devolved-administrations.pdf

[48] Ministry of Housing, Communities & Local Government (2019) National Planning Policy Framework. Available at: https://www.gov.uk/government/publications/national-planning-policy-framework--2
[49] Scottish Government (2014) National Planning Framework 3. Available at: https://www.gov.scot/publications/national-planning-framework-3/
[50] Welsh Government (2021) Planning Policy Wales - Edition 11. Available at: https://gov.wales/sites/default/files/publications/2021-02/planning-policy-wales-edition-11_0.pdf
[51] Welsh Government (2021) Future Wales: The National Plan 2040. Available at: https://gov.wales/future-wales-national-plan-2040-0
[52] Planning (Wales) Act 2015. Available at: https://www.legislation.gov.uk/anaw/2015/4/contents/enacted

Table 7. Planning governance in England, Scotland and Wales. (continued)

<table>
<tr><th>Planning/consents</th><th>England</th><th>Scotland</th><th>Wales</th></tr>
<tr><td>Onshore wind electricity generating projects (up to 10 MW)</td><td rowspan="2">Local Planning Authorities – Town and Country Planning Act 1990</td><td rowspan="2">Town and Country Planning (Scotland) Act 1997</td><td>Local Planning Authorities – Town and Country Planning Act 1990</td></tr>
<tr><td>Onshore wind electricity generating projects (10 MW+)</td><td>Welsh Govt -DNS Regime</td></tr>
<tr><td>Onshore wind electricity generating projects (10 MW+)</td><td rowspan="2">NSIP Regime under the Planning Act 2008</td><td rowspan="2">NSIP Regime under the Planning Act 2008</td><td>Welsh Govt – Section 39 under the Wales Act 2017[53]</td></tr>
<tr><td>Offshore wind and water energy developments 1- 350 MW</td><td>NSIP Regime under the Planning Act 2008</td></tr>
</table>

[53]Wales Act (2017) – Section 39. Available at: https://www.legislation.gov.uk/ukpga/2017/4/section/39

England >50 MW and Wales >350 MW (NSIP Regime)

Nationally Significant Infrastructure Projects (NSIPs) are major infrastructure developments in England and Wales which, for electricity generation include power plants and large renewable energy projects above 50 MW in England (except onshore wind projects, which have been removed from the NSIP regime) and above 350 MW in Wales. As mentioned in Section 2.2 of this report, under the Planning Act (2008)[54], NSIPs are required to provide climate change risk assessments to the Planning Inspectorate as part of the EIA stage of their planning application (known as a Development Consent Order (DCO) for NSIPs).

As required by the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017[55] ('the EIA Regulations'), as of May 2017 all EIAs submitted under the EIA Regulations as part of a DCO need to consider:

- The impact of the development on climate (for example, the nature and magnitude of greenhouse gas emissions);
- The vulnerability of the development to climate change; and
- The impacts resulting from the interaction of identified environmental impacts of the development with climate change (in-combination assessment).

Proposed developments would therefore need to consider and address all relevant impacts of climate change (gradual changes and extreme events, taking into account the expected design life of the project), alongside any relevant adaptation measures designed to improve the project's resilience. Developers are required to provide details about the methodologies and the climate modelling inputs used to assess the potential impacts on their projects within an Environmental Statement (ES) which is submitted alongside the planning applications and legal orders to show the results of the EIA. It is a legal requirement for applications relating to EIA projects to be accompanied by an ES.

Planning practice guidance supported by Environment Agency guidance[56] stipulates that developers preparing flood risk assessments for planning applications, and DCOs should take climate change into account." In order to do so, the assessment should apply climate change allowances for the following; peak river flow, peak rainfall intensity, sea level rise, and offshore wind speed and extreme wave height.

The National Planning Policy Framework57 (NPPF), published in February 2019, sets out the Government's planning policies for England and how they would be applied. Adaptation to, and mitigation of, climate change forms one of the core land use planning principles underpinning the planning process.

Under Section 14 of the NPPF, 'Meeting the challenge of climate change, flooding and coastal change' it stipulates that:

> "…Plans should take a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures. Policies should support appropriate measures to ensure the future resilience of communities and infrastructure to climate change impacts, such as providing space for physical protection measures, or making provision for the possible future relocation of vulnerable development and infrastructure.

150. New development should be planned for in ways that:

> a) avoid increased vulnerability to the range of impacts arising from climate change. When new development is brought forward in areas which are vulnerable, care should be taken to ensure that risks can be managed through suitable adaptation measures..."

Under the NSIP process, decisions are made on the basis of twelve UK National Policy Statements, six of which cover energy policy. The National Policy Statement for Fossil Fuel Electricity Generating Infrastructure (NPS EN-2)[58] sets out additional policy requirements related to climate change adaptation for energy generating capacity of over 50 MW. NPS-EN-2 specifies that climate resilience should be considered by an applicant in their ES, including how the development would be resilient to weather-related climate change risks.

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[54] Planning Act (2008). Available at: https://www.legislation.gov.uk/ukpga/2008/29/contents

[55] The Infrastructure Planning (Environmental Impact Assessment) Regulations (2017). Available at: https://www.legislation.gov.uk/uksi/2017/572/contents/mad

[56] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances (updated in July 2020)

[57] Ministry of Housing, Communities & Local Government (2019) National Planning Policy Framework. Available at: https://www.gov.uk/government/publications/national-planning-policy-framework--2

[58] Department of Energy and Climate Change (2011) National Policy Statement for Fossil Fuel Electricity Generating Infrastructure (EN-2). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47855/1939-nps-for-fossil-fuel-en2.pdf

Wales (>50 MW, <350 MW)

The Wales Act 2017 devolves competence for the consenting of electricity generating stations up to 350 MW both on- and off-shore. The Planning (Wales) Act 2015 introduced the Welsh Government Developments of National Significance (DNS) process for developments between 10 MW and 350 MW. The Developments of National Significance (Specified Criteria and Prescribed Secondary Consents) (Wales) Regulations 2016 set out the criteria for DNS.

One of the Key Planning Principles under the Planning Policy Wales (Edition 11)[59] states that the planning system has a vital role to play in managing the unavoidable risks of climate change to development in line with the Resilient Wales well-being goal.

Local Plans are also required to reflect this principle and enable the delivery of sustainable development in accordance with the policies in the NPPF. These include the requirements for local authorities to adopt proactive strategies to mitigate and adapt to climate change in line with the provisions and objectives of the Climate Change Act 2008 and to cooperate to deliver strategic priorities which include climate change.

Scotland (>50 MW)

All planning matters are devolved in Scotland. The Planning (Scotland) Act 2019 was passed by the Scottish Parliament in June 2019 which determines the future structure of the modernised planning system and also includes preparation of the fourth National Planning Framework (NPF4). The Scottish Government sets out the purpose of the Scottish planning system and its specific land use policies in the Scottish Planning Policy.

Scottish Ministers are responsible for approving applications to build, operate or modify onshore electricity generating stations with capacities exceeding 50 MW. Applications concerning onshore electricity generating stations with capacities of 50 MW or less are approved by the local planning authority.

Applications concerning marine energy infrastructure, including sub-sea cables, wave, tidal and offshore wind electricity generating stations, are approved by Marine Scotland, which also provides guidance on monitoring watercourses in relation to onshore energy developments.

As highlighted above in relation to the English and Welsh Planning System, developers of over 50 MW capacity electricity generation projects in Scotland are also required to submit EIAs which have specific climate change risk assessments in line with the updated Town and Country Planning (Environmental Impact Assessment) Regulations 2017.

Competent authorities and the Scottish Ministers have a statutory power to require submission of an EIA Report in particular cases and a statutory duty not to grant any form of consent to a project which should be subject to the EIA process, without taking the likely significant effects on the environment into account. The Scottish Ministers have wide powers to enforce the EIA regime in Scotland.

[59]Welsh Government (2021) Planning Policy Wales - Edition 11. Available at: https://gov.wales/planning-policy-wales

Case Study

Keadby 2 Power Station – planning for resilience

As the UK transitions to Net Zero, the key role for flexible, low-carbon thermal generation is becoming clear. Analysis from the Climate Change Committee shows a role for carbon-abated gas in all the Pathways to Net Zero explored under the Sixth Carbon Budget. Fundamentally, this role is to support the mass expansion of renewable energy in the UK by providing:

- a flexible and efficient energy source when renewable energy output is low;
- system stability services to support transmission and distribution networks with high penetration of renewables; and,
- improved system diversity and security of supply.

Consistent with the above, SSE Thermal is at the forefront of proving state-of-the-art gas turbines today at Keadby 2. The 840 MWe power station, which is expected to be fully operational in 2022, brings first-of-a-kind, high-efficiency gas turbine technology to the UK, and is expected to become the cleanest and most-efficient gas-fired power station in Europe. Utilising Siemens Energy's class-leading 9000HL turbine with unparalleled efficiency, Keadby 2 will help the UK to move away from older, more carbon-intensive generation in the decades ahead. With the ability to reach full power in just 30 minutes, it will also provide vital flexibility to complement the increasing amount of renewable energy on the system and maintain security of supply. Keadby 2 will also be capable of being upgraded to further decarbonise its generation through carbon capture or hydrogen technology, as routes to market develop.

Resilience to future climate change was considered at the early stages of design and during planning for Keadby 2. The development passed the sequential and exceptions tests which were stipulated under the National Planning Policy Framework, supported by a Flood Risk Assessment, including a Breach Modelling Analysis report by Wallingford Hydro Solutions, in 2015. Keadby 2 is located in a defended flood plain and, with Keadby 1, is 'essential infrastructure'. Information provided by the Environment Agency showed that the crest level of the flood defences at the site is at 6.2m AOD, providing around 180mm of freeboard over the predicted 200-year flood levels. Breach analysis was carried out to demonstrate that Keadby 2 could pass the exceptions test. Detailed 2-D modelling showed that, in the unlikely event of a breach of the River Trent tidal defences, the flood level would be at 2.2m AOD. It was therefore possible to create a development platform at 2.6m AOD, with a freeboard of 400mm meaning that Keadby 2 has been constructed to sit above the predicted flood level. The development is therefore protected and there will be safe access under the most extreme flood conditions.

SSE Thermal is simultaneously developing Keadby 3, which could be the UK's first power CCS project.

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8.4 Climate Change Adaptation condition in Environmental Permits

From 1 December 2019, the Environment Agency introduced, through the Environmental Permitting process, a requirement for operators to carry out a climate change risk assessment for any new bespoke waste or installation environmental permit application, if the site is expected to operate for more than five years. The intention is that the Agency will use the information to review the climate change risks that may be relevant to the site and, if appropriate, apply permit conditions to manage climate change risks. Operators will then need to meet these conditions through development of a management system.

Energy UK took part in a trial of the original concept; some modifications to the original proposals were made prior to implementation. An overview of the process is provided below with further detail available online[60].

Initially operators carry out a screening assessment based upon a set criteria of, years of operation, risk to flooding and if water is used for operations or fire prevention, with each attribute being given a score out of 5. A total score of 5 or above triggers the need for an Environmental Permitting Regulations climate change risk assessment to be submitted to the Agency. If operators score less than 5 they are still required to complete the risk assessment, but not to submit it to the Agency. The subsequent climate change risk assessment involves completing a specific template of questions dependent upon the river basin district in which the site is located. Each different district has specific numeric values (for rainfall, temperature rise, river flow change, etc.) which make up the 'hazards'. The UK climate projection data (at the time of writing) is drawn from UKCP09, though the Agency indicates this will change to reflect UKCP18 at a future date.

The Environment Agency's risk assessment comes with its own definitions of impact and likelihood, with impact being linked to the possibility of permit compliance breach. For individual risk scores (pre-mitigation) that are greater than a threshold risk score, the Agency requires details of proposed mitigation and the resulting risk reduction.

For illustrative purposes, the Humber river basin district risk assessment form is reproduced below.

Potential changing climate variable

1. Summer daily maximum temperature may be around 6°C higher compared to average summer temperatures now.
2. Winter daily maximum temperature could be 4°C more than the current average.
3. The biggest rainfall events are up to 20% more intense than current extremes (peak rainfall intensity).
4. Average winter rainfall may increase by 29% on today's averages.
5. Sea level could be as much as 0.6m higher compared to today's level.
6. Drier summers, potentially up to 34% less rain than now.
7. At its peak, the flow in watercourses could be 30% more than now, and at its lowest it could be 65% less than now.

The effects of climate change are already being experienced and it is important that all operators understand how changes in climate and weather may affect operations in the future and the measures that may be needed to mitigate against short-, medium- and long-term risks thereby avoiding incidents which may impact the environment.

As stated above, representatives from the generation sector took part in the pilot study for this new permitting process in 2019. Energy UK recognises the important role that this method has in helping companies that may not be so familiar with the risks of climate change to start to understand these risks and act accordingly. Since the pilot stage, Energy UK members' experience of the new process has so far been limited. However, while the introduction of the process is welcome, operators believe that it represents a simplified approach that does not consider existing plant and may not be entirely appropriate for more complex permits and major projects associated with the sector, where a specific site assessment may be more suitable, for example through the EIA process.

[60] https://www.gov.uk/guidance/adapting-to-climate-change-risk-assessment-for-your-environmental-permit

The electricity generation sector has been reviewing the risk and associated impacts of climate change since the Adaptation Reporting process began in 2010. Consequently, the assessments companies in the sector have completed are more detailed than those which the Environment Agency requires operators to undertake when applying for a new environmental permit. Furthermore, these assessments take into account the challenges of implementing adaptation measures on existing operations as well as new projects and have become an integral part of operators' management systems. Therefore, companies are confident that climate change risks are identified, managed and mitigated for existing sites as well as new installations in the sector.

While at this time Energy UK is not aware of any initiative to apply the Environment Agency's new permit condition to existing sites, it is important to note that some of the scenarios in the Agency's tool and potential mitigation or adaptation measures which could be implemented for new plant may not be appropriate or cost effective for existing sites, or in the case of new or significantly amended plant being installed on an existing site.

Some examples of this are:

Scenario: The flow in the watercourses could be 40% more than now at its peak: A suggested mitigation would be to reduce or cease water discharge to river. This would not be possible for power plant operators who rely on being able to abstract and discharge cooling water for generation and alternative measures may be more appropriate.

Scenario: Sea level could be as much as 0.6m higher compared to today's level: A suggested mitigation is to raise the level of the site or locate items of plant above the ground floor level. An operator of an established site may not be able to raise site levels or locate plant above ground level and may choose to raise flood defences or stop operating in the event of a flood.

The electricity generation sector is diverse, therefore flexibility to allow operators to develop the most appropriate site-specific measures to mitigate climate change would be beneficial, provided the risk to operations remains suitably mitigated.

8.5 ISO 14090

The generation sector has long understood the importance of having robust plans in place to adapt to the impacts of climate change such as extreme weather events and increasing temperatures. Energy UK sees the benefits of having these plans as being absolutely key, not least for the success and longevity of its member companies. Ignoring or not fully preparing for these potential impacts can leave businesses open to infrastructure damage and significant disruption to their operations.

In June 2019, the first international standard on resilience to climate change, ISO 14090 'Adaptation to climate change. Principles, requirements and guidelines', was published. ISO 14090 was initially developed by the British Standards Institution and is the first in a range of ISO standards in this area which provide a framework for developing climate adaptation practice. This is designed to help organisations assess climate change impacts and put plans in place for effective adaptation so as to help identify and manage risks.

ISO 14090 offers a framework that enables organisations like Energy UK's members, to give appropriate consideration to climate change adaptation when designing and implementing policies, strategies, plans and activities. The standard enables a flexible approach to adaptation, whether an organisation is developing an adaptation plan from scratch, assessing existing plans, or carrying out 'deep-dive' analyses of one or several elements of adaptation. Assessments using ISO 14090, and particularly certification, can be used to demonstrate that an organisation's approach to climate change adaptation is credible. For infrastructure operators, assuring that assets and investments are secure is of great value and the standard can be used to help identify risks in supply chains for critical infrastructure. The standard offers a flexible way to make a plan that is consistent, replicable and verifiable to identify impacts and prioritise actions to ensure resilience.

ISO 14090 is intended to be the overarching standard for adaptation to climate change, and the committee that established it is also working on other standards that will provide further guidance. These include ISO 14091 'Adaptation to climate change. Guidelines on vulnerability, impacts and risk assessment' and ISO 14092 'Adaptation to climate change. Requirements and guidance on adaptation planning for local governments and communities'.

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Even before the launch of the new standard, Energy UK members already had robust climate adaptation plans and processes in place, and as described in Section 2.3, had been working to standard ISO 14001 on environment management systems which, as well as helping organisations identify and mitigate their environmental impact, provides a framework to respond to changing environmental conditions.

Building on that already strong foundation, the new standard, ISO 14090 provides a benchmark to assess whether or not those plans meet absolute best practice and provides a voluntary framework and guidance which companies can follow to assure the effectiveness of their adaptation plans. This is still a relatively new standard and many member companies will be, or are already, considering how it contributes to their climate change and adaptation strategies.

Case Study

ISSO 14090 Workshop with Climate Sense

In December 2019, Energy UK was invited to help test ISO 14090, and several member companies expressed an interest in learning more about the new standard. Given restrictions on numbers, the workshop was only able to accommodate members of Drax Power and RWE Generation UK. The organiser, Climate Sense, used the session to describe ISO 14090, and took participants through a semi-automated capability assessment. This reviewed the standard's Clause 5 which covered:

- leadership and broader governance required for climate change adaptation;
- human resources;
- roles and responsibilities;
- financial resources;
- levels of expertise and knowledge, information and data sources; and
- identifying the moments when organisations make strategic decisions.

The outcome of the exercise was prioritising action to meet the standard's requirements covering: impact assessment, decision-making and capacity, planning, implementation, monitoring and evaluation, and reporting and communications.

Generators have a good understanding of the climate impacts they are faced with and individual business decisions are already made on the basis of risk aversion and resilience. However, the standard goes a step further and provides a useful, yet flexible framework for companies to follow to ensure their existing plans are watertight and match up to the standard's best practice.

8.6 Review of resilience to drought

In 2017, Energy UK and electricity generators collaborated with Defra, the Environment Agency, BEIS and National Grid Electricity Transmission (NGET) in a project to assess the impacts of drought and low flows in rivers on individual power station output in England and Wales[61]. The project assumed that electricity generation capacity in Scotland and other European countries was unaffected. The parameters that affect output vary per station, but include water levels, flow, abstraction licence conditions, temperature limits on discharge and water quality issues which may cause biofouling. The analysis assumed no change to abstraction licences. Only the impacts during the drought scenarios and under current licence conditions were considered.

Summer droughts were considered, as well as cold, dry, cloudy periods when water availability was low and there was low renewable electricity production, combined with high demand for electricity due to heating. Two scenarios were modelled: the first for a 1 in 200 years (0.5% annual probability) 'severe' drought event and the second for a 1 in 500 years (0.2% annual probability) 'extreme' drought event. Risks to the security of electricity supply were then assessed under the two scenarios. In doing this, NGET used information provided by electricity generators to assess whether there would be sufficient generation available to meet demand if the severe or extreme drought events were to be experienced in 2017 or 2018, based on National Grid's Future Energy Scenarios (FES) available at the time. The FES provided reasonable assumptions about electricity generation in the near future using current predictions of demand, the mix of electricity generation technology, and changes to the regulatory framework.

NGET's analysis indicated that, even if such drought scenario conditions were experienced, the impact on security of supply should be relatively immaterial. The modelling exercise also showed that, even in non-drought conditions, periods of very low levels of surplus generation margin or even insufficient generation available to meet demand could potentially occur (under the assumptions of the model) during a winter cold spell, particularly at midweek peak demands. The duration and frequency of these periods were however found not to be notably affected by the drought scenarios under investigation. Such periods are expected to be limited in number and duration and well within the reliability standard for GB that NGET typically plans for. Such events could be mitigated by either a market response or actions available to NGESO, which are both within the normal bounds of operation. The analysis also showed it was not expected that there would be significant issues if the severe or extreme drought scenario conditions occurred in summer, as electricity demand is much lower at this time.

The conclusions helped to inform Energy UK's contribution to the Environment Agency's 'Exercise Arica', which was run in 2017 to identify and test the National Drought Group's strategic decisions and their consequences in response to a scenario of severe drought (Level 4) conditions in South East England over a 42 month period running from April 2018 to September 2021.

[61]Environment Agency (2018) National review of electricity generation resilience to drought.

8.7 Engagement in regional, multi-sector water resource planning

Electricity generation remains a major user of water[62]. The risk of sufficient access to water was recognised in the ARP1 sector overview produced by the AEP and the industry has played a full part in discussions with Defra and the Environment Agency regarding water abstraction reform since 2011.

As described in Energy UK's CCAR2 report, Energy UK was a member on Defra's Abstraction Reform Advisory Group until the group was dissolved in 2015. The potential water management systems under discussion for England and Wales at the time when the CCAR2 report was written were postponed in favour of a new approach set out in a Defra policy document in December 2017[63]. Defra's revised approach to water abstraction has three main elements:

- making full use of existing regulatory powers and approaches to address unsustainable abstraction and move around 90% of surface water bodies and 77% of groundwater bodies to the required standards by 2021
- developing a stronger catchment focus – bringing together the Environment Agency, abstractors and catchment groups to develop local solutions to existing pressures and to prepare for the future. These local solutions will:
- protect the environment by changing licences to better reflect water availability in catchments and reduce the impact of abstraction
- improve access to water by introducing more flexible conditions that support water storage, water trading and efficient use
- supporting these reforms by modernising the abstraction service, making sure all significant abstraction is regulated and bringing regulations in line with other environmental permitting regimes.

To track the first of the three elements set out above, Energy UK participates in the Environment Agency's Water Leaders Group, which also provides an overview of the River Basin Management Planning process required under the EU Water Framework Directive.

To respond to the greater focus on developing solutions at catchment level, Energy UK participates in the Abstraction (Water Resources) Working Group of the Catchment Based Approach (CaBA[64]), an inclusive, civil society-led initiative that works in partnership with Government, Local Authorities, water companies, businesses and more, to maximise the natural value of the environment. There are 100+ river catchments across England and cross-border with Wales, but Defra and the Environment Agency have identified 10 priority catchments[65] for developing and testing innovative solutions to achieve greater access to water and address unsustainable abstraction. However, none of the priority catchments selected includes water abstraction for electricity generation, so there has been no opportunity to explore potential solutions such as water trading with an entity having the commercial characteristics of a power plant. These characteristics are quite different from those of the public water supply, farming and environment examples that the priority catchment studies are exploring. This means that approaches developed in the priority catchments may not be appropriate to extend to the major lowland rivers on which power plants operate, although opportunities for water sharing are beginning to be explored within the regional water resource planning initiatives described later in this section.

The third element has involved planning for water abstraction licences to be brought into the Environmental Permitting Regulations regime. Since 2018, members of Energy UK have made significant contributions to the relevant Environment Agency Advisory Group to ensure that the new Regulations and associated guidance are fit for purpose and will not cause disruption to electricity generation. Following consultation, Defra expect these new arrangements to be implemented in 2023.

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[62] Booth, M-J. and Edwards, N.A. (2019) ***Water use at thermal power plant***. Joint Environmental Programme, Report JE 18WTB03. Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7466

[63] Department for Environment, Food & Rural Affairs (2017) Water Abstraction Plan. 15 December 2017 (latest update 11 February 2020). Available at: https://www.gov.uk/government/publications/water-abstraction-plan-2017/water-abstraction-plan#addressing-unsustainable-abstraction

[64] https://catchmentbasedapproach.org/about/

[65] https://consult.environment-agency.gov.uk/water-resources/water-resources-priority-catchments/consult_view/

In parallel with the water abstraction activities outlined above, Energy UK and its members are engaged in the planning process for the future management of water resources. Although water companies in England have an existing statutory duty to produce water resource management plans dealing with the supply/demand balance for public water supply, in August 2018 they received a joint letter[66] from Defra, the Environment Agency, Ofwat and the Drinking Water Inspectorate setting out what is needed to build resilient water supplies, including:

- how government and regulators are joining up to give clear direction to water companies through the water resources national framework
- how water companies and other large water users should plan at a regional scale to identify the best solutions for regions and the nation as a whole – they should look beyond their own direct needs and their own boundaries
- how government and regulators will provide a responsive regulatory approach to support regional and national planning by dealing with issues and barriers as they arise.

The National Framework mentioned above is based on a shared vision to:

- leave the environment in a better state than we found it
- improve the nation's resilience to drought and minimise interruptions to all water users.

Energy UK has been represented on the Senior Steering Group of the Water Resources National Framework since its inception and, in 2019, contributed to a preliminary study on behalf of Defra by Wood Environment & Infrastructure Solutions UK of future water demands outside of the water industry[67].The study highlighted the complexities around assessing future water demand in the electricity sector and the uncertainties associated with the many variables determining future growth of freshwater demand out to 2050. The themes of complexity and uncertainty fed into the Environment Agency's first National Framework report published in March 2020[68], which also drew attention to the likely future water needs for CCUS and hydrogen production. Energy UK was not given the opportunity to comment on the final output of the national framework report prior to its publication.

The report by Wood for Defra cited some early work carried out for the JEP on scenarios for water use in future thermal power stations[69]. This previous work was updated by JEP in 2020[70] based on a suite of scenarios of technology use and future electricity and hydrogen needs produced by NGESO in its Future Energy Scenarios (FES) 2019. The FES were used because the commercially competitive nature of the electricity generation sector precludes the existence of a sector plan, statutory or otherwise. The FES cover a range of possible futures responding to the challenge of climate change with differing societal behaviour and rates of adoption of the innovative or transforming technologies (including BECCS, hydrogen production, CCUS and combustion of blended or pure hydrogen) required to achieve the UK's greenhouse gas emissions goals. Energy UK shared the updated report with the National Framework Senior Steering Group.

The JEP modelling work was further updated following the release of FES 2020[71](which, in contrast to FES 2019, which were published before the UK formally adopted its Net Zero 2050 target in 2019, are now consistent with Net Zero) and also to incorporate the scenarios presented in the Sixth Carbon Budget report [72]published by the CCC in December 2020. Results[73] [74] were published early in 2021 to feed into the Regional Revised Resource Positions due to be published in March 2021 by the five regional planning groups in England described later in this section. Some examples of results are illustrated in the following case study.

[66] Department for Environment, Food & Rural Affairs (2018) Building resilient water supplies – a joint letter. 9 August 2018. Available at: https://www.ofwat.gov.uk/wp-content/uploads/2018/08/Building-resilient-water-supplies-letter.pdf

[67]Wood Environment & Infrastructure Solutions UK (2020) Understanding future water demand outside of the water industry. Available at: https://sciencesearch.defra.gov.uk/Default.aspx

[68]Environment Agency (2020) Meeting our future water needs: a national framework for water resources. https://www.gov.uk/government/publications/meeting-our-future-water-needs-a-national-framework-for-water-resources

[69]Gasparino, U. (2012) Independent development of water use in scenarios for future thermal power stations. Joint Environmental Programme, Report ENV/520/2012. Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=6337

[70] Gasparino, U. and Edwards, N.A. (2020) Scenarios for the projection to 2050 of water use by power producers – with a focus on WRE. Joint Environmental Programme, Report ENV/660/2020. Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7666

[71]https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents

[72]https://www.theccc.org.uk/publication/sixth-carbon-budget/

[73]Gasparino, U and Edwards, N.A. (2021) Projections of Water Use in Electricity and Hydrogen Production to 2050, under the 2020 Future Energy and CCC Scenarios including BEIS 2020 lowest system cost analysis – with a focus on the East of England. Joint Environmental Programme, Report ENV/675/2021. Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7941

[74]Moores, A. (2021) Projections of Water Use in Electricity and Hydrogen Production to 2050, under the 2020 Future Energy and CCC Scenarios – Regional Analysis. Joint Environmental Programme, Report ENV/677/2021.Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7942

Case Study

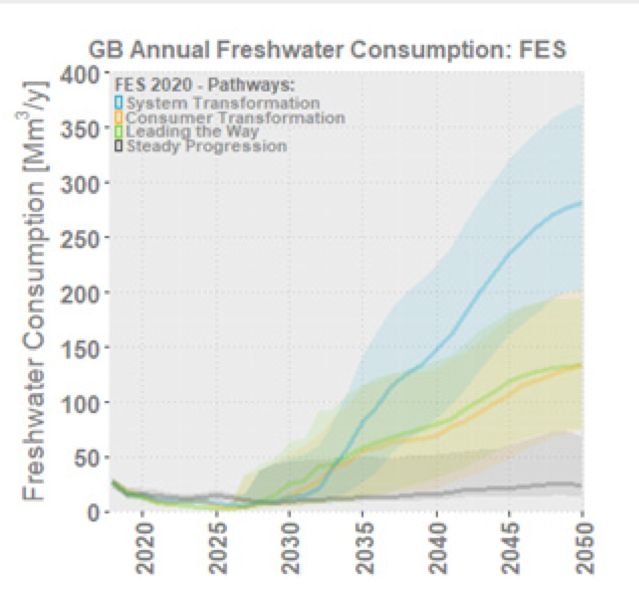
Projections to 2050 of Water Use in Electricity and Hydrogen Production

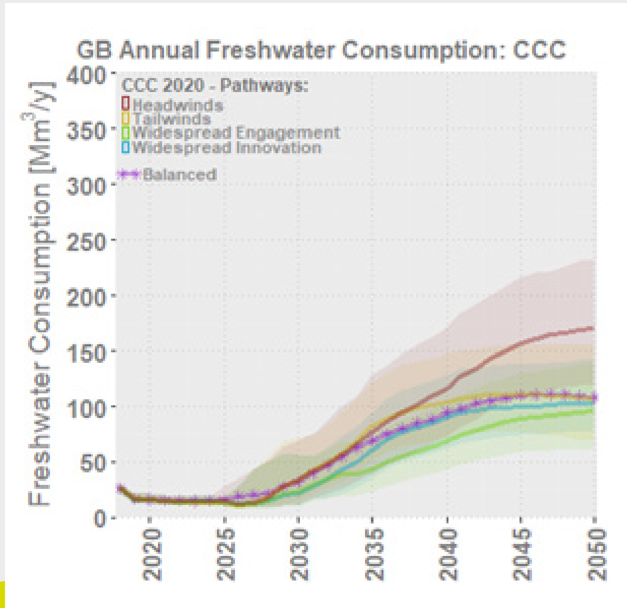
The modelling approach implemented by JEP relies on deriving consistent combinations of plant located in viable sites across GB that precisely deliver the capacity and output trajectories prescribed by the considered scenarios (FES 2020 and CCC 2020), and evaluating their corresponding water use trajectories. Since locations, types of plant, cooling technology and water use per unit output are all uncertain, the quantification was carried out in a Monte Carlo framework. In this, a set of 'rules' is used to model policy uncertainties and choices that will be made by owners and developers in the light of their perception of their commercial risk and reward in their overall business context. This will include risks associated with water availability through plant life.

Cooling water (gross and consumed for both saltwater and freshwater) and high quality (feedstock) water needs were each quantified. Results were presented at the scale of GB and each of the five Water Resource Regions quantifying annual (Mm3/y) and short-term (daily, Ml/d) water use, the latter reflecting each power plant operating at maximum output capacity when called upon to meet an electricity system stress event. The modelling approach is not designed to be suitable for inference of possible outcomes at individual site level and does not constitute a power/energy sector plan. It provides illustrative quantitative information with which to engage in water resource planning and the broader policy arena. It promotes the importance of multi-sector considerations in regional water resource planning that are essential to meet the challenge of climate change and deliver resilient infrastructure.

The principal findings are summarised at the end of this section (in the main text). Example results are illustrated below for:

- Modelled annual freshwater consumption for electricity and hydrogen production in GB, under the FES 2020 (top left chart) and CCC 2020 scenarios (top right chart). For each scenario: the solid lines illustrate the 'most probable' pathway (i.e. the median of the Monte Carlo ensemble), while the shaded areas report 'the 95% confidence intervals';





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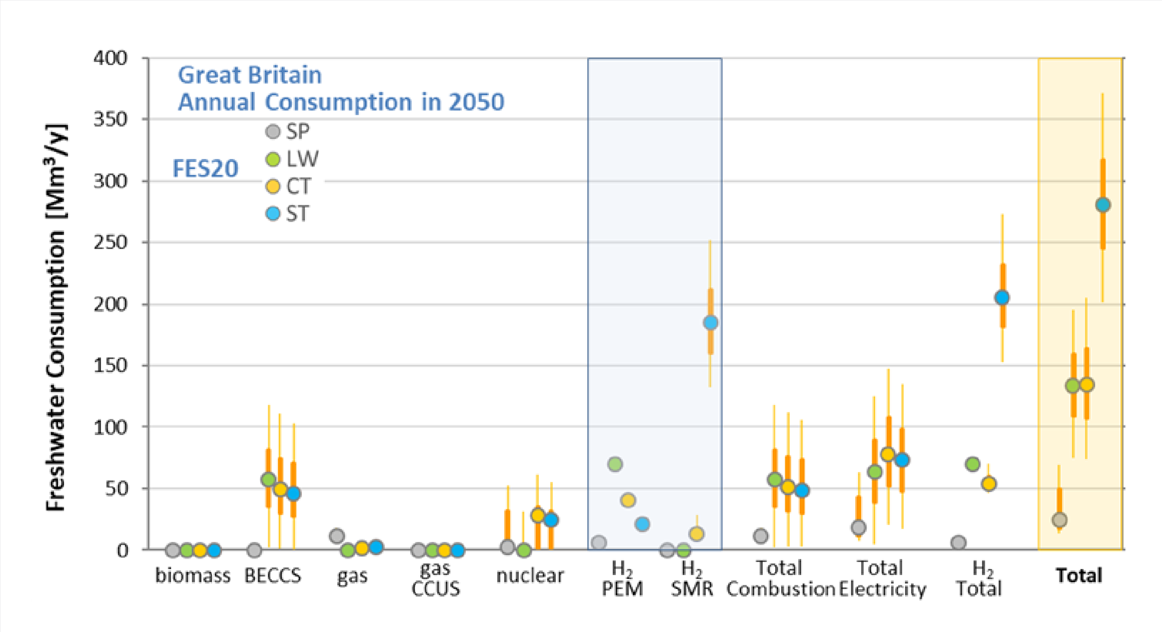
Case Study

Projections to 2050 of Water Use in Electricity and Hydrogen Production (continued)

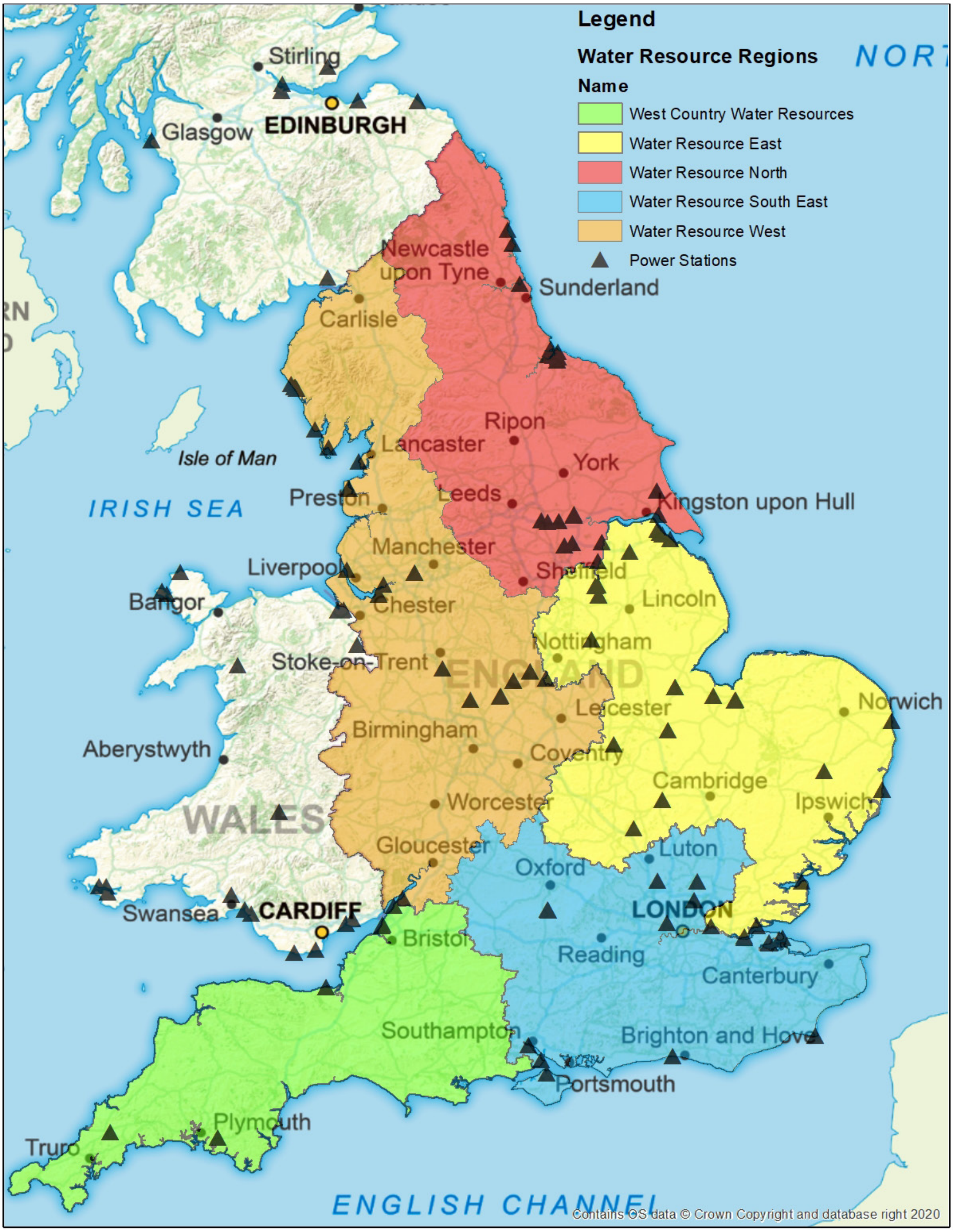
– The bottom chart (for the FES 2020) shows a snapshot of the various contributions to the 2050 freshwater consumption. ‘H_2 PEM’ and ‘H_2 SMR’ refer to hydrogen production (by electrolysis and Steam Methane Reforming, respectively). ‘Total Combustion’ aggregates the consumption by: conventional biomass and gas-fired plant, CCUS-fitted biomass and gas-fired plant and hydrogen-fired CCGTs. ‘Total Electricity’ also includes nuclear contributions. The chart reports the medians (dots) and the 25%-75% (boxes) and 5%-95% (whiskers) confidence intervals.



National water resources planning

The National Framework requires water companies in England to plan collectively on a regional basis as well as individual companies and, in a significant change from the previous planning process, to take a multi-sector approach. Consequently, five regional planning groups (shown in Figure 21 below) have been established to deliver final plans by September 2023, which will feed directly into the next water company water resource management plans.

Figure 21. Areas covered under the five regional water resource planning groups in England. Power stations (both operating and historical sites) are also shown.



Energy UK and its members represent the energy sector in the regional groups as follows:

Regional Group	Representation
Water Resources East Ltd	Board – RWE Generation UK Strategic Advisory Group – Energy UK, EDF Energy, SSE, Uniper Technical Delivery Group – Energy UK/JEP
Water Resources South East	Stakeholder Group – RWE Generation UK Multi-Sector Sub-Group – Energy UK, RWE Generation UK, Uniper General Stakeholder Community – Energy UK
Water Resources West	Senior Management Group - Energy UK, Calon Energy (until December 2020)
Water Resources North	Stakeholder Steering Group - Energy UK, Drax Power
West Country Water Resources	No direct engagement required to date

Energy UK/JEP are also represented on the Trent Working Group, a collaboration between Water Resources East and West, because several power station sites rely on the River Trent for cooling water. In 2021, the regional planning process is expected to address trade-offs between the future requirements of a range of actors e.g. public water supply, energy, agriculture, industry and the natural environment.

Water resource planning in Wales has had a much lower profile, but in 2019 Energy UK engaged with a study run by Arup on behalf of the Welsh Government and Natural Resources Wales to examine future water demand in sectors outside public water supply (Phase 1) and to scope out drivers for future changes in water demand, means to mitigate them and research priorities (Phase 2). Energy UK was interviewed by Arup in 2019 for Phase 1 and participated in a workshop at the beginning of March 2020 for Phase 2.

The study report (which is available only on application) acknowledges that, outside public water supply, electricity generation is by far the greatest user of water within Wales, accounting for 95% of the licensed volume. However, many of the processes associated with power generation are often considered to be non-consumptive, e.g. hydro-electric power or non-evaporative cooling, meaning the water is returned to the environment close to the point of abstraction.

Whilst not consumptive, this volume of water is still required for initial abstraction and use. The issues around future water resource planning in England and Wales that are highlighted above, and how they relate to combustion-based generating technologies (other than nuclear), are explored in more detail in a JEP report completed in 2020[75].

[75]Booth, M-J. and Edwards, N.A. (2020) Positioning combustion power plant in water resource management planning. Joint Environmental Programme, Report JEP18WTB02 (Revision 1). Available at: https://www.energy-uk.org.uk/publication.html?task=file.download&id=7740

Principle findings of projections of water use in electricity and hydrogen production to 2050

Future access to sufficient and reliable freshwater supplies will remain a priority issue for the energy sector for the foreseeable future. There has been a significant decrease in water use since 2010 due to the closure of coal-fired power stations and gas-fired stations running more intermittently as the generating capacity of renewable technologies increases. From the JEP analysis and modelling of future energy scenarios (illustrated in the case study above), the following conclusions can be drawn:

There is considerable uncertainty in future potential water need for electricity and hydrogen production at all of national, regional and sub-regional scales.

Whilst there are considerable differences in detail between the various scenarios and policy backdrops considered in the modelling, the general trends common to all are clear:

- Continuing decline in freshwater use until the mid-2020s
- Followed by a sharp increase in freshwater requirements from then through the 2040s, with future freshwater use returning to or, in some scenarios, exceeding that occurring in 2010.
- Hydrogen production accounts for a significant proportion of future water use.
- The relative uncertainty increases at smaller spatial scales
- This emphasises the importance of decisions taken at individual site and asset level by owners and developers.
- Whilst there are indications that future energy sector developments using water might be attracted to the estuarine CCUS clusters that are beginning to emerge, there are other locational signals that would attract hydrogen infrastructure to inland sites.

As illustrated by BEIS[76], there is no unique optimal technology mix for 2050 and there is considerable current variability in technology trajectories in successive FES and CCC studies, with the prospect of further changes as new technologies emerge. Therefore, it is important to the sector and society as a whole to keep options open when planning for future water resource needs and to ensure that the option for future development at freshwater sites is not unduly impacted or excluded. This would allow the development of fresh water dependent electricity and hydrogen production assets at riverine sites in response to relevant locational and market signals. These assets would contribute to the diversity of the future generation fleet and make use of existing infrastructure.
The high quality water requirements for electricity and hydrogen production may be significant at local level if sourced from potable water supplied via public water supply.

Existing thermal power plant will play an important role in the transition to a low-carbon generation fleet and will require continuing access to sufficient water and reliable water rights in order to generate electricity, underpin participation in the Capacity Market and provide additional important services to NGESO. Future water-dependent energy projects e.g. for CCUS, BECCS, hydrogen production and hydrogen use, will require sufficient, reliable access to water rights; this is essential to secure future financial investment in the new technology. An unintended consequence of restricting water abstraction and water rights for the energy sector could be the failure to meet the UK's Net Zero target in a timely, efficient and resilient way.

[76]Department for Business, Energy & Industrial Strategy (2020) Modelling 2050: electricity system analysis. Available at: https://www.gov.uk/government/publications/modelling-2050-electricity-system-analysis

9. Future uncertainties

The energy/water nexus

For individual operators, the greatest risks may not be related to climate change itself, but to regulatory and policy measures that Government may choose to adopt in order to encourage organisations to deliver the country's adaptation strategies. Areas of uncertainty in policy development, especially with regards to water policy, were therefore considered in the previous CCARs. Uncertainty in the regulatory regime is generally undesirable, and can affect corporate capital investment decisions. In this respect, it is important to recognise the basic differences in attitude and investment risk between companies within an economically regulated market with near geographic monopoly (as is the case, e.g. for water companies regulated by Ofwat; or electricity and gas transmission and distribution network companies regulated by Ofgem) and those of a purely commercial industry (some with multi-national ownership) active in a competitive market (as is the case for the electricity generating companies) in which possible investments in UK assets are in competition with other opportunities outside of the UK.

Since the CCARs submitted in 2011 and 2015, much has changed in the areas of water policy and regulation (see Section 8.7). There remain many active debates relating to the regulation of the aquatic environment and water resource management many of which, at least in part, are motivated by climate change adaptation. These together present challenges and uncertainty for power generation and energy sector companies considering the potential role of existing water-dependent power generation assets and options for new water-dependent assets against the backdrop of the UK's Net Zero commitment by 2050.

There is still much to be done to develop water resource regulation, allocation plans and policies in order to provide sufficient confidence to make long-life strategic infrastructure projects investable, given the likely intense competition for scarce reliable freshwater resource in the coming years. Whilst the importance of considering the resilience of PWS and appropriate environmental protection are recognised, there remain concerns regarding the way in which non-PWS sectors can secure access to water. The transition of water abstraction law to Environmental Permitting Regulations, along with updated supporting regulatory guidance, may provide an opportunity to develop an updated regulatory framework. This might be better equipped to support the more dynamic, multi-sector and cross-sector approaches to water resource management which may provide improved economic efficiency in water resource allocation and use, whilst also providing resilience.

The introduction of Marine Spatial Plans is a welcome step in seeking to provide a development framework for the many sectors which currently make responsible use of the marine environment, and aspire to do so in future. However, despite their best efforts as active stakeholders, electricity producers are concerned at the lack of recognition within the existing plans of the vital role of non-nuclear thermal power plant in delivering robust, affordable security of electricity supply in the next few decades, as the power sector continues to respond to decarbonisation drivers.

Other notable areas of uncertainty include:

- The way that the EU Water Framework Directive may be interpreted regarding the setting of targets for the aquatic environment beyond 2027, and the way those targets may or may not take account of climate change influences, especially on aquatic ecology.
- Changes in the way current and future Water Framework Directives may influence aquatic regulation in the UK following its exit from the EU.
- Implications for environmental ambition in combination with Devolved Administration environmental aspirations (such as the 25 Year Environment Plan in England or the Environment (Wales) Act 2016). The Environment Agency is urging stakeholders to seek environmental ambition beyond legal requirements in respect of water resources and this could put additional pressure on power/energy and other sector water rights.
- The overall approach to the objective of Net Zero by 2050 and climate change adaptation (the IPCC is producing its Sixth Assessment Report, AR6, currently due for release in 2022 and both mitigation and adaptation strategies may need reassessment after that).

The inevitable changes to the biological, chemical and physical aquatic environment which will be brought about by climate change in the coming decades, combined with uncertainty in aquatic environmental regulation, provide considerable overall uncertainty regarding the delivery of the major future water-dependent power plant, CCUS and hydrogen production projects that the UK will require in order to deliver Net Zero.

Future reporting and addressing interdependencies

As explained in Sections 8.3 and 8.4, requirements on operators to demonstrate the climate change resilience of their site or plant will be increasingly addressed in the early stages of, or before, development, such as through environmental permitting and in the EIA stages of the planning process. This means that any new energy developments from December 2020 will have had to go through at least one, if not both, of these processes and future-proof their assets against projected climate change risks.

There are existing assets which, although they predate these obligations in the permitting and planning regimes, already undertake comprehensive climate change risk assessments as part of their standard business forward planning process. As some of these plants may come to the end of their lifespans in the next 5 to10 years, the focus of future ARP rounds will logically become more of a light-touch review and 'top up' assessment of the sector's additional actions on climate change adaptation and resilience.

Attention may then turn more to the sector's key role in the web of infrastructure interdependencies across the UK. While key mapping exercises have already been undertaken in recent years and understanding of the interdependencies has grown, in the coming years we expect that recommendations and actions such as those proposed by the NIC or those coming out of significant events such as the August 2019 power outage, will start to emerge to address potential vulnerabilities to cascading failures.

These actions will need to be embedded into existing regulatory frameworks and processes as far as possible to streamline the requirements on infrastructure operators and ensure actions become common practice. It may be challenging to do so when trying to encompass multiple sectors, each with its own existing level of resilience, long or short history of addressing climate change-related risks and unique adaptation plans. It is therefore important that all sectors have the opportunity to engage with the process of devising approaches to tackle interdependencies, to ensure that these are fit for purpose in all cases.

10. Conclusions

Energy UK has collated information on the progress made in the electricity generation sector in adapting to climate change since its CCAR2 report was delivered in 2015. This has been undertaken at sector level within GB, on a voluntary basis, in response to a request from Government under ARP3.

As a result of the sector's leading role in the reduction of greenhouse gas emissions, the portfolio of generating technologies in operation and the ownership of particular plant has changed markedly since 2015. Consequently, the scope of this report has been broadened from the large (>100 MWe) thermal and hydroelectric power stations considered in CCAR1 and CCAR2, to include commentaries on smaller (50 MWe to 100 MWe), distributed thermal plant and large (>100 MWe) wind turbine arrays.

In CCAR1 and CCAR2, climate change risks were quantitatively assessed by generating companies (out to 2039, which will encompass the remaining lifetime of most of the existing assets). The analysis relied on the UKCP09 climate projections, available at the time. A review by JEP has shown that, for the timeframe of interest, the conclusions of the previous assessment continue to hold under the updated UKCP18 projections, released in November 2018. For new developments, the demonstration of resilience against future climate change, undertaken as part of the planning and environmental permitting processes required for new plant, will use UKCP18.

New regulatory initiatives in the planning and environmental permitting systems since CCAR2 have served to further strengthen consideration and mitigation of climate risks at the development stage of new energy projects. Generating companies are also increasingly embracing voluntary initiatives on climate-related financial disclosure and adoption of new international standards for the management of climate change adaptation.

All adaptation actions identified in CCAR1 by the companies that were directed to report in ARP1 have been progressed and 73 of the 88 agreed actions have now been completed. This has led to a further decrease in risk, albeit from an already low base. 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 ongoing processes and plans are put in place to mitigate potential impacts, thus ensuring a flexible response to future changes in climate risk drivers.

External reviews such as CCRA2 in 2017 and the Adaptation Committee's progress report to Parliament in 2019 have raised no significant concerns about the adaptation response of electricity generation itself, but better understanding and management of the interdependencies between infrastructure sectors is a recurring theme. Energy UK continues to seek improvements in those areas through participation in multi-sector fora, independent studies and through close collaboration with regulators. Despite several episodes of extreme weather since 2015, there has been only one significant loss of generating capacity; a combination of events resulted in a major power outage in August 2019. While the interruption to power supply was of relatively short duration (NGESO restored the system to normal operation within 45 minutes), the full extent of the disruption was characterised by knock-on impacts on other essential services, such as rail transport.

A key area of current engagement and future uncertainty for the sector is the energy/water nexus. Existing thermal power plant will still play a valuable role in supporting the transition to a decarbonised power system and will require continuing access to sufficient water and reliable water rights in order to generate. Furthermore, future water-dependent energy projects e.g. for CCUS, BECCS and hydrogen production, will also require sufficient, reliable access to water rights to secure future financial investment. An unintended consequence of restricting water abstraction and water rights for the energy sector could be the failure to meet the UK's Net Zero 2050 target in a timely, efficient and resilient way.

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