Adapting to Climate Change

Nov 2021 >

NORTHERN POWERGRID

Foreword

Our climate is changing and, despite international efforts to reduce greenhouse gas emissions, it is expected to continue to change. Winters will be warmer and wetter, summers will be hotter and drier and both with increased likelihood of extremes. We know it is critical to homes, businesses and the emergency services to keep the power on during these extremes in weather. At Northern Powergrid we are proud to be positioned at the heart of our regions delivering a secure electricity supply to our customers. We are committed to providing the highest levels of customer service, network reliability and environmental care.

Our long-term success is dependent on how well we prepare for the challenges that the future operating environment will bring.

We have had experience of dealing with extreme weather events, most recently major floods have affected wide areas of our network which appear to be increasing in frequency. These events have enabled us to ensure that our emergency plans are robust and to examine our performance during these events. We continue to learn lessons from every major incident and proactively build upon the improvements to resilience that we have been implementing for the last 20 years. Our accelerated and expanded investment in flood defences in the current price control is an example of this – by 2023 we will have made 295 sites more resilient to flooding, well beyond the 156 we committed to in our 2015-23 business plan.

Looking forward, we have considered a variety of climate scenarios ranging from 2°C to 4°C global warming and the impact this would have on our network and operations. Whilst we understand that a 4°C scenario is certainly not desirable or acceptable from a global policy perspective, it is a viable worst case, scientifically plausible outcome that we must consider.

Our role in society is changing. Our aim is to lead the drive towards decarbonisation in our regions. We recognise that we are a cornerstone of an energy system that enables an exciting transformation to combat climate change and build a more sustainable future for future generations. Our long-term success is dependent on how well we prepare for the challenges that the future operating environment will bring by accounting for, and adapting to, the effects of climate change on our assets and operations. Collaboration with other parties is a major part of that and we are committed to working with partners within and outside the energy system to improve infrastructure resilience for customers.

This report sets out our progress in adapting to climate change since our last report in 2015 and details how we will continue to improve the resilience of our network as our customers' use of electricity and our network changes over the decades to come.

Our 2023-2028 business plan will continue to build upon the resilience measures we have implemented to date. The plan includes significant investment in asset resilience which will build resilience for the long-term and continue with bespoke adaptations to respond to the future climate predictions.

Alex Jones
Director of Performance and Planning

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Executive Summary

1. Executive Summary

Northern Powergrid is responsible for delivering electricity to over 8 million customers across 3.9 million businesses and homes. Our network consists of more than 63,000 substations and over 96,000km of overhead power lines and underground cables spanning 9,650 square miles.

In 2011, we published our first Climate Change Adaptation Report. This document is the third update to this report and sets out our approach to ensuring a resilient network and organisation. The Northern Powergrid Adaptation Management Pathway is shown on the next page.

8 million
customers

3.9 million
homes and businesses powered

9,650
square miles

64,355
substations

96,814km
overhead lines and cables

1. Executive Summary

Adaptation Management Pathway

Anticipate

Predict long and short-term variations utilising:

- a range of plausible climate change projections;
- weather forecasting.

Assess

Assess the impact of climate change and severe weather on the organisation and the asset base to understand the risk in order to target adaptions.

Adapt

Implement bespoke adaptions to either:

- resist the impact or effect; or
- recover more quickly following an event.

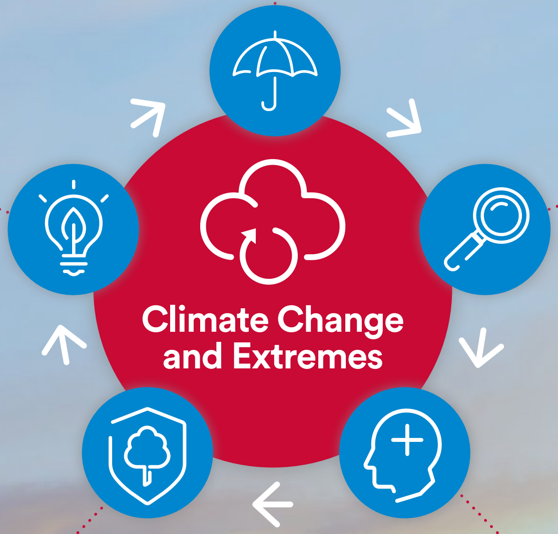
Recover

When events are imminent and interventions are at risk of being overwhelmed, robust incident management and recovery plans are mobilised.

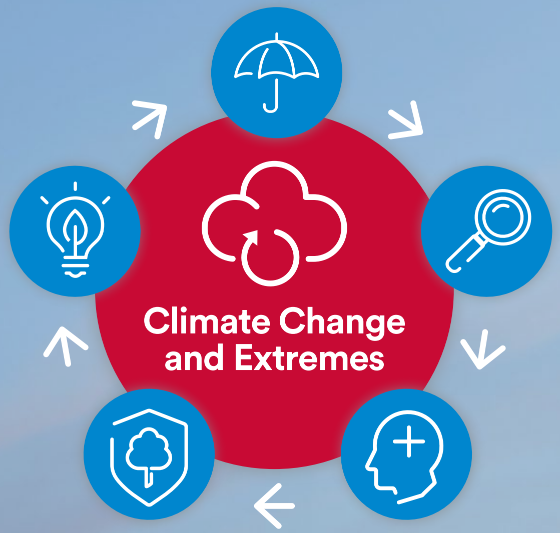
Transform

Using learning from past events to:

- inform adaptions;
- improve future resilience; and
- enhance recovery response.



1. Executive Summary



Anticipate

We have utilised the UKCP18 Climate Change Projections produced by the Met Office to ensure that we are using the latest and most robust scientific data on climate change. Each climate condition that could potentially affect our network has been considered and the projections to the end of the century examined across a number of plausible climate scenarios. The climate conditions considered to be of most concern to Northern Powergrid relate to flooding and rainfall levels and increases in temperature.

In addition to exploring the available data, we have also consulted extensively with stakeholders to ensure that we capture their concerns and appetite for investment.

Assess

In order to fully prepare for the changes highlighted during the Anticipate phase, we have considered the impact of the projected changes on both our network and organisation as well as the potential interdependencies with other infrastructure organisations. The risks of most concern include flooding and vegetation management although there are potential impacts on network performance from temperature rises and other extreme events.

Adapt

Following on from the risk assessment, we have considered how best to adapt to the challenges. This may be by resisting through the use of preventative measures, such as flood defences, or responding to incidents by making changes to our network, such as increased automation, to allow us to restore supplies in a more timely manner following an incident occurring.

Recover

We recognise that in some cases interventions may be overwhelmed. We have ensured that we have robust incident management and recovery plans in place to help us quickly restore the network to the expected levels of service. These plans have been implemented multiple times and are subject to continual review to ensure that they continue to provide the best possible service for our customers.

Transform

The final stage of our adaptation pathway ensures that we continue to transform our organisation to enhance the resilience of our network. This is achieved by considering lessons learnt from network incidents alongside continually reviewing best practice to allow our adaptations and organisation to evolve.

We continue to invest in innovation and research and to build emerging technologies and practices into our organisation to allow us to continue to provide the service that our customers expect from us.

2 Introduction

2. Introduction

2.1 Business Overview

Northern Powergrid[1] is responsible for delivering electricity to over 8 million customers across 3.9 million businesses and homes. We operate through our subsidiary companies, Northern Powergrid (Northeast) Ltd in the North East and North Yorkshire and Northern Powergrid (Yorkshire) plc in South, East and West Yorkshire and northern Lincolnshire.

The Northern Powergrid network consists of more than **63,000 substations** and some **60,000 miles** of overhead power lines and underground cables spanning **9,650 square miles.**

As a distribution network operator (DNO), our role is to ensure safe, secure and cost-effective delivery of electricity to our customers. To do this, we:

- invest around **£1 million a day** to maintain and strengthen the resilience of our network
- provide customers with new connections to the network. These can range from moving a single domestic supply to providing connections for new housing or commercial developments.

Figure 1 – Northern Powergrid's Area

1. northernpowergrid.com/

2. Introduction

2.2 Electricity Networks Overview

In the UK, generation is a competitive market. Energy supply companies buy electricity in bulk from generation companies and pay transmission and distribution companies to transport electricity through their networks to homes and businesses.

Transmission and distribution companies are responsible for providing a reliable supply of electricity to their connected customers across the UK in an efficient manner whilst delivering excellent standards of customer service.

These are regulated businesses, operating under licences issued by Ofgem[2], and are subject to a common regulatory framework. They are also subject to common statutory requirements including The Electricity Act and Electricity Safety Quality and Continuity Regulations (ESQCR)[3] which are overseen by Department for Business, Energy and Industrial Strategy (BEIS) and the Health and Safety Executive (HSE).

This basis of a common background, asset standards and regulatory processes means that UK electricity DNOs have very high commonality when approaching the assessment of climate change impacts on their networks. The level of climate change will vary across the UK but the assessment of impact per unit of change, such as degrees centigrade, can be established using common methodology.

As a consequence of these common drivers, UK Electricity DNOs have worked together through the Energy Networks Association (ENA)[4] for many years across a wide range of activities including:

- establishing UK network owner input to the content, development and modification of national and international standards
- establishing common equipment specifications and design standards, across the full spectrum of network assets, to reduce procurement costs and ensure availability of product
- providing a unified input to UK Government and regulators (Ofgem, HSE etc) on development of regulations, processes, reporting etc
- collaborating on research and development, including impacts of climate change and work on asset designs/ratings.

Allowed revenues for the industry are currently set by Ofgem with individual network operators and these periodic reviews govern all expenditure, including resilience against natural hazards and emergency planning. This provides common oversight and accountability to Ofgem and BEIS. Any costs associated with adaptation to climate change are subject to regulatory scrutiny.

Transmission and distribution companies are responsible for providing a reliable supply of electricity to their connected customers across the UK.

2. ofgem.gov.uk/
3. hse.gov.uk/esqcr/index.htm
4. energynetworks.org/

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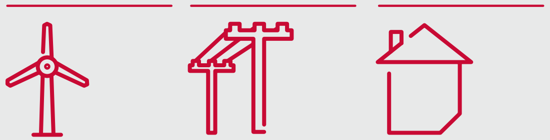
2. Introduction

2.3 System Overview

Electrical power is transported from generating plants to customers over networks managed by transmission and distribution companies. The transmission system operates at typically 400,000 Volts (400kV) or 275kV and the distribution system, as operated by Northern Powergrid, uses voltages from 132kV to the normal household voltage of 230V.

The system comprises a mixture of overhead lines and underground cables. In addition, there are sites, called substations, where voltage transformation takes place and switching and control equipment are located. The characteristics of different types of substation are described in Table 1 – Types of Electrical Substation.



400/275kV Typical voltage used on the transmission system

132kV to 11kV Range of voltages used on the distribution system

230V Typical household voltage

The transmission system is owned and operated by National Grid and the interface between them and the Northern Powergrid distribution systems takes place within grid supply or super grid substations, typically at 132kV.

Network design takes account of normal load growth which has historically been around 1.5% to 2% per annum. Although this historical level of growth may reduce due to economic and energy efficiency pressures, load on the network is expected to double over the next forty years.

Northern Powergrid, along with the other distribution network operators in the UK and their industry body, ENA, have contributed to all rounds of climate change adaptation reporting, producing reports under all rounds of the Adaptation Reporting Power (ARP).

- In ARP1 we established the response as a collaborative project amongst electricity network operators and identified key risks to network assets and operation posed by climate change impacts.
- In ARP2 we built on our understanding of the risks and updated Defra on industry mitigation measures being put into place on the networks. We developed the consistent reporting methodology from ARP1 and provided further evidence of actions taken in response to key climate risks.
- In ARP3 we aim to provide an update on existing risks, mitigation measures and programmes but will also look to identify new risks being realised in order to provide a fuller picture of the potential for climate change impacts to affect networks.

Figure 2 – Typical Electricity Supply Chain

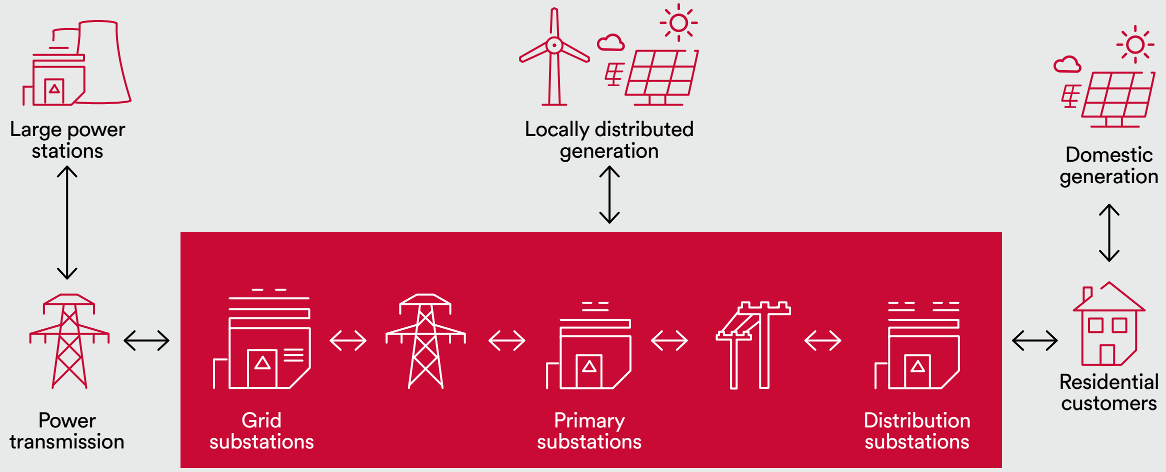


Table 1 – Types of Electrical Substation

Substation Type	Typical Voltage Transformation Levels	Number in Northern Powergrid Region	Typical Size	Typical Number of Customers Supplied
Grid	400kV to 132kV (owned by transmission companies)	36	250m x 250m	200,000/ 500,000
	132kV to 33kV	115	75m x 75m	50,000/ 125,000
Primary	33kV to 11kV	571	25m x 25m	5,000/30,000
Secondary	11kV to 400/230V	27,386	4m x 5m	1/500

2. Introduction

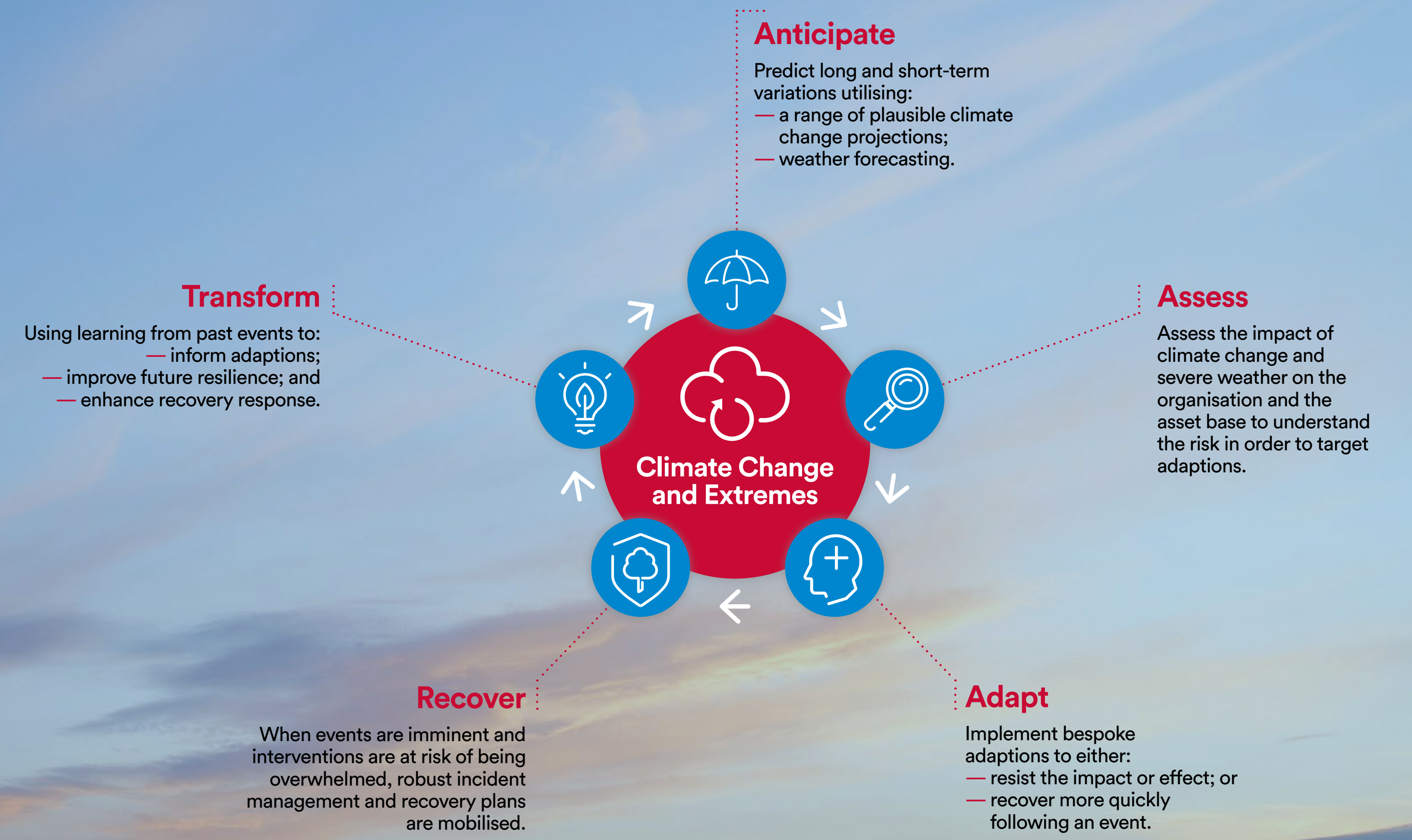
2.4 Resilient Infrastructure

The climate resilience process followed by Northern Powergrid closely aligns to the framework set out by the National Infrastructure Commission in its report "Anticipate, React, Recover"[5] from May 2020.

- Anticipate future impact through thorough assessment and analysis.
- Implement adaptions to resist and/or recover from shocks and stresses.
- Drive a cycle of continual improvement by learning from past events, new climate science and innovative solutions.

Our process is separated into five elements which form a cyclical approach to adaptation and resilience. Figure 3 illustrates this process.

Figure 3 – Adaptation Management Pathway



5. nic.org.uk/app/uploads/Anticipate-React-Recover-28-May-2020.pdf

3

Anticipate

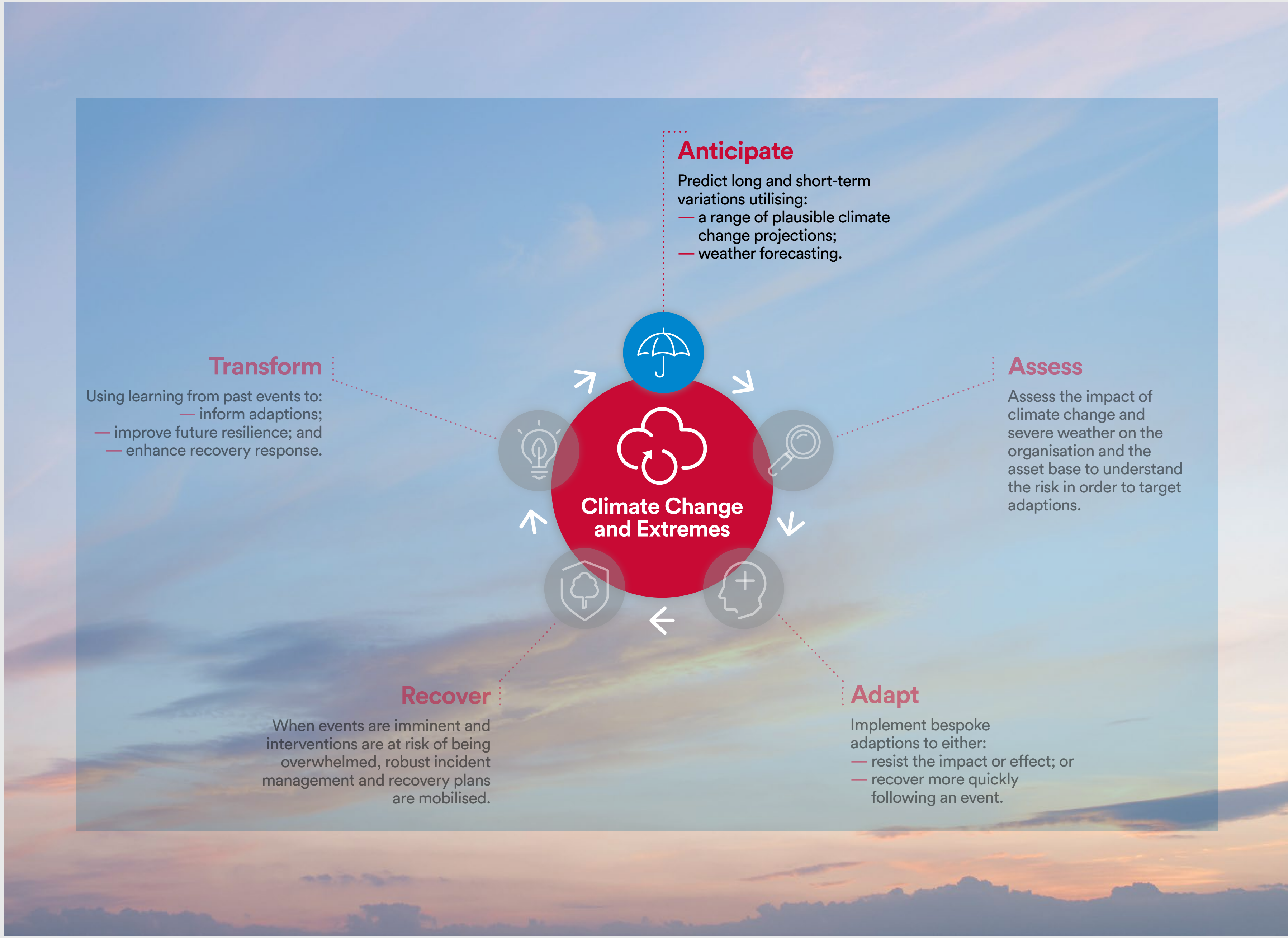
3. Anticipate

3.1 Stakeholder Engagement

In order to prepare ourselves for any impact from climate change, we have tried to anticipate the effects this may have on our network in order to be prepared for most eventualities. This has been done through stakeholder engagement and the analysis of the latest climate change projections.

As an organisation that provides an essential service to our customers, ensuring that the actions we take have the support and backing of our stakeholders is vitally important and climate adaptation is no different.

We engage regularly with customers and stakeholders on how we run our business. We are constantly looking for ways to improve our approach, including responding to learning from Ofgem's Stakeholder Engagement and Consumer Vulnerability (SECV) assessment process and our accreditation against the AA1000SES stakeholder engagement standard.



3. Anticipate

We have developed a stakeholder charter, shown on this page, which sets out our promise to ensure that we run high quality engagement that ultimately reflects the views of the customer in a transparent and evidence-based manner.

The scale of our stakeholder engagement has been growing during the current RIIO-ED1 price control period and we are using these insights to inform how we run our business day-to-day and how we shape our plans for the next price control period, RIIO-ED2.

Prior to 2015, we conducted willingness to pay research which reinforced the importance that our stakeholders placed on our flood defence works. This research led to the acceleration of our proposed flood mitigation programme so that it completed in four years instead of the originally programmed eight. Following reviews of flooding standards, due to the appetite of stakeholders for flood prevention, we expanded this programme to cover sites with in excess of 10,000 customers by the end of 2021 rather than waiting until the RIIO-ED2 period to complete the additional recommended works.

In September 2019 we established our Customer Engagement Group (CEG). This is a group of ten independent experts charged with scrutinising our RIIO-ED2 business plan and the quality of the engagement undertaken to inform it. They help to ensure that customers' needs and views are reflected in our plans and will publish a report on their findings in 2021, alongside our business plan submissions to Ofgem.

Stakeholder engagement on climate change adaptation throughout 2020 has produced a number of themes of importance.

- Planning For The Worst: A 2°C global temperature rise by 2100 should be considered but a 4°C+ risk should also be considered as a worst-case example.
- Collaboration: There is a need for collaboration between infrastructure sectors to ensure resilient infrastructure and that we are all working towards a common goal. Stakeholders would like to see Northern Powergrid considering catchment based flood protection.
- Interdependencies: Interconnection between different industry sectors is a major source of risk with failures in one sector cascading and impacting another.
- Comprehensive Climate Analysis: Stakeholders would like to see broader proposals that consider climate challenges other than flooding.
- Ambition: Stakeholders want to see ambitious targets.
- Innovative: Stakeholders expect innovation to be used to manage risk and cost.
- Cost and Willingness to Pay: Support amongst all stakeholder groups is particularly high for improving resilience to flooding.

Northern Powergrid Stakeholder Charter

1 Stakeholder Led	— Our engagement is flexible, shaped by your priorities, and evolves as outcomes become more defined — Early, deliberative engagement informs the structure of our plans and initial working assumptions to test with you
2 Representative & Inclusive	— Everyone in our region has the opportunity to contribute to our plans so that all voices are heard from across the diverse communities we serve — New and innovative techniques are used to engage with those of you who are 'hard to reach'
3 Open & Transparent	— You are actively encouraged to participate in our planning process — You are kept informed of our decisions and rationale throughout the engagement process
4 Accessible	— Engagement methods are flexible, varied and unrestrictive to accommodate your differing needs — We will educate you as required to help you understand our business and the options available so that you can make better-informed decisions and provide richer input
5 Responsive & Adaptive	— Best practice and lessons learned inform our approach — Our programme is flexible, evolving and adapting to change as we learn more about your needs

3. Anticipate

3.2 Climate Change Projections

The latest UK Climate Projections (UKCP18)[6] were produced by the Met Office and released in November 2018. UKCP18 uses the latest developments in climate science to provide the most up-to-date national climate projections and Northern Powergrid has utilised UKCP18 as the definitive source on climate data for this report. Our two prior Adaptation Reports utilised UKCP09, the predecessor to UKCP18. The main signals within UKCP18 remain unchanged from those within UKCP09.

To model and predict future climate it is necessary to make assumptions about the economic, social and physical changes to our environment that will influence climate change. UKCP18 uses Representative Concentration Pathways (RCPs)[7] to capture those assumptions. These pathways represent a broad range of climate outcomes, including a wide range of assumptions regarding population growth, economic development, technological innovation and attitudes to social and environmental sustainability.

Risk assessments have focused on the 'high emissions scenario', RCP8.5. This represents the highest greenhouse gas concentrations and has a best estimate increase in global mean surface temperature of 4.3°C by 2081-2100. This is in line with the recommendations in the Supplementary Green Book Guidance on Accounting for the Effects of Climate Change[8] published by Defra in November 2020 which recommends that if the project, policy or programme has a lifespan that goes beyond 2035 then two climate scenarios should be considered – that of 2°C warming in line with the Paris Agreement and that of the worst-case scenario of 4°C warming. RCP2.6 roughly aligns to the Paris Agreement, in that warming is limited to below or around 2°C and has also been considered in our approach. Within the Ofgem Business Plan guidance issued in February 2021[9], it states that "each DNO should consider a range of plausible climate change projections and the impacts for its region, as demonstrated through the adaptation pathway approach".

The choice of RCP was made based on a desire to be aware of the plausible worst-case scenario for the key hazards, and also a pragmatic decision based on data availability.

To model and predict future climate it is necessary to make assumptions about the economic, social and physical changes to our environment that will influence climate change.

6. metoffice.gov.uk/research/approach/collaboration/ukcp/index
7. metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf
8. gov.uk/government/publications/green-book-supplementary-guidance-environment
9. ofgem.gov.uk/system/files/docs/2021/02/ed2_business_plan_guidance_-_published_1_february_2021.pdf

3. Anticipate

3.2.1 Summary of UKCP18 and Met Office Report

The key findings from UKCP18 indicate that we are likely to experience warmer, wetter winters and hotter, drier summers. Northern Powergrid has carried out some analysis on the information available for our region in order to assist with our risk assessments and this can be seen in Section 3.3.

In order to ensure that ENA members had understood and correctly interpreted the findings of UKCP18, the DNOs, together with the gas distribution operators, commissioned the Met Office to provide bespoke analysis and peer-reviewed results regarding the hazards impacting our businesses. This analysis was based on the key hazards identified and prioritised by the companies involved during a series of workshops[10]. The findings of this work are presented in section 3.2.2.

In addition to an analysis of the impact of future climate change and the identification of any regional hotspots and differences, the societal response to climate change and the interconnections between different industry sectors were also considered.

Table 2 – Future Projections for Key Climate Hazards

Reference	Hazard	Headline Projections to 2100	Level of Concern for Northern Powergrid
i	Extreme High Temperatures	Increasing frequency in the future.	Moderate
ii	Heavy Rainfall/Drought Cycles	Little to no change in the future.	Moderate
iii	Prolonged Rainfall	Increasing frequency in the future with largest increase in the west of the UK.	Major
iv	Intense Short-Duration Rainfall	Heavy daily rainfall projected to increase in winter not summer. Extreme hourly rainfall projected to increase in winter & summer. Largest increases for hourly precipitation expected to occur in autumn.	Major
v	Strong Winds/Storms	Decadal variability of windstorms eclipses any trend in wind speed for the UK.	Moderate
vi	Sea Level Rise	Sea level is currently rising and will continue to rise, with central projections up to 1m by 2100.	Major
vii	Storm Surge and Wave Height	Best estimate is no change in storm surge. Any changes in extreme sea level will be the result of sea level rise as opposed to atmospheric storminess. Projections of wave height are uncertain, with some indication of a decrease in average wave heights, but an increase in extreme wave heights in some regions.	Minor
viii	Wetter Conditions Coincident with Warmer Temperatures and/or Followed by Strong Wind	Observational studies indicate growing seasons and nesting seasons are lengthening, particularly with spring becoming earlier. Warmer wetter winters could indicate an increase to risk from uprooting of trees, even in the absence of a signal in storm numbers.	Moderate
ix	Snow and Ice	Downward trend in winter means snowfall and lying snow through time.	Minor
x	Wildfire	Evidence of increasing risk of wildfire in future climates. Increased severity & frequency of fire weather conditions, increased fuel load & flammability hazard of vegetation result in increased risk of wildfire, most notably when coupled with human ignition sources (accidental or intentional as part of land management). Can also be considered a compound hazard as its occurrence is either the result of, or exacerbated by, other meteorological hazards such as extreme temperatures, drought and wind.	Minor
xi	Lightning	Response to climate change uncertain.	Minor
xii	Solar Storm	High impact-low frequency event. High impact space weather event is considered to be 1 in 100-year event.	Minor
xiii	Diurnal Temperature Cycles	Climate change projections indicate increases in summer diurnal temperature ranges.	Minor

10. Energy Industry Specific Risk Assessment on Climate Change Impacts – Work Packge 3 Report; Met Office: Dr Emily Wallace, Katie Chowienzyk, Megan Pearce, Isabel Rushby; November 2020

3. Anticipate

Figure 4 Figure 5 Figure 6

3.2.2 Climate Analysis

i. Extreme High Temperatures

High temperatures impact our business through reduction in the performance and efficiency of assets. Thresholds were chosen to understand the current frequency of days which constitute 'extreme temperature' across the UK and how these may change under future climate projections:

- Frequency with which the daily maximum temperature exceeds 28°C, 30°C and 35°C.
- Frequency with which the daily maximum temperature exceeds 28°C for 3 consecutive days.

Trends in observational records show that the UK climate is warming. The average hottest day of the year, in the most recently available decade within UKCP18 (2008-2017), has been on average 0.1°C warmer that the 1981-2010 average and 0.8°C warmer that the 1961-1990 average hottest day of 26°C.

In general, the frequency with which the high temperature thresholds are exceeded each year is expected to increase in the future under RCP8.5. This is consistent with UKCP18 headlines that hot summers are expected to become more common. In the recent past (1981-2000), the chance of seeing a summer as hot as 2018 was low (<10%). The chance has already increased due to climate change and is now between 10-25%. With future warming, by mid-century these hot summers could become even more common, near to 50% in all emission scenarios.

The rate of change of this hazard is expected to be smaller for cooler regions of the UK such as the South West and North of England. Analysis suggests that by the 2060s the frequency with which this hazard occurs in these areas will be equivalent to that of the warmest areas of the UK in today's climate. Northern Powergrid may therefore be able to learn from the warmer locations such as the South East of England and London.

Figure 4 – Extract from UKCP18 for Northern Powergrid region (RCP2.6)

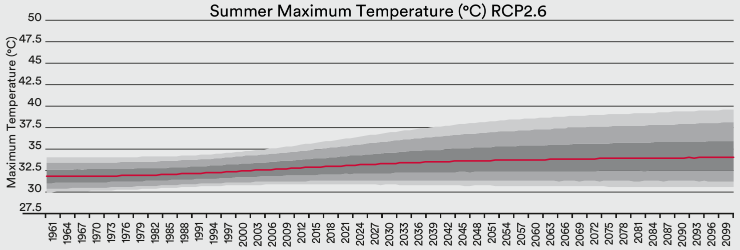


Figure 5 – Extract from UKCP18 for Northern Powergrid region (RCP8.5)

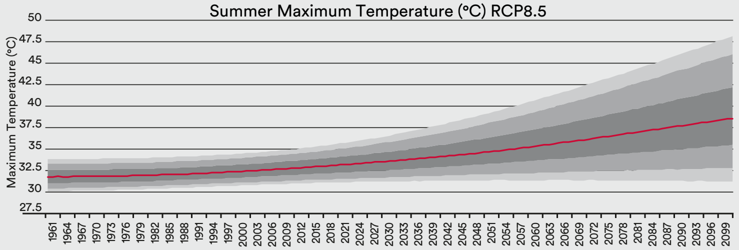
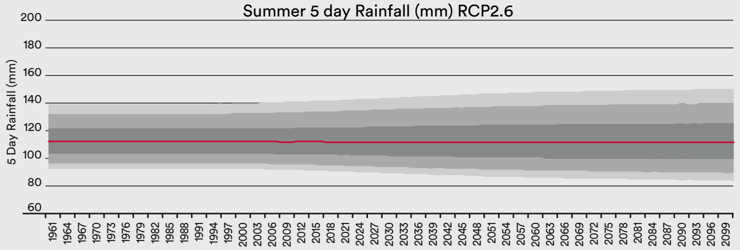


Figure 6 – Extract from UKCP18 for Northern Powergrid region (RCP2.6)



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3. Anticipate

3.2.2 Climate Analysis

ii. Heavy Rainfall/Drought Cycles

Ground movement is directly linked to asset damage. Assets located in clay soils are most vulnerable to the hazard of ground movement, with anecdotal evidence suggesting assets located in peat/fenland soils are also vulnerable.

In order to assess the impact, the Soil Moisture Deficit (SMD) was chosen as an indicator. This can be linked directly to rainfall accumulation of the preceding 30 and 60 day periods. It has been shown that the fastest rate at which the soil dries out occurs in May to August.

In general, there is very little reduction in seasonal rainfall, the patterns for projected changes of both the 20 and 60 day rainfall accumulations are very similar, with the main effects expected to be felt in the South East of England due to geology and the fact that this area is drier in general.

iii. Prolonged Rainfall

Rainfall resulting in flooding and erosion is associated with a broad range of impacts including access issues, asset damage and reduced performance. Rainfall that can result in flooding has been split into two hazards:

- Long periods of above average precipitation leading to fluvial flooding events and river erosion.
- Intense rainfall events, such as thunderstorms, leading to pluvial or flash flooding events as surface run-off inundates small catchments.

The accumulation of rainfall over a month and where it exceeds the 90th and 95th percentile of today's climate was considered. Analysis of climate projections show that there are large regional variations in how the frequency of this hazard is expected to change in future climates. In the East of England, the frequency will remain roughly the same, however, in the West of England and much of Scotland and Wales, the projections are indicating that more prolonged rainfall will result in the thresholds being exceeded more frequently. These events would be expected to be focused in the autumn and winter months.

We have experienced many rainfall events in our area. Case studies on some of these events can be found in Section 6.2.2.

Figure 7 – Extract from UKCP18 for Northern Powergrid region (RCP8.5)

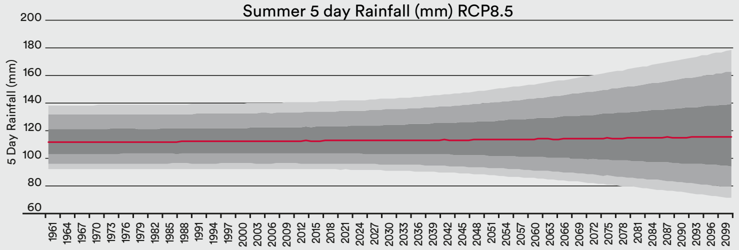


Figure 8 – Extract from UKCP18 for Northern Powergrid region (RCP2.6)

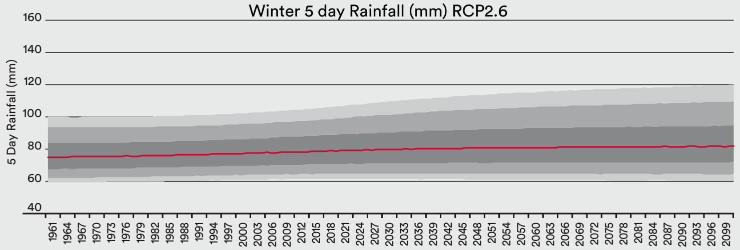
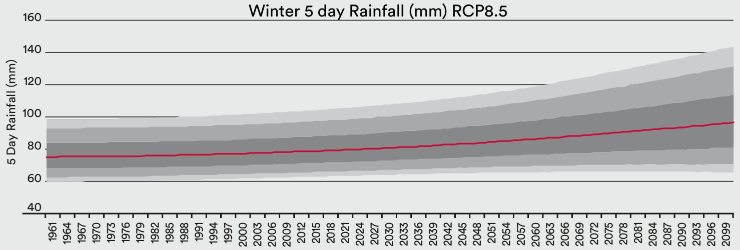


Figure 9 – Extract from UKCP18 for Northern Powergrid region (RCP8.5)



3. Anticipate

3.2.2 Climate Analysis

iv. Intense Short-Duration Rainfall

Short, intense rainfall events, such as thunderstorms, lead to pluvial or flash flooding which is associated with a broad range of impacts including access issues, asset damage and reduced performance.

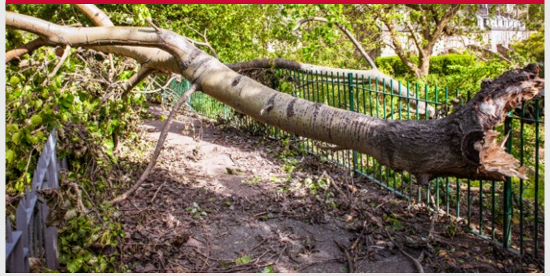
In order to consider changes in heavy daily events, percentage changes in the 99th percentile of seasonal daily mean precipitation were examined. In winter these are projected to increase across most of the UK, with the greatest increase expected to occur in Southern England. There is little suggestion of changes for heavy daily events in summer.

Changes in heavy hourly precipitation events were also considered. These are expected to increase in both winter and summer but decreases may be possible in the South. The largest relative increases are anticipated to occur in autumn. In the current climate, summer has the greatest occurrence of high threshold exceedances, however, in the future, summer and autumn are similarly important.

This may be important if vulnerability to the hazard is increased in autumn due to fallen leaves exacerbating the risks of flooding.

UKCP09, utilised in previous risk assessments, was not capable of representing high intensity hourly rainfall and therefore this represents an emerging risk for consideration.

v. Strong Winds/Storms



Strong winds are a significant hazard to our network, particularly in storm conditions which will often also bring heavy rain. It can lead to operational failure of above ground assets, resulting in increased faults and loss of supply to customers and the associated impacts to customer service. The potential for damage to telecommunications infrastructure, leading to the inability to communicate with staff in the field or control technology, could impact repair efforts further.

There is no strong signal within the climate projections for a change to storminess and therefore the risk of strong winds has been assessed in the current climate only. The current frequency of exceedance of thresholds has been considered across the UK and an indication of year-to-year variability highlighted.

vi. Sea Level Rise

The proximity of energy network assets to the UK coastlines makes them vulnerable to changes in sea level, both during extreme events in the current climate and as a result of future changes in mean and extreme sea levels caused by climate change. The Humber Estuary and Seal Sands were noted as particularly vulnerable areas in the Northern Powergrid region.

Coastal hazards that exist or can arise as a result of sea level rise include permanent submergence of land, more frequent or intense flooding, enhanced erosion, loss or change of ecosystems, salinisation of soils, ground and surface water and impeded drainage. The impact of this is likely to lead to the requirement for modifications to existing and future infrastructure and in some cases the relocation of assets away from coastal risk zones.

The rate of global sea level rise currently being experienced is 3–4mm per year. Under RCP8.5 this will increase, resulting in global mean sea level rise between 0.23–0.40m by 2050, in comparison to 0.17–0.32m under the RCP2.6 scenario. Uncertainty in future sea level rise, driven by climate change, up to 2050 is relatively small. The rate of global mean sea level rise is expected to increase to 10–20mm per year by the end of the century under RCP8.5. This equates to global mean sea level rise of between 0.61–1.10m by 2100, relative to 1985–2005, and is projected to continue to rise beyond 2100 in all RCP scenarios. However, it should be noted that uncertainty increases beyond 2050.

The UKCP18 Marine Report provides a spatial map of sea level rise change around the UK coastline in 2100, under the RCP8.5 scenario. The figure indicates that larger sea level rise is projected in the south and in general these decrease towards the north, indicating a broadly north-south gradient.

Humberside is located along the coastline at greater risk of significant sea level rise by 2100, with a projected change of greater than +0.7m, suggesting that assets or operations at these locations should also be considered at potential risk.

3. Anticipate

3.2.2 Climate Analysis

vii. Storm Surge and Wave Height

Storm surges, caused by atmospheric forcing on the sea surface, can pose a significant risk to coastal zones. The likely damage to assets is considered the same as that associated with sea level rise and future change projections are dominated by this factor. On the other hand, storm surges pose more of an acute risk when compared to gradual time-mean sea level rise, as these can occur at short notice with varying intensity.

Three main factors are considered to influence the generation of storm surges:

- meteorological influences (wind speed, direction, persistence and spatial distribution);
- oceanographic effects (sea-surface temperature, water density and sea ice cover); and
- topographic features (water depth, width of continental shelf, presence of sands bars and reefs).

Within UKCP18, 'skew surge' is used to indicate storm surge since variation is independent of tidal level. There is disagreement in the signal direction and magnitude of the five climate simulations utilised to drive the storm surge model and as a result the best estimate is that there is no change in storm surge along the UK's coastlines and any changes in extreme sea level will be as a result of time-mean sea level as opposed to atmospheric storminess.

viii. Wetter Conditions Coincident with Warmer Temperatures and/or Followed by Strong Wind

Warmer and wetter conditions may extend vegetation growing seasons and result in changes to nesting patterns. The increased or accelerated growth of vegetation could result in reduced access and increased costs associated with maintenance and cutting cycles, whilst extensions in nesting seasons would impact the timeframes and windows available for construction or maintenance, particularly in locations where protected species are present.

Further impacts can arise when the increased frequency of warm, wetter weather is combined with periods of high wind speeds and/or heavy rainfall. The additional risk is introduced due to the presence of increased levels of vegetation and the subsequent likelihood of greater instances of wind throw or destabilisation of tree roots, resulting in vegetation falling and damaging assets.

Compound hazards are not currently investigated within UKCP18. The signals for the component parts have been studied as part of the ENA/Met Office analysis and this information, along with the available literature on growing/nesting seasons, may be used indicatively to aid consideration of the potential impacts.

Whilst the Met Office is unable to quantify the likelihood of the compound hazard, analysing the individual component projections indicates that there may be a subsequent chance of increased risk in the future for compound impacts. The headline messaging and component signals would indicate that there is a greater chance of warmer, wetter winters and hotter, drier summers across the UK in future, and it would be reasonable to infer from the projections of hourly rainfall extremes and the wind experienced in today's climate that there is a chance that these hazards will occur concurrently, most likely in autumn and winter months. The associated impacts may be exacerbated further if strong winds in the future increase in frequency.

An additional emerging risk for consideration is the influence of this compound hazard, particularly warm, wetter conditions, on the length of vegetation and nesting seasons. The length of the growing season is calculated using mean daily temperature; it begins at the start of a period of five successive days where the daily-average temperature is greater than 5°C and ends on the day before a period of five successive days when the daily-average temperature is less than 5°C. The average growing season length between 1961 and 1990 was 252 days, compared to the recorded length in 2012 of 282 days, indicating an approximate 30 day increase in growing season length. This is reported as largely due to an earlier onset of spring.

Taking into consideration the component climate signals, there is a reasonable likelihood that during wetter winters the risk associated with destabilised roots could increase and current autumnal and winter impacts, such as damage from wind thrown vegetation, may occur more frequently. However, the risk may not be exacerbated by an additional abundance of vegetation in these seasons, as the cited increased length of the growing season appears to be the result of an earlier spring. Therefore, the impact on autumnal cutting schedules is unknown.

The earlier onset of breeding and nesting seasons and how this may impact upon current maintenance and construction schedules should be considered as an emerging risk.

3. Anticipate

3.2.2 Climate Analysis

ix. Snow and Ice

Snow, ice and extreme cold day events can result in asset damage, this can include compromised structural integrity, accelerated ageing from greater mechanical tensions and increased fault durations. Some of these faults are common to telecommunications networks thus increasing the risk to personnel in the field due to loss of communications. Access issues may occur where staff struggle to reach isolated sites for repairs or maintenance, or even get to work at all if the transport network is heavily impacted. Snow and ice can also influence customer demand and behaviour.

Greater demand during cold weather and snow events places a greater strain on the networks due to the connection of additional heating and/or electrical appliances. This poses an additional problem if the electricity network suffers a fault, placing more pressure on alternate circuits to meet supply.

There is also an increased probability of aeolian vibration and galloping of overhead lines that are coated with ice, and the increased probability of electrical flashover of insulators. Snow or ice on the lines also reduces the clearance level for people safely passing under the assets and blocks line of sight telecoms signals for the system.

Overall, UKCP18 suggests that winters are going to become warmer in future, so snow and ice related hazards are likely to decrease. However, it should be noted that extreme cold and snow events are still a possibility. The projected changes in decreasing snowfall and lying snow are smaller in mountainous regions compared to low lying regions, with the model projecting almost 100% decrease in lying snow in lowland areas by end of the century.

x. Wildfire

Wildfire has been identified as an emerging risk in the UK Climate Change Risk Assessment (2012 and 2017) and subsequent National Adaptation Programmes (2013 and 2018). Fixed level and linear overhead assets in proximity to moorland and heathland could be considered particularly vulnerable and wildfire (and also associated smoke) poses a risk to supply, fault restoration times, safety of staff and damage or loss of the asset itself.

Projections for fire severity indices under UKCP18 scenarios are not available in published material yet, however this is an active area of research. In general, UKCP18 projections of hotter, drier summers as well as increases in summer hot spells would suggest fire risk in the UK will increase in future climates. This is supported by evidence in peer-reviewed literature.

xi. Lightning

Lightning strikes pose a risk to both fixed assets and overhead lines. Hazards fall in two categories:

- Indirect effects of lightning strikes are arcing and induced currents.
- The direct impacts of lightning strikes are caused by current flow and heat. Impacts can be arranged into four broad categories (physical damage, fire, power surge and shock wave) which are not mutually exclusive.

Faults and damage due to lightning strikes may lead to loss of supply to customers. In addition, there may be loss of instrumentation and telemetry systems and lightning strikes may cause faults on other networks such as telecommunications and rail networks, leading to interdependencies. Staff/operator safety is also a key consideration of lightning storms – the longer the lightning storm, the longer the time taken to access the network for repair.

The response of lightning to climate change is uncertain. In UKCP09, lightning was estimated using convective available potential energy, and future increases in the number of lightning days were found. However, UKCP09 modelling neglected cloud ice fluxes that are fundamental to thunderstorm charging. These were included in UKCP18; however, the modelled lightning output has poor performance both in terms of frequency and spatial distribution. The future revision of the 2.2km projections from UKCP18 (expected spring 2021) may provide better insight into the expected changes to lightning frequency in the future. In light of the current uncertainty in the UKCP18 projections, a cautious approach would be to assume an increase in number of lightning days as analysed in the UKCP09 projections, until further research is presented.

3. Anticipate

3.2.2 Climate Analysis

xii. Solar Storm

The impact of solar storms falls into two categories: asset damage and damage to telecommunication resulting in health and safety considerations and loss of control of technology. A solar storm encompasses three main components: solar flares, solar energetic particles (SEPs) and coronal mass ejections (CMEs). A solar flare is an intense burst of high energy radiation coming from the release of magnetic energy associated with sunspots. CMEs are often responsible for generating the most intense geomagnetic storms, which are temporary disturbances of the magnetosphere. A geomagnetic storm may generate geomagnetically induced currents (GICs) in the ground by inductive effects due to the increased electric field propagating into the atmosphere.

The longest series of measurements for solar storms are from ground-based magnetometers. The measurements date back to the 1840s and indicate that most solar storms are relatively minor and only a few are severe. The largest storm on record occurred on 2-3 September 1859. This is known as the Carrington event and serves as a benchmark for many studies and impact assessments. In the UK, for planning purposes a reasonable worst-case superstorm with the strength of the Carrington Event is currently considered to be a 1-in-100-year event. Any system with a design lifetime of more than 8.25 years needs to consider the risk from severe space weather events similar to that of the Carrington Event. Such events can thus be considered high-impact (or high-consequence) and low-frequency.

xiii. Diurnal Temperature Cycles

The daily (or diurnal) temperature range (DTR) is defined as the daily difference between the maximum and minimum surface-air temperature. There has been a small increase in the average daily temperature range in recent years and, in general, the long-term average diurnal temperature range has been increasing with time.

The observed mean summer UK DTR is around 8–10°C. There is a North-South divide aligning with greater diurnal temperature ranges occurring in climatologically warmer areas of the UK, i.e. Southern England. Future projections suggest a general increase in DTR across Europe of around 12%. The projected increases are larger in the South of England than the North (approximately 12% compared to 6%) corresponding to greater increases in areas of the UK where the diurnal temperature cycle is already more extreme.

Particular joint failures of underground assets have been attributed to large diurnal temperature cycles. This is a relatively new risk and 2018 provides a case study for this type of event, with the greatest number of faults occurring in May, June and July 2018, following a series of prolonged hot and dry spells. Additional weak points in the network may be identified if it is exposed to conditions similar to or more extreme than those experienced in 2018.

3. Anticipate

3.3 Regional Climate Change Considerations

The following table contains a summary of each of the Northern Powergrid operating zones and any relevant historic climate events.

Table 3 – Summary of Northern Powergrid Zones

Operating Zone	Network Configuration	Areas of Note	Known Climate Events
South Yorkshire/ North Lincolnshire	South Yorkshire has an extensive underground cable network and a significant number of substations that supply densely populated areas. North Lincolnshire contains many customers supplied by long stretches of overhead line.	— Peak District National Park — Lincolnshire Wolds Area of Outstanding Natural Beauty (AONB) — 652km of overhead lines.	South Yorkshire has historically been subjected to flooding. In 2007 the River Don over-topped its banks, causing significant flooding in the Sheffield area. The NGET site at Neepsend suffered significant flooding, with the loss of supply to 40,000 customers and the supply to many other customers in the centre of Sheffield was threatened when cracks were discovered in the Ulley Reservoir.
West Yorkshire	A compact zone in terms of size, it is huge in terms of cable length and numbers of substations.		The West Yorkshire area, in particular Calderdale, experienced flooding in 2015 during Storm Eva.
Tyne & Wear, Northumberland and County Durham	Many customers are supplied by long stretches of overhead line.	— Northumberland National Park — North Pennines AONB & UNESCO Global Geopark — Northumberland Coast AONB — Northumberland National Park.	Historically the area has been subjected to flooding. In 2012, the centre of Newcastle suffered from severe surface water flooding and, in December 2013, the quayside area was badly affected by a coastal surge.
Humber Estuary	Heavy industry and other large customers whose continuous reliability of supply is paramount to their businesses.		Historically the area has been subjected to flooding. In 2007, 8,600 homes and 1,300 businesses were subjected to severe flooding due to the drainage system becoming overwhelmed.
Teesside	Heavy industry and other large customers whose continuous reliability of supply is paramount to their businesses.		Historically the area has been subjected to flooding. In December 2013, areas of Teesside were affected by a coastal surge.
Yorkshire Dales, Moors and Wolds	Many customers are supplied by long stretches of overhead line.	— Nidderdale AONB — Yorkshire Dales National Park — 1,187km of overhead lines.	In April 2012, this area was subjected to an unseasonable snow event and power was lost to 12,000 customers.

3. Anticipate

3.4 Levels of Service

Licensed electricity distribution businesses are obliged, under Condition 21 of our licences, to maintain a Distribution Code detailing the technical parameters and considerations relating to connection to and use of our electrical networks, again approved by Ofgem.

Overall levels of supply security are agreed by Ofgem and contained in ENA Engineering Recommendation P2 – Security of Supply – in England and Wales. These security standards specify the requirements for the availability of alternative supplies at various levels of customer load. Although these standards allow for the loss of multiple circuits, they do not provide for certain low probability events, including multiple failures or the total failure of a grid or primary substation. Particular attention must therefore be given to grid and primary substations when considering network resilience.

Whenever a customer loses supply, details of that interruption are recorded by transmission and distribution companies. Distribution networks are much more affected by climate impacts than the transmission system and all supply interruptions on distribution networks are recorded in the NaFIRS (National Fault and Interruption Reporting Scheme) database. This information is shared nationally and summaries are submitted to Ofgem. Data is available for over thirty years but the quality of the data has improved significantly over the last fifteen years since the introduction of the Ofgem Interruptions Incentive Scheme (IIS).

ENA Engineering Recommendation (ER) G43-3 (Instructions for Reporting to the NaFIRS) sets out the details to be captured for each fault. For each interruption, we capture a large amount of information and up to 100 separate data fields will be populated. These include:

— location
— type of equipment
— number of customers affected
— manufacturer
— duration
— cause of the fault.

Using this information, we can identify trends in all these areas and can monitor how our networks are performing, identify any trends in weather-related faults and respond accordingly. We capture data at a detailed level, attributing faults to one of 99 different direct causes specified in ER G43-3. Eleven of these are weather related:

— lightning
— wind and gale (excluding windborne material)
— rain
— airborne deposits (excluding windborne material)
— snow, sleet, blizzard
— condensation
— ice
— flooding
— freezing fog and frost
— windborne materials
— solar heat.

Distribution networks are much more affected by climate impacts than the transmission system.

3. Anticipate

3.4 Levels of Service

There are financial incentives to minimise the number and duration of interruptions, including those caused by climate impacts. Ofgem introduced the IIS in April 2002. Under this scheme we are set a target for the number of interruptions each year that last over three minutes, and the total length of those interruptions. If we beat these targets we are rewarded and conversely are penalised if we do not achieve the targets. We are also subject to Guaranteed Standards (GS) of Performance enacted through the Electricity (Standards of Performance) Regulations which is a Statutory Instrument made under powers conferred in the Electricity Act 1989.

The GS are a set of standards of service agreed with Ofgem, and backed by a financial guarantee – customers receive a payment if we fail to meet these standards. For both IIS and GS there are variations in the case of severe weather, recognising the additional difficulties in restoring supply under these conditions.

Whilst every effort is made to ensure network security, Northern Powergrid has well-developed business continuity and emergency plans to ensure an effective response to a range of events that can affect both transmission and distribution networks. Under the terms of the Civil Contingencies Act, Northern Powergrid is a Category Two responder and works closely with other utilities, the emergency services and local authorities. We are also active participants in the BEIS Energy Emergencies Executive Committee (E3C).

For both IIS and GS there are variations in the case of severe weather, recognising the additional difficulties in restoring supply under these conditions.

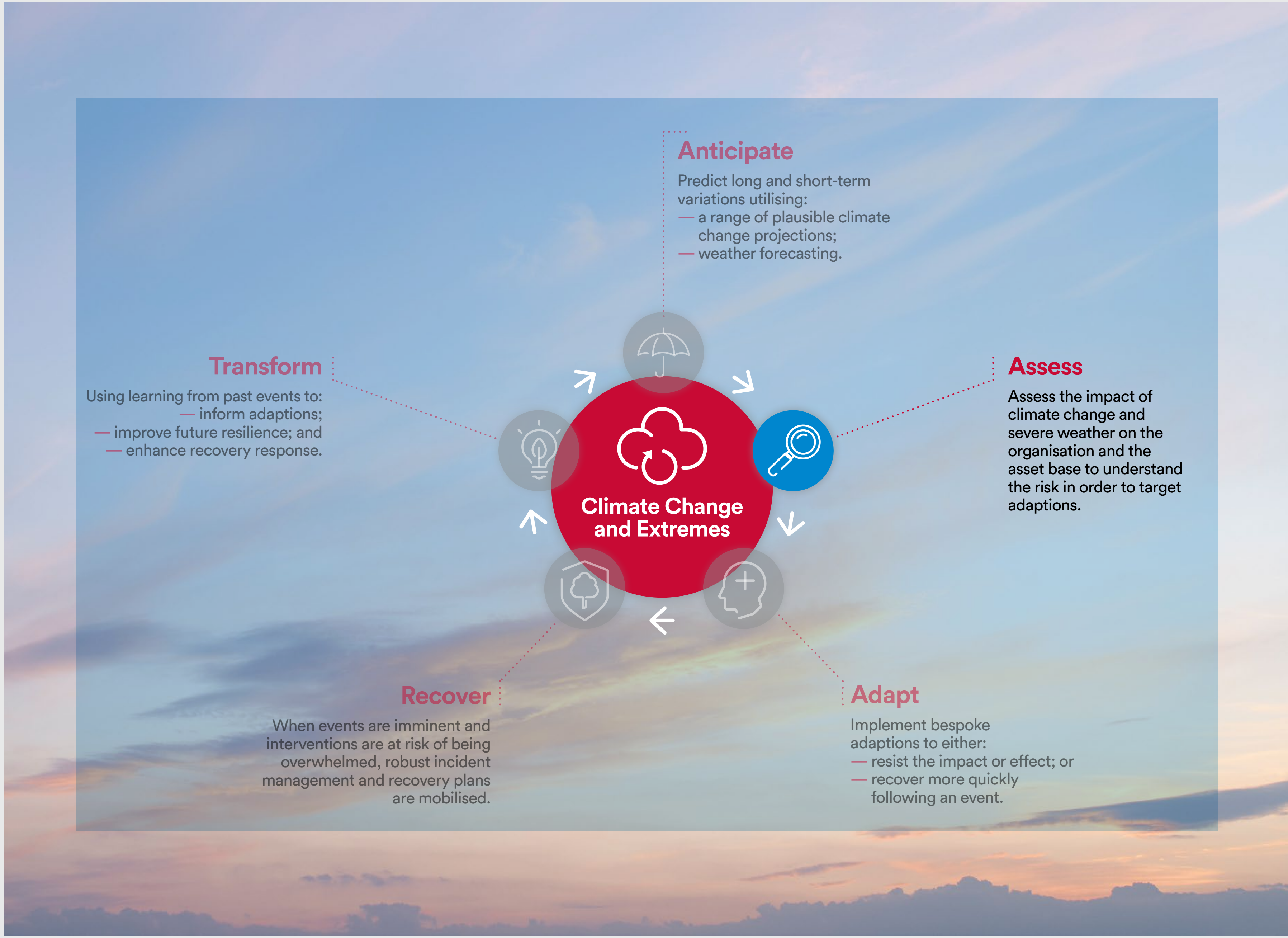
4

Assess

4. Assess

In order to fully prepare for the changes highlighted during the Anticipate phase, the impacts of the projected climate change on both our asset base and our organisation have been considered in detail.

Following the full Northern Powergrid risk assessment, which can be seen in Appendix 1, the risks were prioritised at a sector level and assessed against criteria laid out by Defra, as detailed in Section 4.1 Defra Risk Assessment.



4. Assess

4.1 Defra Risk Assessment

Although the risks to the network are assessed at a detailed level by Northern Powergrid, we have worked with ENA to provide a consolidated industry view of the highest priority risks to the operation of the network. These 15 asset risks (AR) are driven by temperature increases, precipitation levels, lightning and wildfire as discussed in Section 3.2.2 – Climate Analysis and have been assessed against the risk matrix provided by Defra to allow for a consistent national approach to feed into national reporting. The following section presents these risks.

Figure 10 – Key Asset Risks Presented in the Defra Risk Matrix

Likelihood of Occurrence					
Almost Certain					
Likely		AR3			
Possible		AR2, AR5, AR6, AR7, AR14	AR1, AR4, AR8, AR10, AR16		
Unlikely		AR9	AR11, AR15	AR12	
Very Unlikely					AR13
Impact	**Limited**	**Minor**	**Moderate**	**Significant**	**Extreme**

Table 4 – Defra Definitions of Likelihood and Impact

Likelihood of Occurrence		Impact	
Almost Certain	The risk is in the process of materialising and may already be under active management as an event.	**Extreme**	Regional area affected with people off supply for a month or more OR asset de-rating exceeds ability to reinforce network leading to rota disconnections on peak demand.
Likely	Past events have not been fully resolved, effective mitigations not yet identified, control weaknesses are known and are being managed.	**Significant**	County or city area affected with people off supply for a week or more OR asset de-rating requires a significant re-prioritisation of network reinforcement and deferment.
Possible	Past events satisfactorily resolved, mitigations are, or are on track to be, in place, control improvements are under active management.	**Moderate**	Large town or conurbation off supply for up to a week OR significant increase in cost of network strengthening.
Unlikely	Events are rare, required mitigations are in place, controls are effective.	**Minor**	Small town off supply for a 24 hour period OR significant increase in cost of network maintenance requirements.
Very Unlikely	No known event or if known extremely rare, extreme industry-wide scenarios.	**Limited**	Limited impact – can be managed within "business as usual" processes.

4. Assess

4.1 Defra Risk Assessment continued

Table 5 – Considerations for Key Asset Risks

Risk Code	Impact		Climate Variable	Current Likelihood	Risk Status				Risk Considerations
	Asset/ Network Effect	Current Rating			Current	2050s	2080s – RCP2.6	2080s – RCP8.5	
AR1	Overhead line conductors affected by temperature rise.	Moderate	Temperature	Possible	Low	Low	Low	Low	Localised increase in pole heights and age related replacement maintains line clearances. No significant changes in UKCP18 predictions over UKCP09.
AR2	Overhead line structures affected by summer drought & consequential ground movement.	Minor	Temperature	Possible	Low	Low	Low	Low	Emerging risk. Impact dependent on geology and topology.
AR3	Overhead lines affected by interference from vegetation due to prolonged growing season.	Minor	Temperature/ precipitation	Likely	Low	Low	Low	Low	Increase in growth offset by increase in cutting at each visit.
AR4	Underground cable systems affected by increase in ground temperature.	Moderate	Temperature	Possible	Low	Low	Low	Low	Limited data on impact on cable ratings.
AR5	Underground cable systems affected by summer drought & consequential ground movement.	Minor	Temperature	Possible	Low	Low	Low	Low	Emerging risk. Impact dependent on geology and topology.

4. Assess

4.1 Defra Risk Assessment continued

Risk Code	Impact		Climate Variable	Current Likelihood	Risk Status				Risk Considerations
	Asset/ Network Effect	Current Rating			Current	2050s	2080s – RCP2.6	2080s – RCP8.5	
AR6	Substation and network earthing systems adversely affected by summer drought conditions.	Minor	Temperature	Possible	Low	Low	Low	Low	Limited test data available. Anecdotally grid and primary substations are buried deep enough to only experience minor impact in performance.
AR7	Transformers affected by temperature rise.	Minor	Temperature	Possible	Low	Low	Low	Low	Temperature rise accommodated in design.
AR8	Transformers affected by urban heat islands and coincident air conditioning demand.	Moderate	Temperature	Possible	Low	Low	Low	Low	Managed through load planning although extended high load may reduce the life expectancy of the transformer.
AR9	Switchgear affected by temperature rise.	Minor	Temperature	Unlikely	Low	Low	Low	Low	Temperature rise accommodated in design.
AR10	Grid and primary substations affected by river flooding due to increased winter rainfall.	Moderate	Precipitation	Possible	Low	Low	Low	Medium	While risk of flooding has increased, the asset protection measures employed have offset and reduced the risk.
AR11	Grid and primary substations affected by pluvial (flash) flooding due to increased rain storms in summer and winter.	Moderate	Precipitation	Unlikely	Low	Low	Low	Medium	While risk of flooding has increased, the asset protection measures employed have offset and reduced the risk.

4. Assess

4.1 Defra Risk Assessment continued

Risk Code	Impact		Climate Variable	Current Likelihood	Risk Status				Risk Considerations
	Asset/ Network Effect	Current Rating			Current	2050s	2080s – RCP2.6	2080s – RCP8.5	
AR12	Grid and primary substations affected by sea flooding due to increased rain storms and/or tidal surges.	Significant	Precipitation	Unlikely	Low	Low	Low	Low	While risk of flooding has increased, the asset protection measures employed have offset and reduced the risk.
AR13	Grid and primary substations affected by water flood wave from dam burst.	Extreme	Precipitation	Very Unlikely	Low	Low	Low	Low	Considered unviable to protect against.
AR14	Overhead lines & transformers affected by increasing lightning activity.	Minor	Lightning	Possible	Low	Low	Low	Low	Existing mitigation measures adequate.
AR15	Overhead lines & underground cables affected by extreme heat and fire smoke damage.	Moderate	Wildfire	Unlikely	Low	Low	Low	Low	Based on Saddleworth Moor incidents and increased frequency of California wildfires.
AR16	Overhead lines affected by strong winds.	Moderate	Wind	Possible	Low	Low	Low	Low	Events are rare but impact has the potential to be quite severe.

4. Assess

4.1.1 Climate Driven Asset Risks

AR1 Temperature
Overhead line conductors affected by temperature rise

(Risk Status: Low – Minor uprating of network may be required)

Thermal expansion of conductors in summer is a common consideration for all overhead lines and supporting structures are designed to account for sag to ensure the minimum ground to conductor clearances are maintained.

Where these lines are exposed to temperatures considered extreme by UK standards, and where the frequency and duration of these events increases, it is possible that sag will exceed the current overhead line design parameters. This could lead to an increasing number of incidents where conductor clearance limits are compromised.

Increasing temperatures also impact the capacity of the conductors and the network as a consequence. Conductors are designed to operate at their maximum efficiency up to a maximum core temperature; as air temperature increases it becomes difficult for the heat from the conductor to radiate. As the core temperature increases so does resistance within the conductor reducing its ability to carry current, thus reducing its capacity.

AR2 Temperature
Overhead line structures affected by summer drought and consequential ground movement

(Risk Status: Low – Minor uprating of network may be required)

Increasing temperatures will, without precipitation, lead to drying of the ground, causing it to shrink. Any structures built on this ground will be subject to movement which, as well as being amplified by the height of the structure, can lead to instability of the foundations. Overhead line structures are more vulnerable to this movement, but it can also impact on ground mounted structures such as transformer bases and switch house foundations.

AR3 Temperature/precipitation
Overhead lines affected by interference from vegetation due to prolonged growing season

(Risk Status: Low – Minor uprating of network may be required)

Increases in both temperature and precipitation will lead to increased vegetation growth. This impacts on overhead lines as increased growth of branches of trees growing adjacent to the overhead lines can impact on minimum clearances leading to faults and physical damage.

AR4 Temperature
Overhead lines affected by interference from vegetation due to prolonged growing season

(Risk Status: Low – Minor uprating of network may be required)

As with overhead lines, increasing temperatures impact the capacity of cables and the network as a consequence. Cables are designed to operate at their maximum efficiency up to a maximum core temperature; as the ground temperature increases it becomes difficult for the heat from the conductor to radiate. As the core temperature increases so does resistance within the conductor reducing its ability to carry current and thus reducing its capacity.

AR5 Temperature
Underground cable systems affected by summer drought and consequential ground movement

(Risk Status: Low – Minor uprating of network may be required)

Ground movement caused by drying and shrinkage will exert tensile forces on cables. Whilst cables have an inherent tensile strength, joints in the network are more vulnerable and can fail by being effectively pulled apart. Extreme wet-dry and freeze-thaw ground movements will have a similar impact.

AR6 Temperature
Substation and network earthing systems adversely affected by summer drought conditions

(Risk Status: Low – Minor uprating of network may be required)

As moisture in the soil reduces, the soil resistivity increases, reducing the effectiveness of the earthing system. Where earthing design parameters are exceeded, system and public safety issues can arise with reduced touch potential distances or failure to fully dissipate fault current leaving exposed metal components, inside and outside the site boundary, live.

AR7 Temperature
Transformers affected by temperature rise

(Risk Status: Low – Minor uprating of network may be required)

As with cables and overhead conductors, transformers are designed to operate within particular temperature parameters. As air temperature increases it becomes more difficult to expel the heat created by the transformation process, consequently transformers can begin to overheat, reducing capacity and life expectancy and, in extreme cases, causing catastrophic failure of the unit.

4. Assess

4.1.1 Climate Driven Asset Risks

AR8 Temperature
Transformers affected by urban heat islands and coincident air conditioning demand

(Risk Status: Low – Minor uprating of network may be required)

Localised build-up of heat, particularly in city environments, will lead to increased demand from air conditioning and ventilation unit operation; some network operators are now seeing very little difference between summer and winter demand where traditionally summer was always the season of reduced electricity usage. Increased demand can overload transformers causing tripping and loss of supply.

AR9 Temperature
Switchgear affected by temperature rise

(Risk Status: Low – Minor uprating of network may be required)

Increasing temperature impacts all plant and equipment and increases will impact switchgear by reducing capacity or, in extreme cases, lead to the switchgear tripping, resulting in loss of supply or operating incorrectly and damaging the network. Prolonged periods of hot weather will increase the temperature inside switchrooms above the maximum optimum operating parameter for the switchgear increasing the potential for faults or mal-operation.

Although, as with overhead lines, switchgear is designed to international standards, there are recorded days where switchroom ambient temperatures have exceeded the operational maximum of the switchgear.

4. Assess

Precipitation/Lightning/Wildfire/Wind Driven Risks

AR10 Precipitation
Substations affected by river (fluvial) flooding due to increased winter rainfall

(Risk Status: Low – Minor uprating of network may be required)

AR11 Precipitation
Substations affected by pluvial (flash) flooding due to increased rain storms in summer and winter

(Risk Status: Low – Minor uprating of network may be required)

AR12 Precipitation
Substations affected by sea flooding due to increased rain storms and/or tidal surges

(Risk Status: Low – Minor uprating of network may be required)

Regardless of the source, the impact of flooding on ground-located assets is the same. Plant and equipment is physically damaged by flood water but water ingress will also cause faulting within the assets and the network leading to extensive loss of supply.

Consequential repair or replacement of assets is costly and time-consuming, extending restoration of supply to local areas. Network operators will often choose to switch out plant and equipment in order to avoid water ingress causing a fault and uncontrolled shutdown.

AR13 Precipitation
Substations affected by water flood wave from dam burst

(Risk Status: Low – Minor uprating of network may be required)

Where substations are located far enough away from dams the impact of water inundation from a dam burst is no different from “standard” pluvial, fluvial or tidal flooding and flooding impacts can be considered similar.

Where substations are close enough to dams to be impacted by the full force of a breach, the damage to a substation would be substantial. Plant and equipment would not only be impacted by water ingress, it is likely to be physically damaged or even washed away by the force of water. Where a substation site has been impacted by the full force of a dam breach, it would not be possible to re-establish supply without fully reconstructing and recommissioning the site.

AR14 Lightning
Overhead lines and transformers affected by increasing lightning activity

(Risk Status: Low – Minor uprating of network may be required)

Increased storm frequency can lead to an increased lightning strike frequency.

Where lightning strikes exposed substation plant or, more likely, overhead line assets, the resulting surge will cause circuits to trip under fault condition. In extreme cases strikes will lead to physical damage to the assets or a loss of generation, leading to other network protection systems operating and leading to loss of supply.

AR15 Wildfire
Overhead lines and underground cables affected by extreme heat and fire smoke damage

(Risk Status: Low – Minor uprating of network may be required)

This risk has been added for the third-round reporting following the Saddleworth Moor wildfires in 2018. Although a consequential risk of increased temperatures and reduced precipitation, wildfires pose a significant risk to overhead line structures and conductors where they are located in susceptible areas such as open heathland.

Operational telecommunication systems should also be considered at risk from this scenario, and without operational telecoms it is impossible to control the network and loss of supply could occur following an unrectified fault.

AR16 Wind
Overhead lines affected by strong winds

(Risk Status: Low – Minor uprating of network may be required)

The risk has been added for the third round reporting following extreme events which have occurred in recent years. Strong winds pose a significant risk to overhead line structures and conductors where they are located in susceptible areas, particularly where ice accretion is also a risk.

Operational telecommunication systems should also be considered at risk from this scenario.

4. Assess

4.1.2 Climate Driven Non-Asset Risks (NAR)

Non-asset risks have been identified where there is a potential that company corporate policy, procedure and strategy may not be adequate to realise and address climate change hazards or where the risk is not directly attributed to damage or reduced operation of an asset.

The requirements for climate change management need to be specified to ensure the necessary procedures and actions are integrated into the organisation's environmental management system and considered for all major network investment decisions.

Asset climate risks need to be afforded the same status as other risks to assets including security, safety and other environmental impacts. Accountability is then required at senior management level and responsibilities included within existing business risk processes.

Table 6 – Non-Asset Risks Presented in the Defra Risk Matrix

Likelihood of Occurrence					
Almost Certain					
Likely					
Possible	NAR1	NAR2, NAR3	NAR4		
Unlikely					
Very Unlikely					
Impact	**Limited**	**Minor**	**Moderate**	**Significant**	**Extreme**

4. Assess

NAR1
Wildlife Impacts

(Risk Status: Negligible)

The effects of climate change could lead to impacts on wildlife due to changes in environments, habitats and behaviours. This could lead to restricted access to assets from changed nesting habits, prolonged nesting seasons, changes to species, migration, subsidence from digging etc.

NAR2
Supply Chain Impacts

(Risk Status: Low)

Business Continuity Management plans could be affected due to severe travel difficulties resulting from extreme weather events. This can result in reduced capability and support from supply chain businesses and impact on the continued operation and maintenance of the networks. The adoption of new technology and equipment will assist in the ability of the workforce to work remotely and continue to manage network assets.

NAR3
Business Continuity Management plans affected due to severe travel difficulties resulting from extreme weather events

(Risk Status: Low)

Business Continuity Management plans could be affected due to extreme weather events. There will be an impact on organisational capability and staff resources and the continued operation and maintenance of the networks. The adoption of new technology and equipment will assist in the ability of the workforce to work remotely and continue to manage network assets.

NAR4
Knock-on effect on other utilities from variable electricity supply due to impact on DNOs

(Risk Status: Low)

One of the potential interdependencies within the sector is the knock-on effect on other utilities from a variable electricity supply. An initial climate impact on the electricity networks, as set out in the electricity network risks, may result in electricity supply interruptions leading to an impact on asset operations and supplies to gas, water and telecoms customers.

4. Assess

4.1.3 Risk Mitigation and Management

Temperature Driven Risks: (AR1, AR2, AR4, AR5, AR6, AR7, AR8, AR9)

While the likelihood of global temperature rise is accepted, the impacts on UK distribution and transmission network operators have not yet begun to be realised. Because of this, networks do not currently see any drivers to invest ahead of the need to offset risks. Network and asset performance will continue to be monitored and developed and will be modified once climate change impacts begin to have a direct and longer-term impact.

Where low ground to conductor clearance has been identified and air temperature sagging is considered to be a contributing or additional factor, some DNO companies have installed taller poles during pole replacement programmes in order to counteract the loss of clearance through thermal sagging. It should be noted that all DNOs use cables and overhead conductors designed and manufactured to international standards and consequently these assets are designed to operate safely in much greater maximum and minimum temperature ranges than those found in the UK.

Many DNO switchrooms and plant enclosures are designed to maximise the use of natural ventilation to keep internal temperature within plant and equipment operating within their optimum parameters. Where heat build-up is perceived to be an issue, forced ventilation is used and, in extreme cases or where the path to an external air inlet is problematic, air conditioning is considered.

Temperature/Precipitation Combined Risks: (AR3)

Currently DNOs treat vegetation growth as a business-as-usual (BaU) activity and manage it as part of their ongoing overhead line maintenance and clearance programmes. No information from overhead line patrols has indicated a requirement for an enhanced or more frequent tree cutting programme.

ENA document ETR132 “Improving resilience of overhead networks under abnormal weather conditions using a risk-based methodology” provides industry guidance on the management of vegetation below and to the side of overhead line routes. This document is reviewed on a regular basis and would incorporate a suggestion of increased frequency of tree cutting and vegetation management if the BaU programmes were not managing to maintain minimum clearances or in the light of increasing storm frequency.

Precipitation Driven Risks: Fluvial and Pluvial Flooding, Sea Level Rise (AR10, 11 & 12)

Throughout the recent price control periods network operators have undertaken an extensive flood protection programme to provide physical protection and network reconfiguration to minimise disruption from localised flood events. Dependent on the outcome of the next regulatory settlement, the flood protection programmes will continue to accommodate recommendations raised in the 2016 Government National Flood Risk Review. New substation development and substation reinforcement schemes will continue to reference guidance from ENA ETR138 document.

Flooding Due to Dam Burst (AR13)

It is understood that dams are now designed to a 1:10,000 risk of failure, far exceeding the 1:1,000 design risk utilised for assessing and developing flood protection measures for substations with more than 10,000 connected customers. While DNOs will try and avoid constructing a new substation within the breach zone of a dam, there is currently no programme to relocate existing substations.

Lightning Driven Risks (AR14)

Storm and lightning frequency are not expected to increase, and technical controls and tripping are currently employed to earth lightning strikes and protect network equipment. More earthing, surge arresters on plant and other equipment, and automated procedures will be considered if strike frequency increases.

Wildfire Driven Risks (AR15)

The impact of increasingly dry and warm summers on the frequency of wildfires has yet to be established. Once established, the frequency would need to be ratified against a potential increase of risk to overhead line and operational telecommunications assets. DNOs acknowledge the possibility of this emerging wildfire risk and are maintaining a watching brief on events and event frequency.

Wind Driven Risks (AR16)

Extreme events are rare but the impact of these events can be severe. Current specifications for overhead lines take account of wind pressure and ice loading. There is no strong signal within the climate projections for a change to storminess therefore the risk from increased frequency or severity of events does not change out to 2080.

Table 7A Table 7B Table 7C

4. Assess

4.2 Detailed Risk Assessment & Action Log

We have carried out a detailed risk assessment of the elements of the network against the climate variables considered. The table contains a summary of the key risks for each area of our operations and the adaptations in place. The full risk assessment and more detailed tables can be seen in Appendix 1.

Table 7 – Summary of Key Risks by Business Category

Key
Current risk (blue line)
2080s risk (red line)

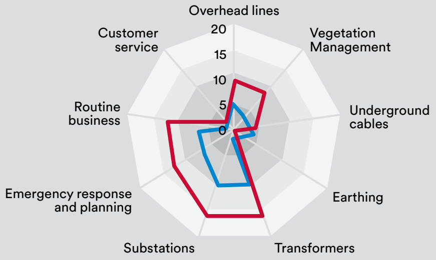
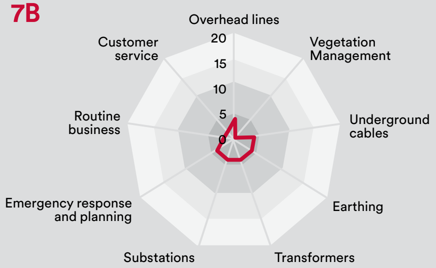
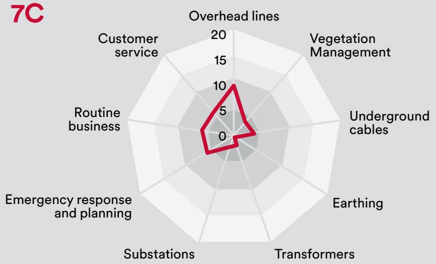
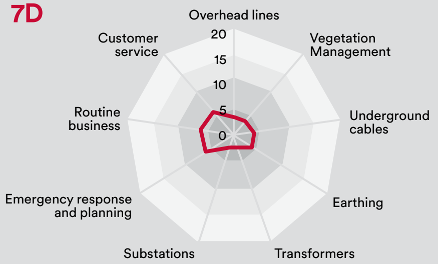
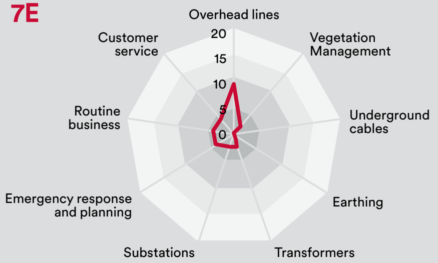
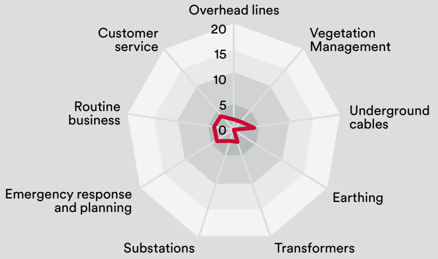
		Risks	Adaptations
Flooding (Fluvial & Pluvial)	7A  	— Corrosion or fast flowing water leads to instability of foundations — Tree roots are undermined by flooding events — Land surrounding cables is flooded or waterlogged leading to additional faults — Erosion of embankments or structures housing cables, leaving cables exposed. — Substation floods leading to equipment failure and loss of supplies	— Regular review of specifications to ensure designs are fit for purpose — Programme of condition monitoring of assets — Vegetation Management programme subject to regular reviews — Potential to identify and protect at risk cables — Flood mitigation measures in place — Emergency planning and major incident management processes in place
Coastal Flooding	7B  	— Substation floods leading to equipment failure and loss of supplies	— Flood mitigation measures in place — Emergency planning and major incident management processes in place
Ice & Wind	7C  	— Ice accretion on overhead lines compromises structural integrity — Ice accretion leads to additional faults due to falling debris from trees — Operation of equipment compromised by ice build-up	— Regular review of specifications to ensure designs are fit for purpose — Vegetation Management programme subject to regular reviews — Substation heating provided within specifications — Emergency planning and major incident management process in place

Table 7D Table 7E Table 7F

4.2 Detailed Risk Assessment & Action Log

Table 7 – Summary of Key Risks by Business Category continued

Key
Current risk (blue line)
2080s risk (red line)

		Risks	Adaptations
Heavy Snow	7D 	— Snow build-up on overhead lines compromises structural integrity — Snow build-up leads to additional faults due to falling debris from trees — Following melt, land surrounding cables is waterlogged leading to additional faults — Access to fault locations hampered by snow	— Regular review of specifications to ensure designs are fit for purpose — Vegetation Management programme subject to regular reviews — Programme of condition monitoring of assets — Emergency planning and major incident management processes in place
Hurricane & High Wind	7E 	— Increased frequency of events may weaken poles and fittings — Increased frequency of events may lead to additional faults due to falling trees — Slow response times and increased fault durations due to a large number of network faults	— Regular review of specifications to ensure designs are fit for purpose — Vegetation Management programme subject to regular reviews — Emergency planning and major incident management processes in place
Heat Wave	7F 	— High ambient temperature leads to a reduction in capacity — Growing season extended leading to additional vegetation — Failure of specific pieces of control equipment due to overheating — High staff absence due to sickness — Certain activities postponed due to unsuitability of PPE for temperature conditions	— Annual review of network loadings to ensure adequate headroom on network — Vegetation Management programme subject to regular reviews — Specifications to consider protection from sun for affected equipment — Pandemic and staff re-location policies in place to deal with increased absence — Routine business is monitored for delivery against targets with appropriate recovery plans implemented as necessary

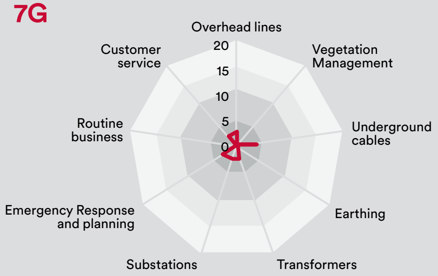
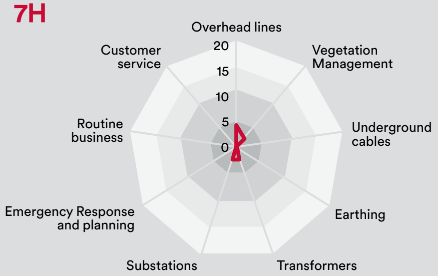
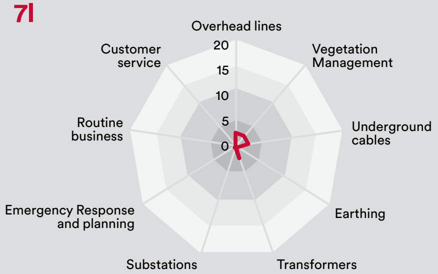
4. Assess

Table 7G Table 7H Table 7I

4.2 Detailed Risk Assessment & Action Log

Table 7 – Summary of Key Risks by Business Category continued

Key
Current risk (blue line)
2080s risk (red line)

		Risks	Adaptations
Cold Spell	7G 	— Additional loading placed on network due to additional heaters etc — Vulnerable customers need additional prioritisation	— Annual review of network loadings to ensure adequate headroom on network — Vulnerable customer register maintained and policies in place for dealing with customer welfare
Lightning	7H 	— Increase in number of faults	— Lightning protection in place on network
Gradual Warming	7I 	— Capabilities of network reduced due to reduction in ratings — Growing season extended leading to additional vegetation	— Annual review of network loadings to ensure adequate headroom on network — Vegetation Management programme subject to regular reviews

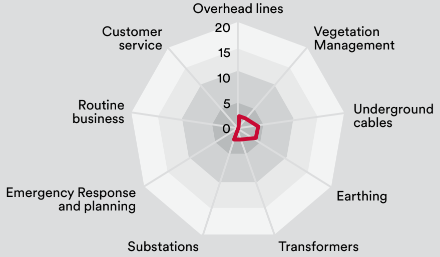
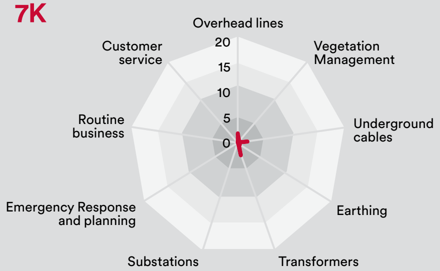
4. Assess

Table 7J Table 7K

4.2 Detailed Risk Assessment & Action Log

Table 7 – Summary of Key Risks by Business Category continued

Key
Current risk (blue line)
2080s risk (red line)

		Risks	Adaptations
Drought	7J 	— Soil drying and movement undermines foundations — Changes in water content of soil have an adverse effect on soil resistivity and hence cause a reduction in cable ratings and may affect earthing systems — Ground movement leads to joint failures on underground cables	— Programme of condition monitoring of assets — Annual review of network loadings to ensure adequate headroom on network — Regular reviews of specifications to ensure designs are fit for purpose — Review of specifications to include additional joint testing
Wildfire	7K 	— Fire damages poles and equipment — Risk of oil insulators catching fire	— Preservative treatment of poles should help prevent fire — Consider use of synthetic ester in at risk areas in place of oil

4. Assess

4.3 Interdependencies

As part of the ENA commissioned Met Office report, interdependencies between sectors were also considered. One of the potential interdependencies within the energy sector is the knock-on effect on gas network operations from increased electricity demand. Increasing temperatures will lead to increased use of air-conditioning systems in both commercial and domestic environments, particularly in urban areas. This in turn will lead to an increase in electricity demand which is often supported by gas-fired generation resulting in a drawdown of gas reserves which could impact supplies as pressures are reduced to meet generation demand.

The electricity networks are also aware that other infrastructure operators and society in general are reliant on having a reliable and resilient supply. DNOs and transmission companies continue to work to ensure that the UK electricity network remains one of the most reliable networks in the world and climate change is one of the impacts considered when developing and reinforcing those networks.

The critical infrastructure network (telecommunications, water, road, rail and air transport, ports and energy) is highly linked, with impacts on one sector affecting all others. The energy sector itself is a critical supplier to all other infrastructure. With systems becoming smarter the sectors are even more tightly linked, with telecommunications becoming a central component of all other sectors, to a greater degree. The telecommunications sector is itself evolving to become more reliant on the electricity network as the older analogue networks are phased out.

Additional to these interdependencies, the COVID-19 pandemic has highlighted the interconnected nature of risk outside of infrastructure, with energy demand affected by changes in usage and maintenance and disrupted office work. However, for some personnel, the situation has reduced the reliance on the transport sector.

A number of key hazards were highlighted for each sector, alongside the knock-on impacts for energy. These, along with Met Office insights from work across the sectors, are summarised in Table 8 – Hazards by Sector.

Table 8 – Hazards by Sector

Sector	Impact	
Gas	— Flooding — High temperature — Wind — Lightning — Erosion	— Ground contamination from flooding — Ground movement — Sea level rise — Vegetation growth
Telecommunications	— Strong winds — Flooding — Snow and ice	— High temperatures (causing line sagging) — Lightning — Solar storm
Water	— Flooding — Erosion	— Ground movement — Drought
Road and rail	— Extreme high temperatures (tarmac melting/rails buckling) — Flooding — Strong winds — Sea level rise	— Storm surge — Longer growing seasons — Snow and ice — Solar storm (rail sector)
Aviation, especially offshore helicopters	— Strong winds — Extreme high temperatures (reducing 'lift') — High wave heights	— Lightning — In-air conditions, such as in-flight icing and turbulence
Ports	— Sea level rise — Strong winds	— High wave heights — Storm surge

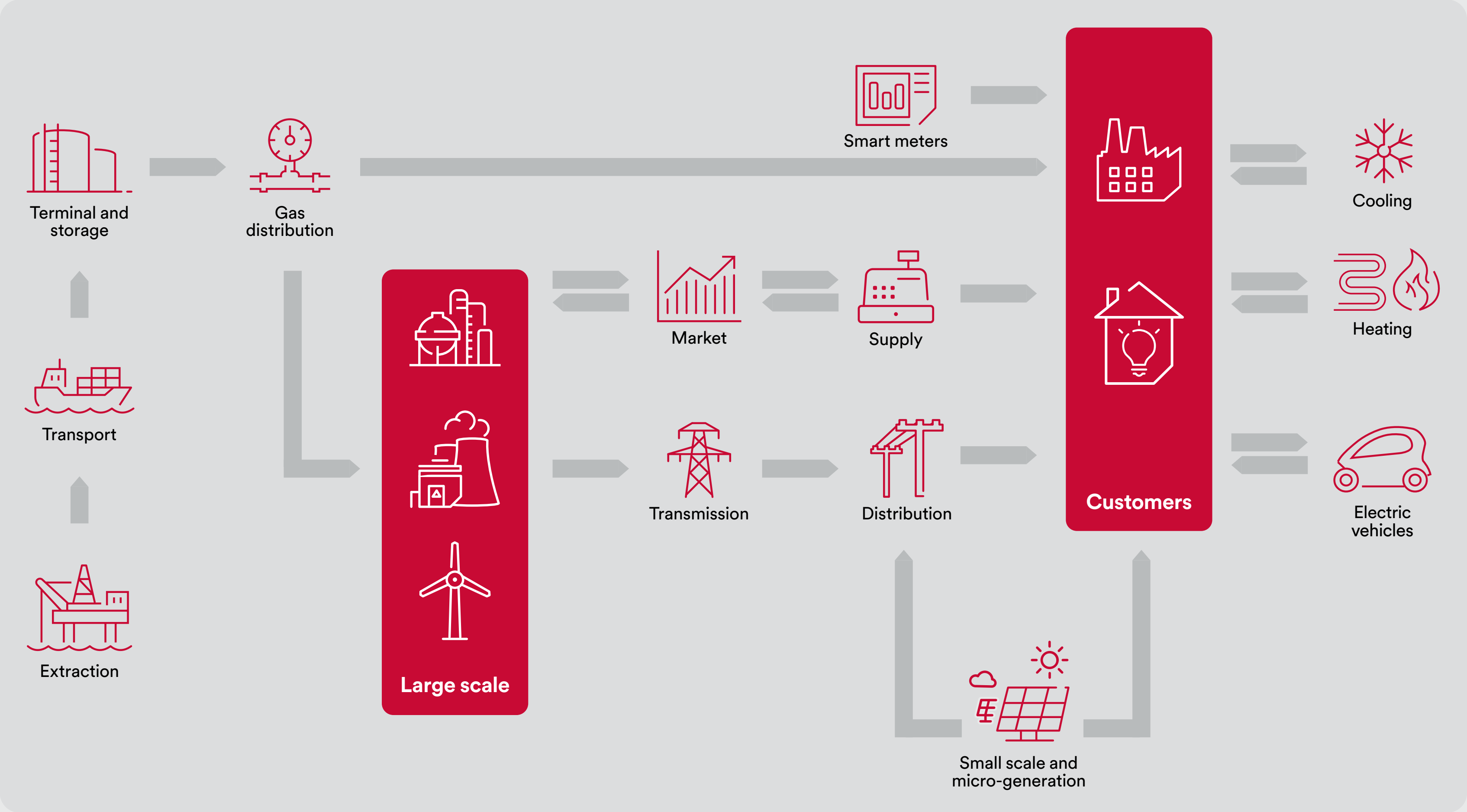
4. Assess

4.3 Interdependencies

It is also worth considering the supply chain to the energy sector (e.g. the system of organisations providing system components). This is not a sector with key national infrastructure, but it is essential for the resilience of the energy network. This network could be impacted by hazards on a global level. These hazards have not yet been investigated.

The interdependencies between sectors have been further explored through examination of a simplified value chain for energy (Figure 11 – Value Chain For Energy) – each element of the value chain is reliant on different interconnections with other sectors. If parts of the value chain are disrupted, this can impact the network itself. This visual map and the responses from ENA members have been used to highlight how impacts on other sectors affect the energy sector itself.

Figure 11 – Value Chain For Energy



4. Assess

4.3 Interdependencies

This is summarised in Table 9 – Summary of Value Chain. Here telecommunications is highlighted as potentially the most critical sector, affecting all parts of the value chain though the impact on maintenance and the reliance on remote operation of some equipment. This is followed by road, which is critical in terms of access to infrastructure and office space. Additionally, in the future, road transport could represent a key consumer of electricity and so affect the resilience of current infrastructure. The water sector can impact underground electrical assets through flooding and is also a key consumer of electricity. Whereas aviation and ports are mostly only relevant to the extraction and transportation of gas. The table also highlights the importance of supply chain across the value chain for energy – delays in supply of key components have the potential to disrupt all aspects of the energy value chain.

Table 9 – Summary of Value Chain

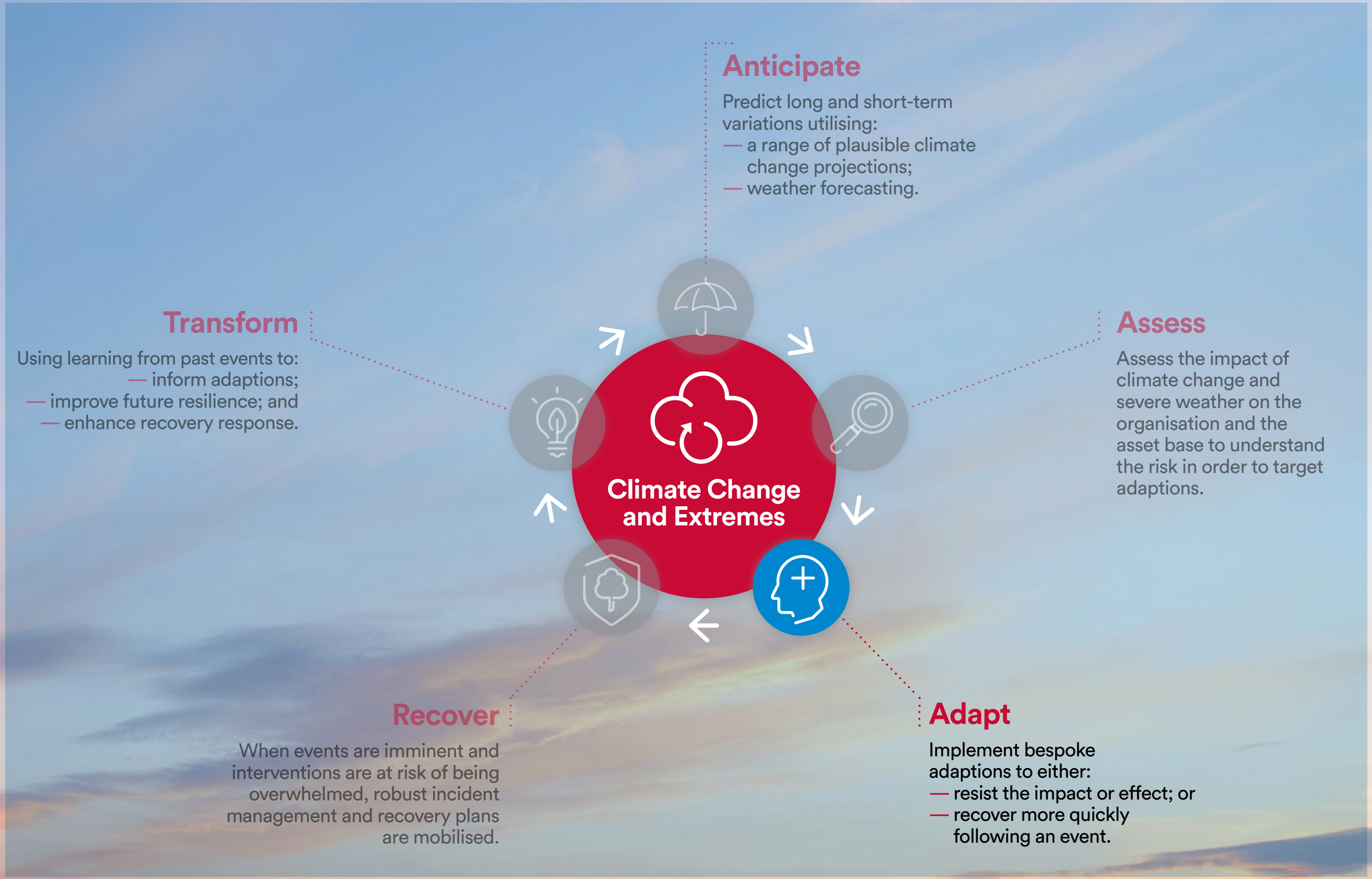
Value Chain	Telecoms	Water	Road	Rail	Aviation	Ports	Supply Chain
Extraction/Transport of Gas	X				X	X	X
Storage	X		X				X
Gas Distribution	X		X				X
Large Scale Generation	X		X				X
Market	X						
Transmission	X		X				X
Distribution	X	X	X				X
Small Scale and Micro-Generation							X
Consumers	X	X	X	X			X

5 Adapt

5. Adapt

Following on from our comprehensive risk assessment we have considered how best to adapt to the challenges presented by climate change. This includes understanding how we can better resist to prevent an impact on our network as well as how we can absorb to minimise the impact when events do occur.

The risks of flooding presented by changes in precipitation rates and sea level rise, alongside changes in growth rates and patterns of trees due to changes in temperature and precipitation, are considered to be the two highest priority areas for the introduction of adaptations and are discussed in the following sections.



5. Adapt

5.1 Assessing Adaptive Capacity

In 2016, Northern Powergrid participated in a collaborative project run by the "Infrastructure Operators Adaptation Forum" (IOAF) to assess our organisational adaptive capacity (the ability to embed risk information on climate change)[11]. This project involved a number of different infrastructure operators and the learning from the assessments was shared between participants.

Our adaptive capacity was assessed using Climate CaDD (Capacity Diagnosis and Development) and the outcome of the assessment provided an action plan for us to ensure that climate change adaptation is fully embedded within our organisation.

The CaDD framework identifies six clear stages of development known as response levels. Each of these response levels (RL) can only become robust if it is built upon the solid foundation of the response level below it.

- RL1 – Core Business Focused – Short-term focus, understanding of direct weather risks.
- RL2 – Stakeholder Responsive – Recognises a need to understand and comply with a complex and rapidly changing set of rules. Keeps up to date with needs of key customers and other stakeholders.
- RL3 – Efficient Management – Quantifies and prioritises issues, common sense and effective management programmes for improvement in place.
- RL4 – Breakthrough Projects – Understands need to learn about strategic threats and to identify responses. Conditions for a strategic response are in place.
- RL5 – Strategic Resilience – Programmes in place to ensure resilience in a very different and fast changing future.
- RL6 – Champion Organisation – Helps society to respond as well as protecting own interests or leads wider social change to slow and reverse climate change.

These response levels are assessed across nine pathways for change to provide an assessment of the current level of adaptive capacity within the organisation.

- Awareness – This is an essential part of any long-term strategy to prevent short sighted decision making.
- Agency – Being able to recognise opportunities and take action.
- Leadership – Level of support, direction and control from the formal leadership team.
- Agents of Change – 'Champions' are vital to initiate action on climate change and keep it moving.
- Working Together – Sharing perspectives and recognising and responding to the needs of other groups.
- Learning – The extent to which learning from experience is supported, promoted and used to implement improvements.
- Managing Operations – Resources are used effectively with appropriate systems in place to monitor progress.
- Programme Scope & Coherence – Activities are coordinated and comprehensive and goals are achievable.
- Expertise & Evidence – The capacity to recognise appropriate expertise and evidence and deploy it where most needed.

11. CaDD Comparison Report IAOF WG4 published by TRIOSS.

5. Adapt

5.1 Assessing Adaptive Capacity

Following the assessment in 2016, we were assessed as moving ahead of the field. Each pathway was assessed at the response levels shown in Figure 12 – Northern Powergrid Response Levels For The Nine Pathways for Change. The dark red areas represent current response levels, and lighter red where there was evidence that we were beginning to move to a higher level but progress had not yet been consolidated.

An action plan was prepared as a result of this assessment which provided areas for Northern Powergrid to target in order to advance our adaptive capacity. Over the period since assessment, we have made significant steps towards further embedding climate change adaptation within our organisation, aiming to improve response levels across a number of pathways to head towards the long-term target.

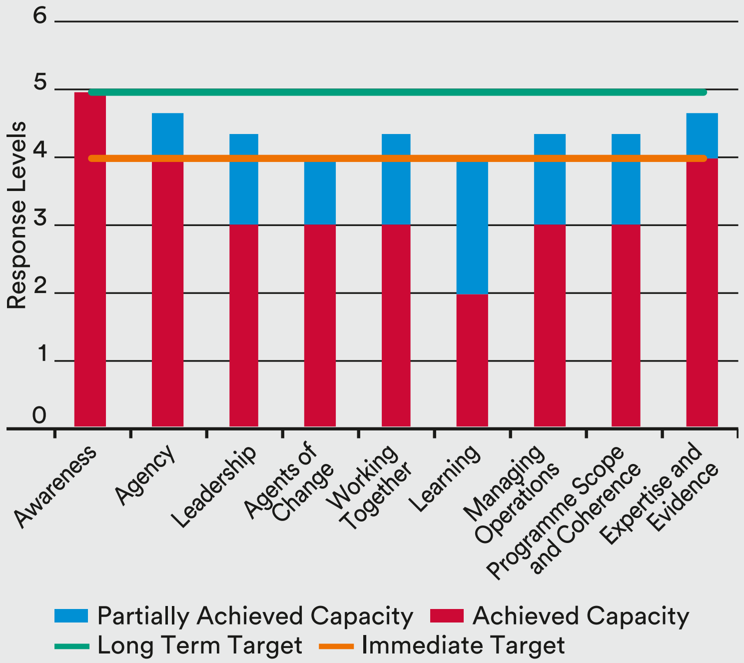
Leadership/Programme Scope and Coherence:
In developing our submissions to Ofgem for our next price control (RIIO-ED2), which runs from 2023 to 2028, we have split our business plan into twelve areas. Climate resilience is one of these areas and as such is subjected to scrutiny in line with the other sections of the plan such as decarbonisation and long-term network condition. This scrutiny is both internal, with sign off from senior management and the Executive team as well as by our independent Customer Engagement Group and Technical Panel. As part of our regulatory requirements for the RIIO-ED2 period, we are required to produce a strategy for our environmental resilience for submission to Ofgem.

Learning/Managing Operations:
This forms a fundamental part of our asset management strategy. We utilise the philosophy of "plan, measure, execute, correct" and as such, we are constantly reviewing performance and implementing learning. This is particularly marked in our emergency planning protocols where we carry out a full debrief each time they are implemented in order to ensure learning is noted and appropriate improvements and changes are made to enhance our responses going forward.

Working Together/Agents of Change:
We have recognised the interdependencies across infrastructure and beyond. During extreme events, we work with the Local Resilience Forums to ensure that we are part of the co-ordinated regional response. We are also currently working with other regional infrastructure providers, local authorities and the Environment Agency to ensure that we identify any areas where joint working would be of benefit to all parties and the region and to allow for sharing of knowledge, experiences and best practice.

Figure 12

Figure 12 – Northern Powergrid Response Levels For The Nine Pathways for Change



5. Adapt

5.2 Resist

5.2.1 Flood Defences

The greatest climate risk to networks is assessed to be flooding. This applies to present risks and future risks as a result of predicted climate change. In the event of serious flooding, electricity substations can be put out of action and the consequences can be severe. The flooding of a large substation can mean the loss of electricity supply to thousands of people, as well as to other types of infrastructure. The UK Climate Change Risk Assessment (UKCCRA2017)[12] states that "an increasing frequency and severity of flooding from a range of sources represents the most significant climate change risk to UK infrastructure".

In November 2000, flooding directly affected eight of our major sites. Osgodby had to be taken out of service for six months whilst major rectification works were carried out. The final cost of recovery from this incident was approximately £4m. The severe flooding during the summer of 2007 resulted in widespread and sustained power interruptions across the Yorkshire licence area, flooding occurred at four major substations and the control centre in Leeds had to be evacuated. The final cost of recovery from this incident was approximately £6m.

Such events show the need to understand and improve the resilience of substations to flooding. Action is particularly vital because, due to climate change, flooding of all kinds is likely to get worse. The Government has recognised this, and in 2007 asked for a comprehensive assessment of substations' resilience to flooding. Sir Michael Pitt's review[13] of the 2007 floods also called for an improvement in the resilience of substations. The 2016 National Flood Resilience Review[14] carried out following major flooding experienced in 2015 recommended that all electricity sites which serve more than 10,000 customers were also protected as appropriate from flooding.

DNOs realised they needed a consistent, sector-wide, approach to flood resilience, but no industry standards existed. Regulations required 'reasonably practicable' measures to be taken to prevent loss of supply, but there was no common view about what this meant. As a result, an industry task group was set up to produce a common approach to the assessment of flood risk and develop target mitigation levels that could be subject to cost benefit assessments. This was enabled by the great improvement in information on flood risk in recent years. The task group comprised representatives from the DNOs, government departments and agencies, and the industry regulator.

The electricity network sector has addressed this gap, developing a systematic approach to flood risk assessment and protection. As a result, the Energy Networks Association's ETR138 – Electricity Substation Resilience to Flooding (Issue 1 October 2009) provides national guidance on how to improve the resilience of electricity substations to flooding:

- The risk-based ETR138 methodology is prescriptive in terms of the level of protection to be applied at substations at risk of flooding.
- It introduced the need to consider the risk of extreme flooding (represented by the Environment Agency's 1 in 1,000 flood maps) at larger installations (supply and grid supply points).
- This represented a change in scope from Northern Powergrid's previous assessments, which only considered 1 in 100 (river), and 1 in 200 (tidal) year flood events.
- In addition, the ETR prescribes the use of cost-benefit analysis and takes into account societal impact of an event, should one of our substations be flooded.

Two revisions were subsequently made to ETR138; the first in 2012 added a requirement to assess the risks posed by pluvial (surface water) flood risk and a further review in 2015/16 recommended that primary sites identified as feeding in excess of 10,000 customers should have enhanced mitigation to the same level as 132kV sites.

Based on the original and updated ETR, companies are now undertaking a long-term programme of work to improve substation resilience to flooding that takes into account predicted climate impacts. This programme was agreed by the industry regulator when they set the current allowances for transmission and distribution companies as part of the regulatory control periods. The respective allowances are published and expenditure monitored on an annual basis.

As part of our ED1 programme of works, we have committed that, by 2023, all 132kV and primary substation sites identified as at risk from flood will have mitigation in place which complies with the requirements of ETR138. Following the 2016 National Flood Resilience Review, we revised that commitment to include providing primary sites identified as feeding in excess of 10,000 customers with enhanced mitigation to the same level as 132kV sites. We have over 130 major substations at which flood mitigation is provided by a combination of fixed barriers and pumps.

By the end of 2021, ahead of our target of 2023, we will have completed flood mitigation works at 295 sites, incurring costs in the region of £36.4 million.

Higher risk sites were completed early in the programme. In the floods in the UK in the winter of 2013/14, no customer supplies were interrupted as a result of river flooding at major substations operated by the DNOs.

12. https://www.theccc.org.uk/preparing-for-climate-change/uk-adaptation-policy/

13. https://webarchive.nationalarchives.gov.uk/20100702215619/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html

14. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/551137/national-flood-resilience-review.pdf

5. Adapt

Standards of Resilience

The ETR identifies three different levels of acceptable flood risk, depending on the importance of the substation. These standards are the default, but can be raised or lowered if an analysis of the costs and benefits suggests that this is appropriate.

- Level 1: most important grid substations (typically supplying 50,000 to 500,000 customers) – likelihood of flooding should be no more than 1 in 1,000 years.
- Level 2: other primary substations (typically supplying 5,000 to 30,000 customers) – likelihood of fluvial flooding no more than 1 in 100 (1 in 200 for Scotland) and 1 in 200 for sea flooding.
- Level 3: for sites where level 1 or 2 cannot be justified – other flood resilience measures.

Data Specification

The ETR specifies the data that should be collected for the purposes of assessing flood risk. The specification requires companies to collect, for each substation:

- the likelihood of flooding in any one year from rivers, the sea and surface water
- the potential depth of flood water
- information about historic flooding
- existence and condition of flood defence scheme
- whether the site is in an area where the Environment Agency (EA) provides flood warnings
- the time required to activate flood protection measures
- Societal risk – number of customers and number of critical/vulnerable customers.

Climate Change Allowances

The ETR recommends allowances to take account of the impacts of climate change on flood risk for both fluvial and sea flooding. An additional allowance is included for uncertainties in data and modelling.

Cross-Sector Approach

The whole of the electricity network sector collaborated in developing ETR138. Work was coordinated by the ENA, and included representatives from all electricity network companies, government (DECC), the regulator (Ofgem), the EA, Scottish Environment Protection Agency (SEPA) and the Met Office. The involvement of Department of Energy and Climate Change (DECC) and Ofgem was particularly important as it helped to support companies' investment plans for flooding resilience.

Benefits

All DNOs now have programmes to raise protection to the agreed standards and the current programme will be completed by 2023. By setting out industry standards and an agreed approach, companies know how to tackle flood risk. Because government and the regulator were involved from the start, business plans which follow this approach have been approved. The respective allowances are published and expenditure monitored on an annual basis by the regulator.

Other benefits are:

- The Government is clear about the standard of protection of this vital service.
- There is consistency across the country – customers in different areas enjoy the same standards of protection.
- Operators of infrastructure which rely on electricity understand the risks to their service.
- Resilience measures will take account of climate change, so will be robust for the foreseeable future.
- Lessons learnt in the development of ETR138 can be applied in other areas.
- Developing a cross-sector approach and acceptable levels of risk.
- Allowing flexibility in the standard, depending on costs and benefits.
- Discussing resilience standards with operators of dependent infrastructure.
- Involving all relevant organisations, including the Government and the regulator to achieve acceptance.
- Agreeing climate change allowances to handle uncertainty about future risk.
- Keeping standards under review, and updating to take account of new information.

These lessons can read across to other areas. This approach was held up as an exemplar by the Infrastructure Operators Adaptation Forum (IOAF) (facilitated by the EA Climate Ready team). The work in developing the ETR is also referenced in the 2014 report on infrastructure resilience by the Adaptation Sub Committee (ASC) of the Committee on Climate Change[15].

A review of ETR138 has taken place in light of the publication of UKCP18 and it has been determined that this standard remains fit for purpose and a revision is not required at this point in time.

15. https://www.theccc.org.uk/wp-content/uploads/2014/07/Final_ASC-2014_web-version-4.pdf

5. Adapt

5.2.2 Vegetation Management

Interference to overhead lines by trees and other vegetation causes a variety of power supply issues ranging from transient interruptions, due to vegetation touching the line, through to severe damage from trees, or parts of trees, falling onto the lines. Under abnormal weather conditions the latter can lead to large scale power outages with some supply restorations taking many days. During periods of high wind a considerable proportion of faults are caused by wind-blown branches and other debris, some of which can originate from relatively long distances from the overhead line on which it impacts.

Current climate change predictions indicate an increased incidence of strong winds, rainfall and other severe weather events combined with extended vegetation growth periods. This may lead to the need for increasing levels of investment to maintain network resilience. The electricity network sector addressed these concerns through the implementation of Engineering Technical Recommendation (ETR) 132.

A 2011 research project commissioned by network operators with ADAS quantified the impact of vegetation growth around overhead lines and, in particular, the manner in which the utility space (that is the physical volume around the utility's apparatus including the volume necessary to ensure its safe and reliable operation) was degraded by vegetation growth over time. The ADAS vegetation management research project established approximately 1,700 experimental sites across the country in representative bioclimatic zones determined by the temperature, rainfall and soil conditions. At each site the Utility Space Derogation (USD) was measured on a biannual basis and these measurements used to infer the net integrated rate of growth at each site to determine the spatial and temporal growth rates for each bioclimatic zone. The initial results showed a marked variation in growth rates across the country, which follow the bioclimatic zone areas. Using UKCP09 data, ADAS predicted the future changes in the size and locations of the bioclimatic zones under different emission scenarios. If the growth rates from the initial observations follow the expected trends then this indicates that climate change will result in a substantial increase in vegetation growth over the next ten years. These conclusions are in line with the findings from the latest Met Office reports which show an increase in the length of the growing season due to the early onset of spring.

During periods of high wind a considerable proportion of faults are caused by wind-blown branches and other debris.

5. Adapt

ETR132: Improving Resilience of Overhead Networks Under Abnormal Weather Conditions Using a Risk Based Methodology.

The ETR focuses on vegetation management as the first and most important step in improving overhead line resilience and it provides guidance on how to improve network performance under abnormal weather conditions by adopting a risk based methodology to identify the most effective locations to carry out resilience related vegetation management, and/or other solutions. Abnormal weather conditions include high winds, ice, snow, prolonged high temperatures and heavy rainfall.

It is acknowledged that there may be restrictions on the amount of tree cutting that can be carried out and that in some areas additional protection may be required to protect overhead lines from wind-blown material. To address these situations, other opportunities for enhancing resilience that could be applied alongside resilience tree cutting are also considered.

These include the following:

— Choice for construction standards of wood pole overhead lines
— Choice for construction standards for tower lines
— Enhanced network protection or automation
— Network diversion and undergrounding.

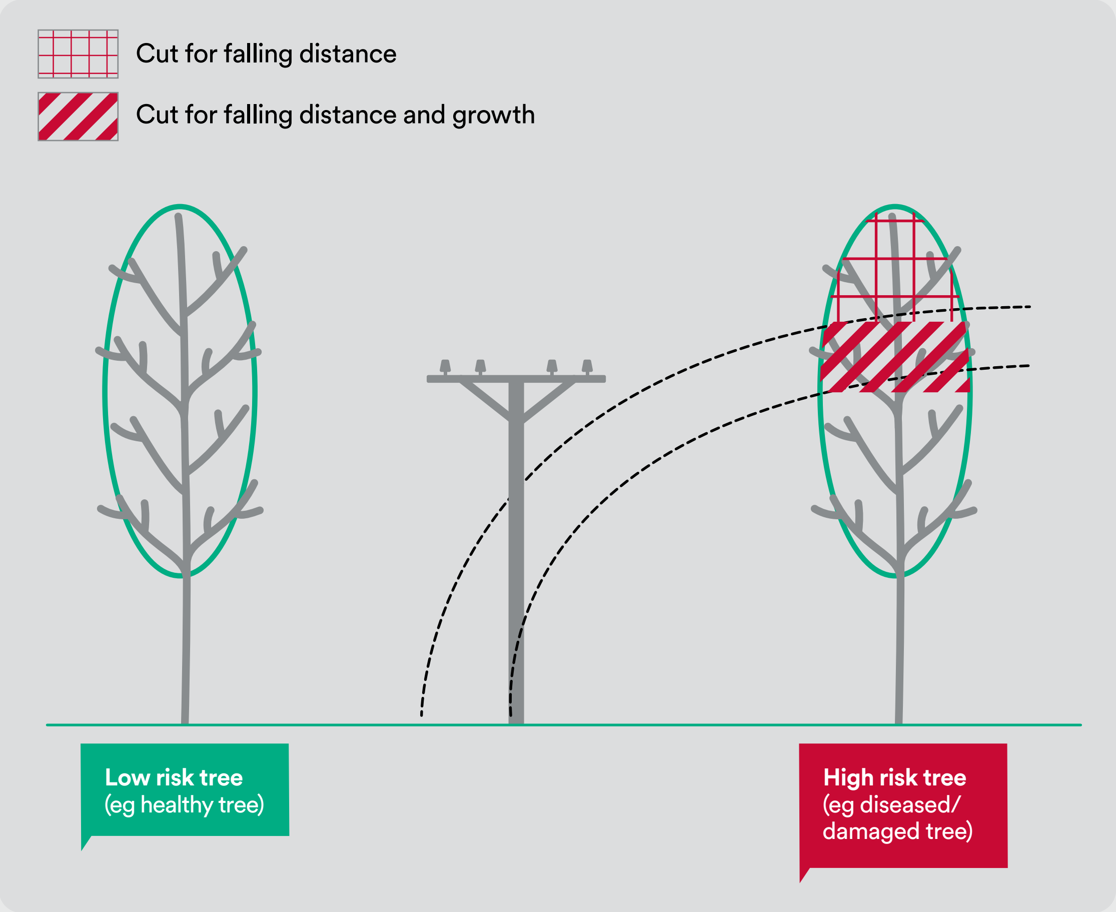
The ETR advocates a risk-based approach to determine where and when to carry out vegetation management or other measures for the purpose of improving network resilience. Figure 13 – Example of a Resilient Clearance shows the requirements of resilient vegetation management.

The winter storms of 2013/14, and particularly the severe storms at Christmas, highlighted again the continued importance of ensuring that overhead line networks are protected, as far as reasonably possible, against falling trees and tree branches which can cause severe damage to overhead lines. As part of the Christmas Storm Review process with DECC and Ofgem, it was agreed that it would be appropriate to take the opportunity to review ETR132 to include consideration of the impact of the 2013/14 storms, the comments of the energy select committee, DECC and Ofgem, performance expectations and lessons learned. The original version of the ETR only considered tree cutting as a means of achieving resilience against falling trees and branches. However, in view of the difficulties in implementing the requirements of ETR132, this revised version provides guidance on alternative methods for achieving a similar level of resilience.

5.2.3 Standards Incorporating Climate Conditions

Many of the standards and specifications in use within Northern Powergrid today include references to climate conditions and set out defined thresholds for operations. A full list of these standards and specifications can be seen in Appendices 4 and 5.

Figure 13 – Example of a Resilient Clearance



5. Adapt

5.3 Respond

Adaptations fall into two categories, those that enable us to resist the effects of climate change, such as flood mitigation and vegetation management discussed in Section 5.2, and those that enable us to respond should events occur. When considering adaptations, it is necessary at all times to ensure that they are cost effective and that they offer benefits to the consumer. In some instances, it becomes more cost effective to prepare to respond to events when they occur rather than to try to prevent the impact.

5.3.1 Automation

Automation is an important tool in our quest for improved resilience. Our Automated Power Restoration System (APRS) provides fault detections, isolation and restoration so that in the event of a fault we are able to locate the problem and often restore supplies remotely in a fast and safe manner.

Use of automation ensures that customers are without power for the shortest duration possible, and the majority of restorations carried out by APRS typically occur within a minute or less, depending on the communications infrastructure.

The use of automation is particularly important during extreme weather events when issues such as flooding, snow or ice may prevent field crews reaching the fault location. It improves our ability to restore and recover from network incidents, especially where they are transient such as tree branches clashing with overhead lines.

Use of automation ensures that customers are without power for the shortest duration possible.

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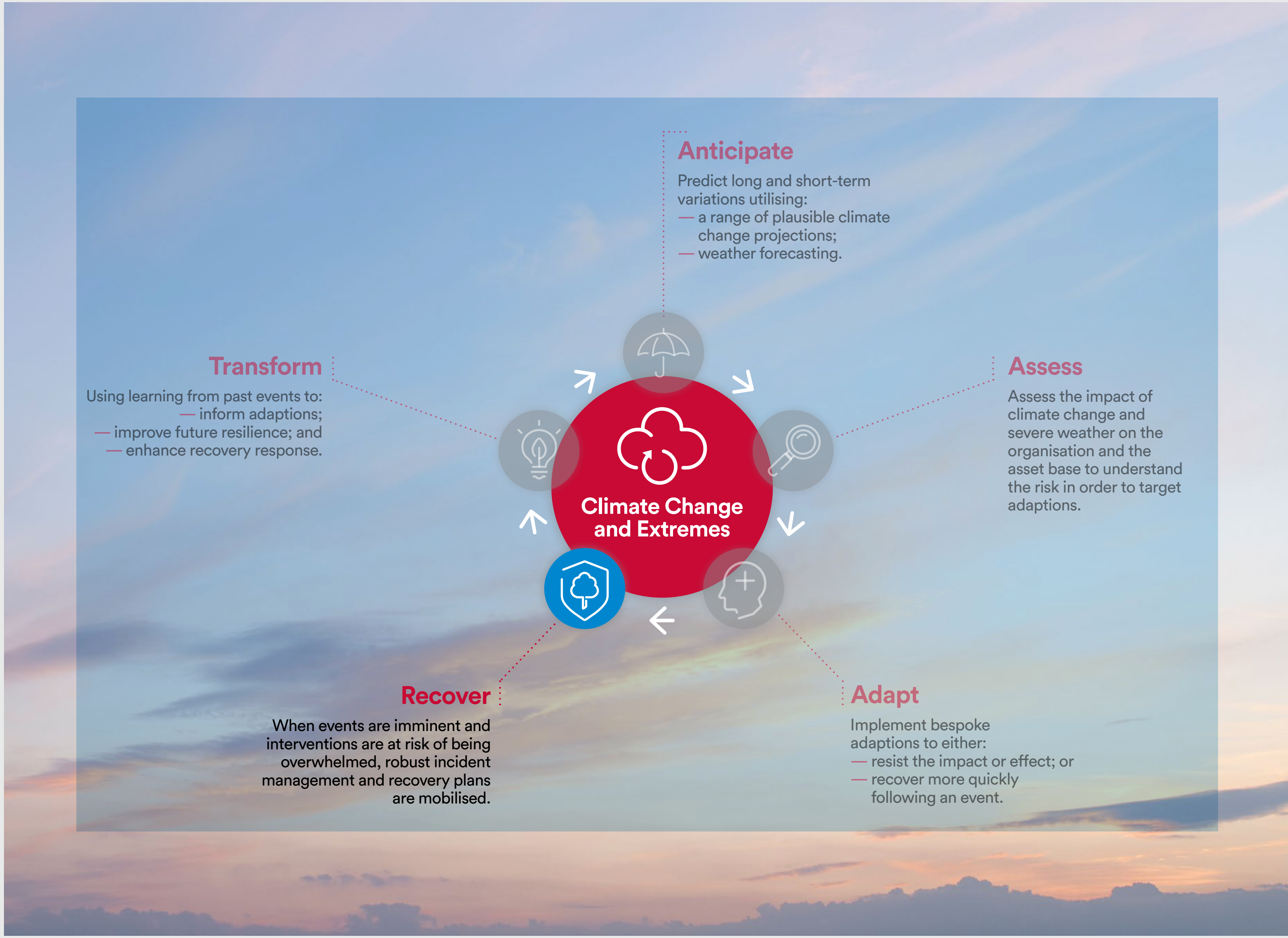
6 Recover

6. Recover

Alongside planning to adapt to the risks presented by climate change, it is also necessary to consider that in some instances, interventions may be overwhelmed and it may be necessary to have robust incident management and recovery plans in place to help to quickly restore the network to the expected levels of service.



6. Recover

6.1 Emergency Planning Protocols

Emergency planning issues of shared interest to the government, industry and the regulator are reviewed and managed through the Energy Emergencies Executive (E3). E3 is made up of a senior representative from BEIS, industry and Ofgem, and is supported by a committee (E3C) chaired by a Director of National Grid and comprising representatives from customer organisations, electricity companies, trade bodies, BEIS and Ofgem. E3C meets every two months and has a number of active task groups working on various issues.

The ENA led review of the resilience of substations to flooding is an example of the work undertaken within the E3C framework (see Section 5.2.1 Flood Defences). Through ENA, DNOs meet regularly to review emergency planning and response arrangements covering issues ranging from wind storms to pandemics.

Northern Powergrid, along with all other DNOs, is a member of NEWSAC (North East South West Area Consortium). In an emergency affecting member companies, NEWSAC representatives assess the availability of resources from those least affected and agree the allocation of these resources to other members based on the level of damage. The NEWSAC mutual aid agreement has been in place and utilised over many years.

Under the terms of the Civil Contingencies Act, Northern Powergrid is a Category 2 responder and works closely with other utilities, the emergency services and local authorities. This includes working with Resilience Teams on emergency planning, taking part in exercises and participating in Gold, Silver or Bronze Commands.

The Electricity Act and the ESQCR include powers for the Secretary of State in relation to continuity of supply, including preserving security of electricity supplies. The Minister twice exercised these powers in 2002 in the setting up of independent reviews of the resilience of the electricity supply industry.

Ofgem have established criteria that identify certain “exceptional events” that include particularly large interruptions that DNOs have limited ability to prevent. In order to reduce the volatility and impact of these occurrences on their performance (and future target setting), these “exceptional events” are excluded from annual performance figures. Exceptional events are classified as being either a severe weather exceptional event or a one-off exceptional event.

Severe weather exceptional events refer to a level of interruptions occurring for a period of time that result directly from bad weather. To be considered a severe weather exceptional event, a specific and verified number of higher voltage interruptions, directly caused by bad weather, are required to have occurred within a 24 hour period. This is referred to as the severe weather exceptional event threshold and is currently eight times the average daily higher voltage fault rate.

One-off exceptional events are those where a single cause outside a DNO’s control causes a significant level of interruption. To be considered a one-off exceptional event, a specific and verified number of interruptions and/or minutes lost are required to have resulted. These numbers are referred to as the one-off exceptional event thresholds and currently stand at 25,000 customers interrupted and two million customer minutes lost.

To justify company claims against these exceptional event criteria, Ofgem undertake an investigation into the incident including the effectiveness of the company’s preparations and response.

6. Recover

6.1.1 Our Emergency Planning Protocols

Whilst every effort is made to ensure network security, DNOs have well-developed emergency plans to ensure an effective response to a range of events and Northern Powergrid is no exception. We have a well-established Major Incident Management Plan (MIMP) in place. This consists of a number of stages which manage the event from initial warnings through to recovery and lessons learnt. The alert levels of this plan are shown in Table 10 – MIMP Alert Levels.

The move to trigger the MIMP is driven by event warnings. Weather forecasts, severe weather warnings, flood warnings and lightning risk levels are received on a 24 hour basis into Northern Powergrid. Weather forecasts are based on statistical analysis and therefore have a confidence level which increases closer to the time of the event. Forecast confidence levels have been built into the comprehensive major incident trigger levels. Example of non-weather related events that may require a MIMP response include territorial denial due to a notifiable animal disease or a declared civil emergency requiring a multi-agency response under the Civil Contingencies Act. We also monitor wildfire risk reports and landslide risk reports from the British Geological Survey.

Following the closure of the event, we carry out a full post-event review. The output of this review will include lessons learned and improvement actions which will be monitored to completion. An important element of the review is asset performance. Any concerns about the performance of specific asset types or unusual failure rates will be highlighted for review and appropriate remedial action.

We participate in all the Local Resilience Forums (LRFs) based within our regional area. LRFs are a multi-agency forum consisting of key emergency responders and specific supporting agencies and are a requirement of the Civil Contingencies Act 2004.

Table 10 – MIMP Alert Levels

Stage	Alert Status	Area Affected	Typical Actions
Business as Usual	None	n/a	Business as usual response process
Awareness	Yellow	Specified Region(s)	Circulate warnings for awareness and minor actions
Preparation	Amber	Licence Area(s)	Agree preparatory actions
Response	Red	Licence Area(s)	Activate full command & control structure
Recovery	All Clear	n/a	Business as usual recover/repair process

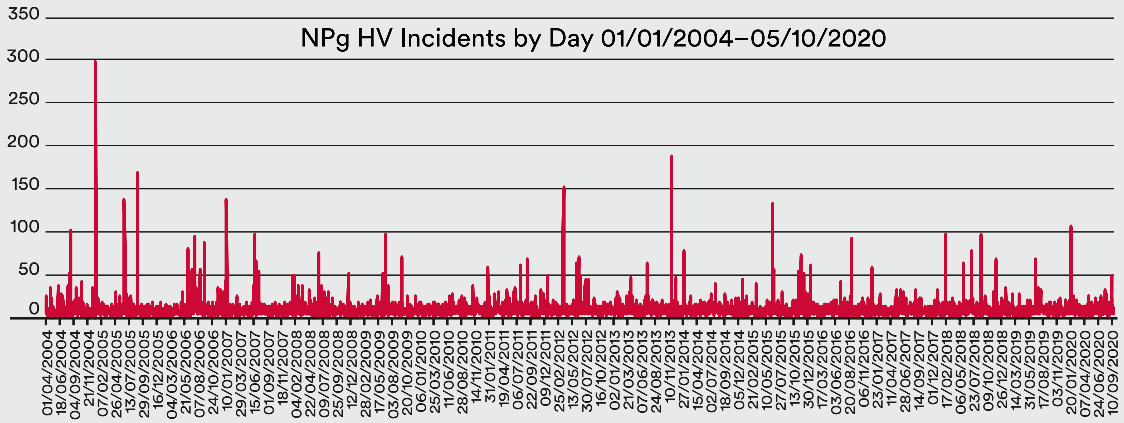
6. Recover

6.2 Incident Recovery

6.2.1 Network Emergencies

The weather can often have a significant impact on the performance of our network. Figure 14 highlights the events which have had the highest impact on our network. The following sections contain brief case studies on a limited number of these events.

Figure 14 – Major Weather Events Affecting The Northern Powergrid Network



6.2.2 Case Studies

Thunder Thursday, June 2012

Record levels of rainfall were experienced between April and December 2012 and the events of 28 June 2012 in Newcastle and Gateshead (known locally as the "Toon Monsoon") led to the reconsideration and improvement of information on surface water flooding. This has become more reliable and is now considered sufficient to justify additional flooding resilience measures. In view of this the ETR138 task group was reconvened to update the document to include the management of surface water risk.

December 2013

During the exceptional winter weather of 2013/14 DNOs nationally faced an unusually demanding sequence of storms, mainly as a result of wind storms causing damage to wood pole overhead lines due to falling trees and windborne material.

In particular, between 22 and 28 December 2013, as a result of two severe winter storms and consequent damage to the distribution overhead line network, almost one million properties nationwide suffered disruption to electricity supplies. Though the vast majority of customers were restored within 24 hours, 1.7% of customers experienced a disruption to supply in excess of 48 hours, and there were lessons to be learnt to improve the effectiveness of the industry response to disruptive events and minimise customer inconvenience as much as possible.

Some DNOs experienced particular difficulties with customer communication and resourcing the amount of repair work. However, it was noted independently that the industry's staff showed remarkable resilience, working long hours in potentially dangerous conditions with no reportable accidents. As a result, staff were thanked for their tremendous efforts at a parliamentary reception.

Due to the serious consequences of the 2013 Christmas storms, two enquiries took place led by DECC and Ofgem, with DNOs required to report on how performance could be further improved in a number of areas. These resulted in reports by Ofgem[16] and DECC[17] which have now been published.

16. https://www.ofgem.gov.uk/ofgem-publications/86460/finaldecember2013stormsreview.pdf

17. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/287012/DECC_-_Festive_disruption_review_-_Final__2_.pdf

6. Recover

6.2.2 Case Studies continued

Following the initial DECC report, the industry undertook a major review of its performance to identify areas of good practice and areas for improvement. This took place through the framework of the E3C with support from ENA. All the DNOs and DECC were involved and specialist task groups were established to address particular issues. A number of actions to improve future preparedness and response were identified, including:

- Developing a single national number for customers to call during a power disruption. The 105 single number for reporting power cuts went live in April 2016.
- Developing worst-case scenarios for customer calls and ensuring that telephony systems and call agents can provide a high level of service.
- Sharing with each other, and key stakeholders, when weather forecast content causes them to trigger pre-emptive escalation.
- Production of a Customer Welfare Good Practice Guide (GPG) which sets down minimum standards for welfare provision during emergency events, with particular emphasis on customers held within the Priority Services Register (PSR).
- Production of a Social Media GPG and development of a social media strategy, based around the recommendations from the GPG.
- Developing and implementing a common framework that clarifies standards expected around the identification and provision of a restoration time to customers and its subsequent proactive update in the manner agreed with the customer.
- Holding a workshop to share resource and contractor management strategies to ensure the rapid availability of adequate resources to deliver resilience, particularly over extended holiday periods.
- Reviewing and updating the NEWSAC mutual aid protocol to ensure it is adequately proactive and criteria around strategic prioritisation are clear.

These actions were reviewed in a DECC report published in December 2014 which recognised that this work is part of an ongoing responsibility to review, maintain and improve the effectiveness of the response to disruptive events. E3C has agreed that an annual review of this work, following each winter, will ensure new lessons are identified and reflected in ongoing processes and procedures for preparedness and response.

It should be noted that during the winter flooding, no electricity supplies were interrupted as a result of river flooding at major electricity substations operated by DNOs and a number of substations were protected by new flood defences that incorporate protection against long-term climate change. Northern Powergrid, however, did see some loss of supplies due to the flood defences at a major substation becoming compromised as a result of a coastal surge event in December 2013. In addition, some sites were protected by portable flood barriers and the NEWSAC agreement was implemented to provide support to the Thames Valley area from the North of England. Helicopter transport and high volume pumps were also made available.

6. Recover

6.2.2 Case Studies continued

Storms Desmond and Eva, December 2015

Storm Desmond occurred at the beginning of December 2015 and a yellow wind warning was issued on Wednesday 2 December for winds greater than 70mph from Friday to Sunday. On Friday 4 December, amber rain warnings were issued for Saturday and Sunday. On Saturday 5 December the wind warning escalated to amber due to forecast winds up to 80mph over the weekend affecting Northumberland and Durham, this was extended to include North Yorkshire on the Saturday.

Storm Desmond concluded as a relatively small event but was of an unusually long duration due to an extended period of wind. The complicated weather forecast implied that Yorkshire would also be affected, although all impacts were confined to the Northeast.

Storm Eva arrived on 25 December 2015 and, throughout Christmas Day and Boxing Day, torrential rain was experienced across the West Yorkshire region. Throughout the morning of 26 December the situation deteriorated, with Calder Valley and Wharfedale being the worst affected areas.

In order to manage the event, additional resources were deployed by Northern Powergrid to provide additional staff to the contact centre, control, dispatch, field activities, customer welfare and service providers, focusing on the areas affected by the flooding.

The weather continued to deteriorate and additional flooding was experienced in areas of Leeds, interrupting supplies to around 27,000 customers. Examples of affected sites can be seen in Figure 15. Some telecommunications problems were also experienced in the Leeds areas due to the rising flood waters. All customers, with the exception of one, were restored on the same day by the re-routing of affected supplies.

Due to the severity of the flooding, roads were closed and several bridges in the affected areas collapsed or were at risk of collapsing. This severely hampered the progress of restoring supplies and many customers had left their properties due to the scale of the flooding.

Proactive communication was made with vulnerable customers during the event to check on their welfare. A large number of customers in the worst affected areas were displaced by the rising flood waters, in the main staying with relatives, and were therefore not perceived to be in danger. In addition, we offered alternative accommodation to a number of customers that required this service. We worked closely with the British Red Cross throughout the event to arrange telephone calls and face-to-face visits with customers where required. The British Red Cross also assisted the Local Resilience Forum (LRF) in the Calder Valley area to operate rest centres.

Figure 15 – Northern Powergrid Substations in Leeds and York, December 2015

In total, 219 'at risk' substation inspections were carried out in the Calder Valley and Leeds area. 18 substations required replacement, 14 required maintenance, 49 required cleaning to remove residue and debris, and the remainder had no issues identified.

6. Recover

The Beast From the East, March 2018

The first event described as the "Beast from the East" was caused by a sudden stratospheric warming over the North Pole, which generated cold air over the UK from Eastern Europe, starting on the afternoon of Monday 26 February 2018. The first heavy snow started across the Northern Powergrid region overnight on the Tuesday with further heavy snow in the following days and no daytime thaw. This snow held little moisture and therefore ice accretion levels remained low.

A second front, caused by a low pressure system moving northwards from the Continent and named by the Portuguese Met Office as Storm Emma, hit the UK on Thursday 1 March and the Northern Powergrid region on Friday 2 March, meeting the cold air system and producing heavy snow. A gradual thaw started from Monday 5 March and was largely complete by the Wednesday although there was further shortlived snowfall over Yorkshire on the Thursday.

Many major roads were closed for long periods across the Northern Powergrid region with up to 42cm of snow and 10ft snow drifts in Northumberland and more than 10cm of snow in all other areas. Specialist 4×4 vehicles and drivers were used to ensure staff access to 24/7 operations centres. A full command and control structure was in place and sufficient staff available in addition to the NEWSAC resource. Winds were also a factor with gusts of 55-65mph during Thursday 1 March.

Storms Ciara and Dennis, February 2020

February 2020 was a month of particular note due to three named storms hitting the Northern Powergrid region. Storm Ciara brought heavy rain and strong (max 70mph) winds across Yorkshire from Sunday 9 February, with winds remaining high for the rest of the week. There was also significant rainfall across North, West and South Yorkshire. We experienced surface water flooding and fast acting catchments led to flooding in Calderdale, Mytholmroyd and Hebden Bridge, affecting two substations. Flood inspections across North, West and South Yorkshire found no additional issues.

Approximately 75,000 customers were affected by almost 550 reported incidents across the voltage levels. 550 Northern Powergrid staff were deployed in response to the event with almost 14,500 calls received into the contact centre.

A yellow alert was issued on Tuesday 11 February for the weekend of 15/16 February due to the impending arrival of Storm Dennis. Yellow weather warnings for wind and rain were issued alongside yellow flood guidance (low risk). This progressed to an amber warning on Friday 14 February, however incidents remained at business as usual levels throughout despite strong winds (max 73mph and heavy rainfall (max 81.2mm). 10,500 customers were impacted by incidents over the weekend which were followed by strong winds (max 66mph) in Northumberland on Sunday night into Monday. Flood inspections were carried out in response to amber/ medium risk and a large number of flood warnings, however no impacts were found.

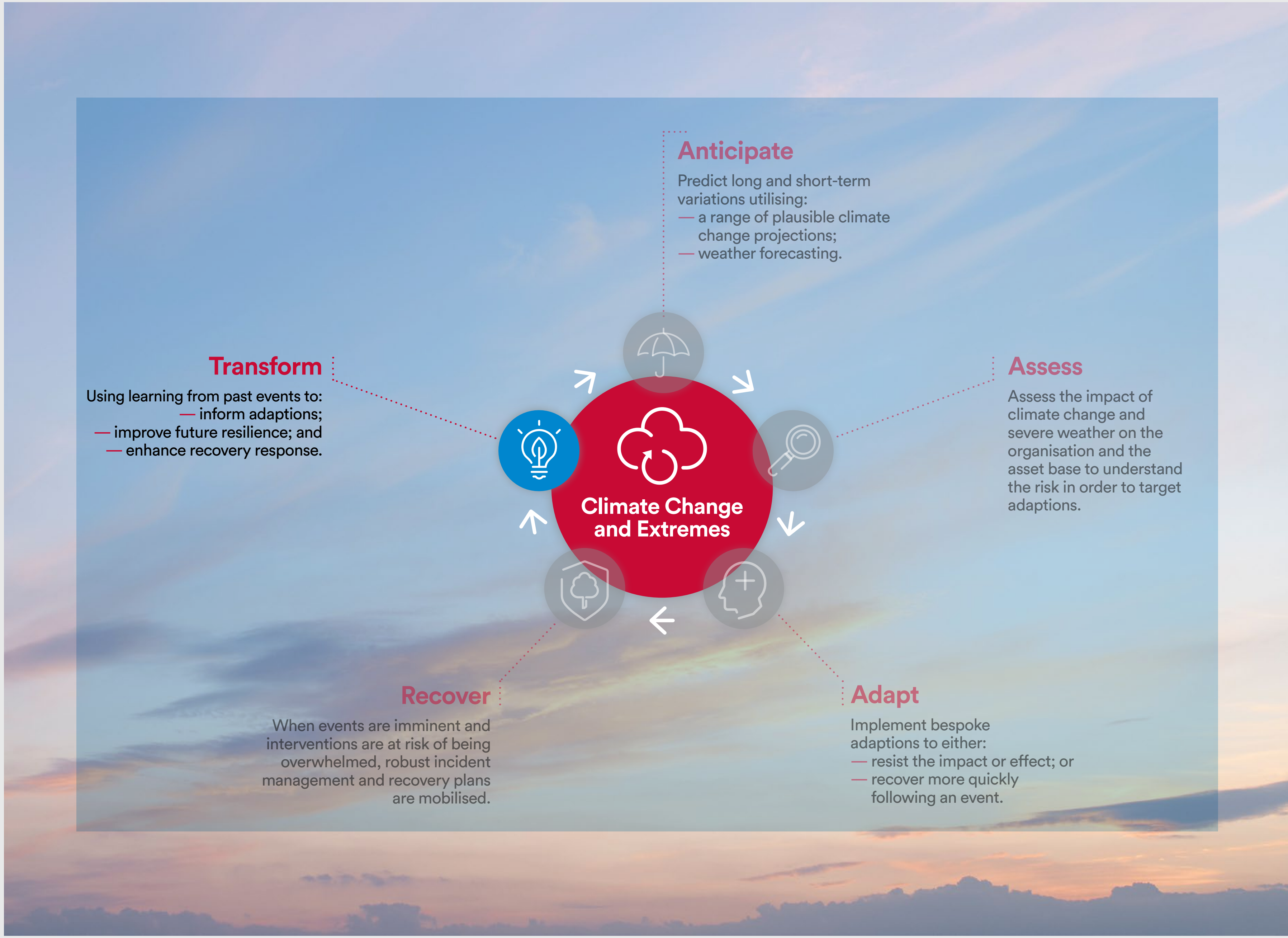
A further yellow alert was issued on Tuesday 18 February for the 20/21 February due to yellow weather warnings for wind and rain and yellow flood guidance (low risk). Again this escalated to an amber alert on 20th to ensure all preparations were in place and to monitor incident levels, however, despite maximum winds of 70mph in the Northeast and heavy rain, incident numbers remained at business as usual levels.

This event was unusual due to the large number of events, one after another with little to no recovery time to complete repairs. As a result we have reviewed contracts with suppliers of generators to ensure that we are adequately covered for any future such events.

7 Transform

7. Transform

In order to ensure that we continue to enhance the resilience of our network it is imperative that we make use of the learning from past events and from other sources to inform our adaptations and transform our organisation.



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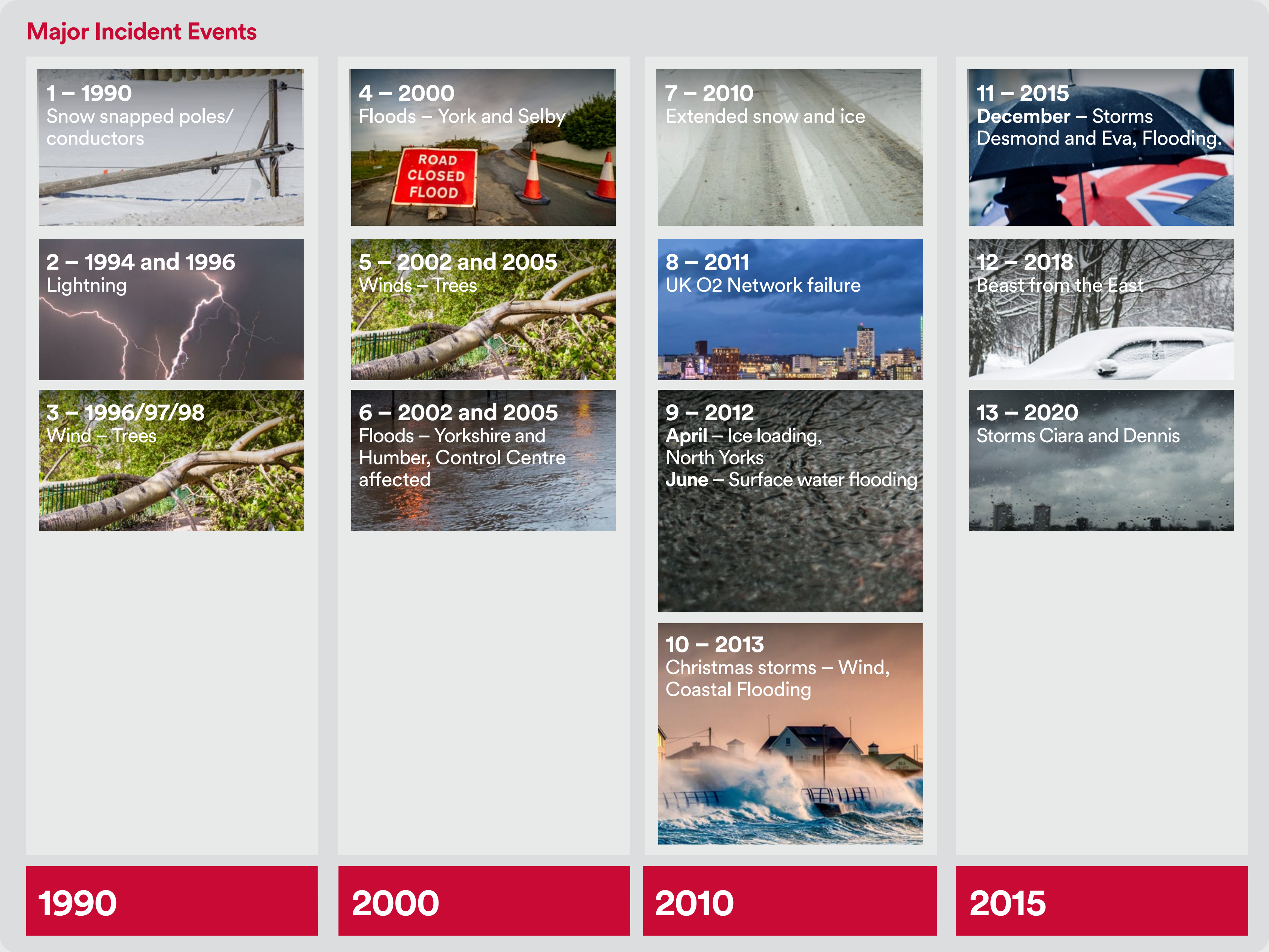
7.1 Lessons Learnt

Following every implementation of the MIMP protocols, a full debrief is held with all parties involved in the recovery of the network and lessons learnt gathered and implemented into the process. Figure 16 – Implementation of Learning From Major Events highlights the major learning from events.

Rollover the the hand icon above to reveal the Resilience Actions.

Figure 16 – Implementation of Learning From Major Events



7. Transform

7.2 External Review

To inform our forward plan we have carried out an external review of our performance against our peers within the industry, the infrastructure sector and external expert organisations.

7.2.1 Climate Change Adaptation Progress Reports to Defra

We have scrutinised the second round reports submitted to Defra by a variety of organisations from industry peers, other infrastructure sectors and organisations located within the same operating region to assess:

- How does our plan compare to others?
- What risks are others addressing that we are not?
- To what extent does innovation or innovative techniques feature in plans?
- To what extent does information and digitalisation feature in plans?

The electricity and water sectors appear to lead the way in terms of the comprehensiveness of their adaptation reports. Northern Powergrid is in line with the majority of the electricity sector, however, there are a number of areas where the example set by the water sector could be utilised to improve our approach to adaptation.

Northern Powergrid, in line with the other electricity distributors, has considered a full range of climate risks and their potential impacts on our network, whether high or negligible. Other sectors have presented only the risks which they have deemed to be high for their operations.

Whilst Northern Powergrid is consistent with the rest of the electricity sector in the adaptations we have proposed, we need to consider a wider approach to adaptation going forwards.

Northern Powergrid, in line with the rest of the electricity sector, has well defined and monitored resilience measures in place for our high risks.

Whilst Northern Powergrid has participated in, and benefitted from a number of industry-wide innovation projects related to climate change adaptation, we lag behind the other members of our sector who have participated in a wider range of projects, including some in the area of vegetation management. We do, however, appear to participate in a wider range of innovation projects that the majority of other sectors.

7.2.2 Assessment Against 'Best Practice'

We are examining whether our performance and plans meet what we would consider 'best practice' relative to a suite of measures.

Vegetation management: Northern Powergrid sits at the lower end of our industry peers when considering expenditure. Our policy of concentrating on the HV network with regards to ETR132 compliance has ensured that we appear to lead the way in terms of total percentage of network compliance, however, this is a misleading picture as other companies have concentrated on the higher voltages which contributes a smaller percentage when considering the total network.

Northern Powergrid's flood mitigation programmes are well advanced with the Yorkshire region having completed more sites than were originally declared at risk and the Northeast region having completed 85% of those sites. This puts the Northeast region mid table and the Yorkshire region leading when considering how far through the programme we are. In terms of unit cost, those experienced in both our Northeast and Yorkshire licences appear high compared with other DNOs.

7.2.3 Committee on Climate Change

In July 2019, the Committee on Climate Change published its report into the "Progress in preparing for climate change"[18]. This report concluded that England is still not prepared for even a 2°C rise in global temperature and that only a handful of sectors have plans that consider a minimum of 2°C global warming.

The report considers that the infrastructure sector compares well to other sectors and, within the infrastructure sector, electricity distribution is amongst the sub-sectors which are performing best. The energy sector is considered to have a high quality plan but is showing mixed progress in managing risk. A score of 8 out of 9 is achieved on the assessment framework presented.

The report finds that the electricity sector has a well-developed understanding of flooding and that flood protection measures are being implemented at major substations but questions a lack of clarity on what other steps are being taken.

18. https://www.theccc.org.uk/publication/progress-in-preparing-for-climate-change-2019-progress-report-to-parliament/

7. Transform

7.3 National Adaptation Programme

The National Adaptation Programme (NAP)[19] addresses the priority risks identified in the CCRA2017, setting out the actions that the Government is taking, outcomes it wants to achieve, and the means by which they will be measuring the progress made towards achieving the objectives. Whilst the NAP primarily sets out the work and approach of Government, as required by the Climate Change Act, it also sets out some of the significant actions that it is expected that those outside of Government are undertaking in parallel over the period of the NAP. This includes the work of organisations, such as infrastructure operators and public bodies responsible for key services, which are reporting on their work on climate change adaptation, in line with the Adaptation Reporting Power. It contains a mixture of policies and actions to help us to adapt successfully to future weather conditions, by addressing the risks and making the most of the opportunities. The document has been organised to mirror the second CCRA evidence report so that there is a clear line of sight from CCRA2017 to areas of action in the NAP.

The NAP vision is that we should have "an infrastructure network that is resilient to today's natural hazards and prepared for the future changing climate". The electricity sector is considered to have a "well-developed understanding of the risk faced by flooding and a high level of mitigation is in place". The key risks to infrastructure set out within the NAP are listed in Table 11 – National Adaptation Plan Update.

19. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727252/national-adaptation-programme-2018.pdf

Table 11 – National Adaptation Plan Update

NAP Ref	Action	Applicable to Northern Powergrid	Update (section in report)
IN1	Risks of cascading infrastructure failures across interdependent networks	✔	Section 4.3
IN2	Risks to infrastructure from river, surface/groundwater flooding	✔	Section 4.2 Section 5.2.1
IN3	Risks to infrastructure from coastal flooding and erosion	✔	Section 4.2 Section 5.2.1
IN4	Risks of sewer flooding due to heavy rainfall	✔	Section 4.2 Section 5.2.1
IN5	Risks to bridges and pipelines for high river flows/erosion	✔	Section 4.2
IN6	Risks to transport networks from embankment failure	✘	n/a
IN7	Low/high river flow risks to hydroelectric generation	✘	n/a
IN8	Subsidence risks to buried/surface infrastructure	✔	Section 4.2
IN9	Risks to public water supplies from drought and low river flows	✘	n/a
IN10	Risks to electricity generation from drought and low flows	✘	n/a
IN11	Risks to energy, transport and ICT from high winds and lightning	✔	Section 4.2 Section 5.2.2
IN12	Risks to shore infrastructure from storms and high waves	✔	Section 4.2
IN13	Extreme heat risks to rail, road, ICT and energy infrastructure	✔	Section 4.2
IN14	Benefits for infrastructure from reduced extreme cold events	✔	Section 4.2

7. Transform

7.4 Innovation and Research

Northern Powergrid has participated in a wide variety of innovation and research projects, both individually and through working with partnership organisations such as the ENA and other DNOs. A summary of these projects can be found in Table 12 – Innovation and Research Projects and case studies on each of the projects can be found in Appendix 5.

Table 12 – Innovation and Research Projects

Appendix Ref	Project	Summary
A5.1	Drones	In 2018, Northern Powergrid began trialling the use of drones to monitor and survey the network within the line of visual sight. This proved to be successful and the use of drones has now become part of our business as usual process. The drones are employed in a number of ways both as a monitoring tool and an aid following major events.
A5.2	LiDAR (Light Detection and Ranging)	Northern Powergrid has been exploring the use of LiDAR in order to carry out more effective and efficient clearance and vegetation management. LiDAR data acquired through flying the complete network at the beginning of each major cutting phase should provide the opportunity to prioritise the cutting responses, as currently the network is surveyed in a serial manner with permissions and cutting following on accordingly. This serial approach inevitably results in higher priority cutting being missed as the contractor may not be aware of its urgency until the network receives it first vegetation inspection (on foot).
A5.3	Overhead Line Ratings	Distribution overhead line ratings are based on research work and assumptions published nearly 30 years ago. Recent work testing these assumptions has found some of them to be erroneous, with the result that existing distribution line ratings are now considered out of date. Following research, we are now able to more accurately decide an appropriate rating for any distribution overhead line.
A5.4	Small Section Conductor	Cadmium copper conductor employed on the Northeast regional network was identified as being at a higher risk of failure than other conductor types. Following further investigations, a line strengthening programme was employed, targeting this conductor and the reliability is now considered comparable to other line types.
A5.5	Self-Sealing Cables	This project developed a new cable fluid that can seal itself when exposed to air and demonstrated that Self-Sealing Cables are suitable for use in commercial, large-scale projects.
A5.6	Foresight	The Foresight project aimed to improve our understanding of indicative pre-fault behaviour of low-voltage (LV) cable networks and our ability to develop management options for it.

7. Transform

7.5 RIIO-ED2 (2023–2028)

In September 2020 we published our Emerging Thinking to build on stakeholder feedback to date and to further consult with stakeholders in building our plan for RIIO-ED2. In this document we asked stakeholders to consider a number of scenarios for climate change adaptation action with a variety of cost implications. Feedback from this consultation will be used to shape our adaptation plans for the RIIO-ED2 period.

We will submit our first draft plans for RIIO-ED2 to the regulator in July 2021. These will then be subjected to regulatory scrutiny and comment, allowing us to utilise their feedback to submit a final proposal in December 2021. This will then be subject to approval by Ofgem.

7.6 Propositions For The Future

The core elements of our propositions for climate change adaptation centre around flood defence and storm resilience whilst maintaining our operational effectiveness during major events and using innovation to support the implementation of further adaptations.

Our stakeholders clearly see flood defences as a key priority, as do we, however the network will meet the best-practice levels of flood defence at the end of ED1 and we see investing at the same level in ED2 as not cost effective for our customers. We intend to continue to improve flood resilience but at a lower cost than we have in the past, improving levels of resilience beyond the best-practice level that our customers receive today by maintaining (or increasing where cost effective) the levels of defence for major substations and proactively defending some distribution substations that are in the highest risk areas.

Storm resilience is driven by two elements of the plan, asset resilience for the overhead network and vegetation management. The fundamentals of vegetation management are not expected to change from this price control to the next, however we do plan to implement the use of LiDAR technology to better target our interventions.

Outside of stand-alone adaptations, we deliver enhanced resilience synergistically through our asset resilience programmes and expect to continue to do so in the next price control. Specifically, to improve this we intend to carry out further research into the effects of weather and climate change on underground assets in order to enable us to better target our interventions through our asset resilience programme.

We will continue to improve our operational response capabilities in order to be able to respond in a timely and effective manner when we do experience extreme events. Focus will remain on continually reviewing this performance and implementing learning to improve as appropriate. We will also continue with our programmes of innovation and research to ensure that we capture and develop any opportunities to enhance our resilience and response which may arise.

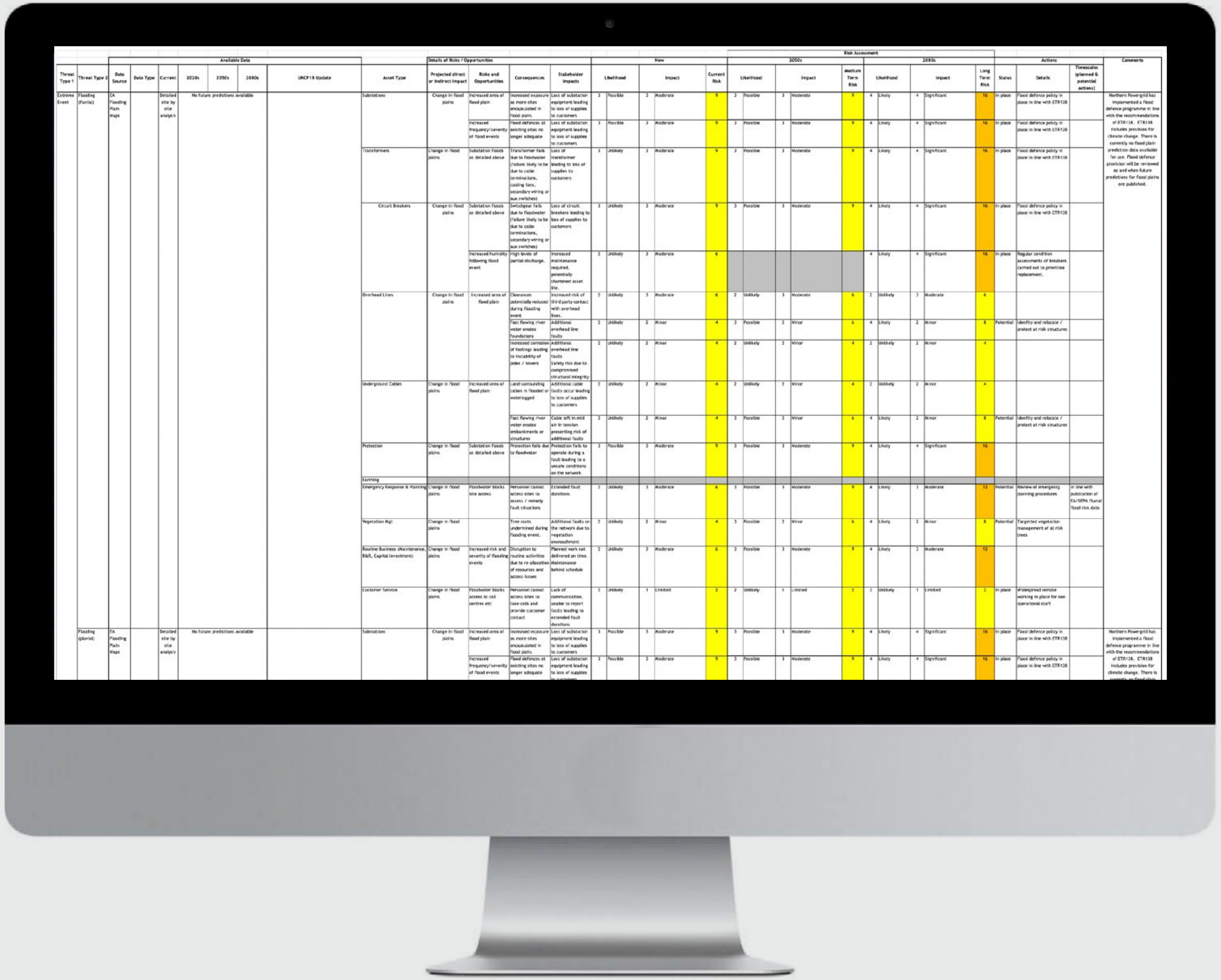
Climate change experts such as the Committee on Climate Change see tackling interdependencies across utilities as a key element to improving environmental resilience. We intend to begin to tackle this with our local partners and regional agencies but it will require a more centrally coordinated national programme to ensure consistency across the country, in particular with infrastructure providers with larger geographic coverage, such as the telecoms providers.

8

Appendices

Appendices

Appendix 1
Risk Assessment

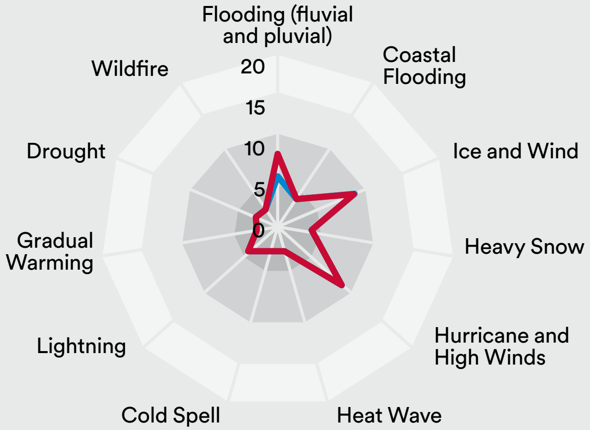


Please find attached the Risk Assessment data

Appendices

Appendix 1 Overhead Lines

Key Current risk
2080s risk

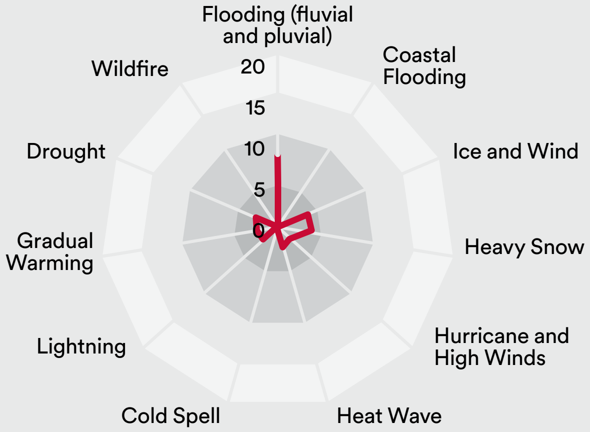


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Reduced clearances during a flood event lead to increased risk of third party contact. — Increased corrosion of footings leading to instability of poles/towers.	— Regular review of specifications to ensure designs are fit for purpose. — Programme of condition monitoring of assets.
Coastal Flooding	— Reduced clearances during a flood event lead to increased risk of third party contact.	— Regular review of specifications to ensure designs are fit for purpose. — Programme of condition monitoring of assets.
Ice and Wind	— Ice accretion occurs on overhead lines leading to compromised structural integrity. — Helicopters unable to fly to carry out fault location.	— EU research COST 727 investigated impacts of ice loading. — Asset resilience programme to rebuild over headlines – over 50k poles to be replaced.
Heavy Snow	— Snow and ice build-up occurs on overhead lines leading to compromised structural integrity.	— EU research COST 727 investigated impacts of ice loading.
Hurricane and High Winds	— Increased frequency of events may weaken poles and fittings.	— Condition based refurbishment programme in place.
Heat Wave	— High ambient temperatures lead to a reduction in available capacity. — Additional loadings placed on network due to air conditioning.	— Annual review of network loadings ensures adequate headroom on network.
Cold Spell	— Additional loadings placed on network due to additional heating and electrical appliances. — Increase in mechanical tension in lines leading to accelerated ageing.	— Annual review of network loadings ensures adequate headroom on network. — Condition based refurbishment programme in place.
Lightning	— Increased lightning storms leading to increased number of faults.	— Lightning protection on network. — Protection policies subject to regular review.
Gradual Warming	— Capabilities of overhead line network reduced due to reduction in ratings. — Ground clearances reduced leading to greater risk of third party contact or infringement of statutory clearances.	— Annual review of network loadings ensures adequate headroom on network. — Programme of condition monitoring of assets.
Drought	— Soil drying and movement undermines pole and tower foundations.	— Programme of condition monitoring of assets.
Wildfire	— Fire damages poles and equipment.	— Preservative treatment of poles should prevent fire.

Appendices

Appendix 1 Vegetation Management

Key Current risk
2080s risk

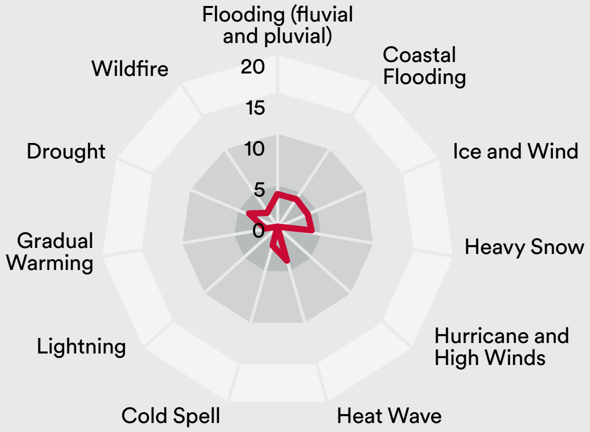


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Flooding events undermine tree roots, leading to additional faults due to falling trees.	— Vegetation Management programme subject to regular reviews.
Coastal Flooding	— Flooding events undermine tree roots, leading to additional faults due to falling trees.	— Vegetation Management programme subject to regular reviews.
Ice and Wind	— Ice accretion occurs on trees, leading to additional faults due to falling debris.	— Vegetation Management programme subject to regular reviews.
Heavy Snow	— Snow and ice build-up occurs on trees, leading to additional faults due to falling debris.	— Vegetation Management programme subject to regular reviews.
Hurricane and High Winds	— Increased frequency of events may weaken trees, leading to additional faults due to falling debris.	— Vegetation Management programme subject to regular reviews.
Heat Wave	— High ambient temperatures lead to an extended growing season and hence additional encroachment of vegetation.	— Vegetation Management programme subject to regular reviews.
Cold Spell	— No specific risks identified.	
Lightning	— Increased lightning storms, leading to increased number of faults.	— Vegetation Management programme subject to regular reviews.
Gradual Warming	— High ambient temperatures lead to a extended growing season and hence additional encroachment of vegetation.	— Vegetation Management programme subject to regular reviews.
Drought	— Change in water content of soil leads to changes in natural habitats of different species.	— Vegetation Management programme subject to regular reviews.

Appendices

Appendix 1 Underground Cables

Key Current risk
2080s risk

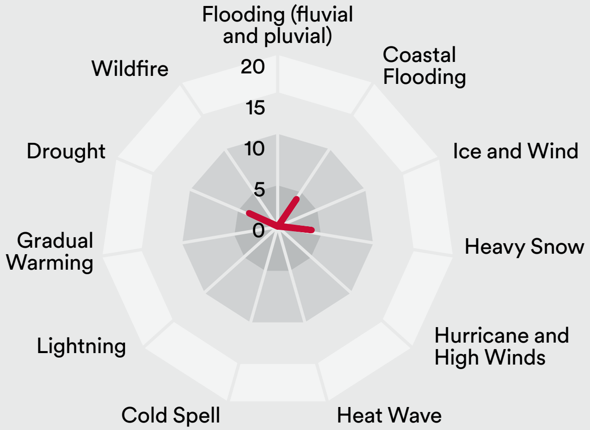


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Land surrounding cables is flooded or waterlogged, leading to additional faults. — Erosion of embankments or structure housing cables, leaving cables exposed.	— Programme of condition monitoring of assets in place. — Potential to identify and protect at risk cables.
Coastal Flooding	— Land surrounding cables is flooded or waterlogged, leading to additional faults.	— Programme of condition monitoring of assets in place.
Ice and Wind	— No specific risks identified.	
Heavy Snow	— Following melt, land surrounding cable is waterlogged, leading to additional faults.	— Programme of condition monitoring of assets in place.
Hurricane and High Winds	— No specific risks identified.	
Heat Wave	— High ambient temperatures lead to a change in soil properties and therefore the capacity of the cables.	— Annual review of network loadings ensures adequate headroom on network.
Cold Spell	— Additional loadings placed on network due to additional heating and electrical appliances in use.	— Annual review of network loadings ensures adequate headroom on network — Review of specifications to ensure cables are fit for purpose.
Lightning	— No specific risks identified.	
Gradual Warming	— High ambient temperatures lead to a change in soil properties and therefore the capacity of the cables.	— Annual review of network loadings ensures adequate headroom on network.
Drought	— Change in water content of soil has an adverse effect on soil resistivity and hence causes a reduction in cable ratings. — Ground movement leads to joint failure.	— Annual review of network loadings ensures adequate headroom on network. — Review of specifications to ensure cables are fit for purpose and to include additional joint testing.

Appendices

Appendix 1 Earthing Risks

Key Current risk
2080s risk

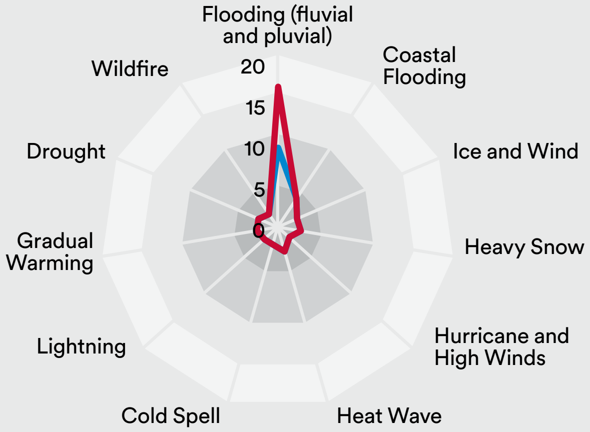


Climate Change Risk	Impact and Consequence	Actions
Drought	— Change in water content of soil has an adverse effect on soil resistivity and may cause a change in the effectiveness of the earthing.	— Climate change to be considered during regular reviews of earthing specifications.

Appendices

Appendix 1 Transformer Risks

Key Current risk
2080s risk

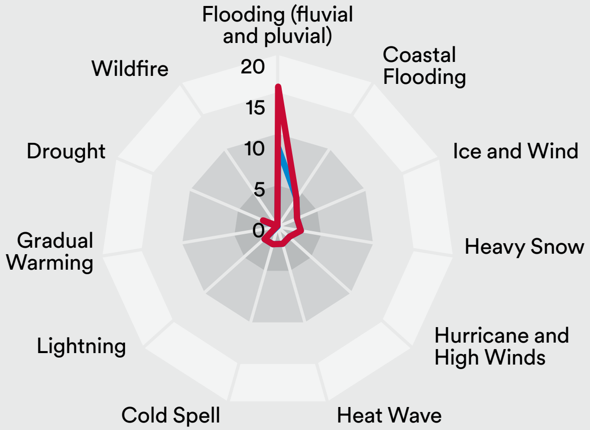


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Transformer failure due to floodwater (likely to be due to cable terminations, cooling fans, secondary wiring or auxiliary switches).	— Policy in place for flood defending at risk substations and subject to regular review.
Coastal Flooding	— Transformer failure due to floodwater (likely to be due to cable terminations, cooling fans, secondary wiring or auxiliary switches).	— Policy in place for flood defending at risk substations and subject to regular review.
Ice and Wind	— Operation of transformer compromised by ice build-up affecting exposed moving parts.	
Heavy Snow	— Tranformer and/or pumps unable to operate due to snow, reducing the transformer ratings.	— Annual review of network loadings ensures adequate headroom on network.
Hurricane and High Winds	— Debris falls onto transformers causing damage and faults.	— Condition monitoring of substation buildings and vegetation management policies in place.
Heat Wave	— Capacity reduced due to high ambient temperature. — Additional load placed on network due to air conditioning. — Tap control failure due to overheating.	— Annual review of network loadings ensures adequate headroom on network. — Amend specification to include equipment sunscreen.
Cold Spell	— Additional loadings placed on network due to additional heating and electrical appliances.	— Annual review of network loadings ensures adequate headroom on network.
Lightning	— Increased number of lightning strikes leading to additional faults.	— Lightning protection in place and policies subject to regular review.
Gradual Warming	— Capacity of network reduced due to increase in ambient temperature.	— Annual review of network loadings ensures adequate headroom on network.
Drought	— Subsidence means that transformer footing may become unstable.	— Condition monitoring programme in place for assets.
Wildfire	— Risk of oil insulator catching fire.	— Amend specification to synthetic ester in at risk areas.

Appendices

Appendix 1 Substation Risks

Key Current risk
2080s risk

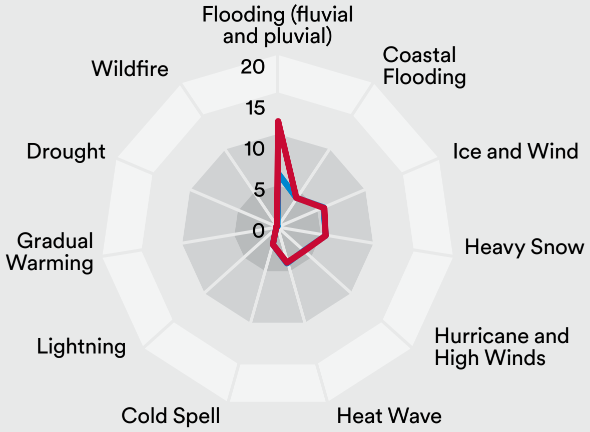


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Substation floods due to extension of flood plains. — Substation floods as existing flood defences are inadequate.	— Policy in place for flood defending at risk substations and subject to regular review.
Coastal Flooding	— Substation floods due to extension of flood plains. — Substation floods as existing flood defences are inadequate.	— Policy in place for flood defending at risk substations and subject to regular review.
Ice and Wind	— Damage sustained to substation buildings, leading to equipment failure.	— Condition monitoring of substation buildings.
Heavy Snow	— Substation buildings unable to support weight of snow.	— Condition monitoring of substation buildings.
Hurricane and High Winds	— Increased frequency weakens or damages substation buildings, leading to equipment failure.	— Condition monitoring of substation buildings.
Heat Wave	— Additional load placed on network due to air conditioning.	— Annual review of network loadings ensures adequate headroom on network. — Specifications reviewed on a regular basis to ensure adequacy.
Cold Spell	— Additional loadings placed on network due to additional heating and electrical appliances.	— Annual review of network loadings ensures adequate headroom on network. — Specifications reviewed on a regular basis to ensure adequacy.
Lightning	— Increased number of lightning strikes lead to additional faults.	— Lightning protection and policies subject to regular review. — Utilise I^2T monitoring to more accurately assess condition of circuit breakers.
Gradual Warming	— Capacity of network reduced due to increase in ambient temperature.	— Annual review of network loadings ensures adequate headroom on network. — Specifications reviewed on a regular basis to ensure adequacy.
Drought	— Subsidence means that substation footings may become unstable.	— Condition monitoring of substation buildings.

Appendices

Appendix 1
Emergency Response and Planning

Key Current risk
2080s risk

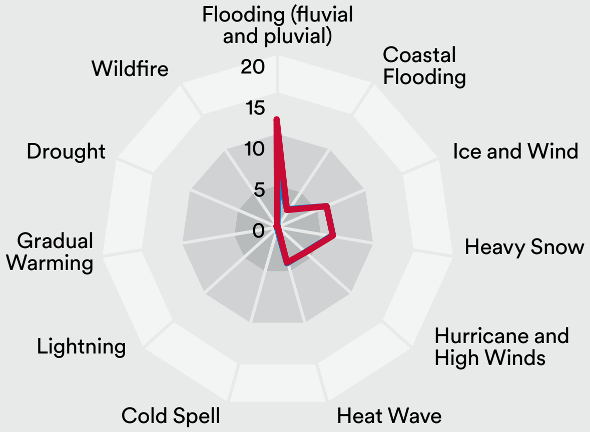


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Increased number of substations at risk of flooding.	— Policy for flood defending at risk substations in place and subject to regular review. — Policy for emergency planning and major incident management in place and subject to regular review.
Coastal Flooding	— Increased number of substations at risk of flooding.	— Policy for flood defending at risk substations in place and subject to regular review. — Policy for emergency planning and major incident management in place and subject to regular review.
Ice and Wind	— An increased frequency of events leads to an increased number of major incidents.	— Policy for emergency planning and major incident management in place and subject to regular review.
Heavy Snow	— Build-up of snow causes additional faults and hampers staff movements, leading to slow response times.	— Policy for emergency planning and major incident management in place and subject to regular review.
Hurricane and High Winds	— Increased frequency causes additional faults, leading to a strain on resources.	— Policy for emergency planning and major incident management in place and subject to regular review.
Heat Wave	— High staff absence due to sickness, leading to a reduced internal workforce.	— Policy to deal with pandemics, staff re-allocation etc in place and subject to regular review.
Cold Spell	— Additional loadings placed on network, leading to additional faults.	— Policy for emergency planning and major incident management in place and subject to regular review.
Lightning	— Increased number of lightning strikes lead to additional faults.	— Policy for emergency planning and major incident management in place and subject to regular review.
Gradual Warming	— No specific risks identified.	
Drought	— No specific risks identified.	

Appendices

Appendix 1
Routine Business (maintenance, restoration and repairs, capital investment)

Key Current risk
2080s risk

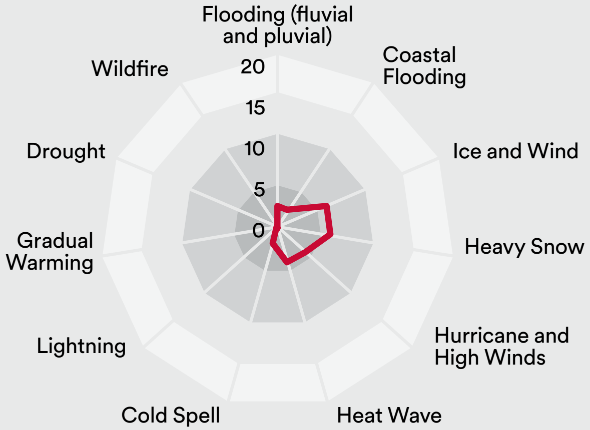


Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Increased number of substations at risk of flooding, leading to diversion of resources away from routine business.	— Routine business is monitored for delivery against targets, with appropriate recovery plans implemented as necessary.
Coastal Flooding	— Increased number of substations at risk of flooding, leading to diversion of resources away from routine business.	— Routine business is monitored for delivery against targets, with appropriate recovery plans implemented as necessary.
Ice and Wind	— Routine business suffers as a result of additional faults on the network.	— Routine business is monitored for delivery against targets, with appropriate recovery plans implemented as necessary.
Heavy Snow	— Build-up of snow causes additional faults and hampers staff movements. Routine business suffers as a result.	— Routine business is monitored for delivery against targets, with appropriate recovery plans implemented as necessary.
Hurricane and High Winds	— Increased frequency causes additional faults, leading to a strain on resources. — Certain activities postponed due to safety concerns.	— Routine business is monitored for delivery against targets, with appropriate recovery plans implemented as necessary.
Heat Wave	— Certain activities postponed due to unsuitability of PPE for temperature conditions. — High staff absence due to sickness, leading to a reduced internal workforce.	— Investigate PPE utilised in other countries with higher ambient temperatures. — Routine business is monitored for delivery against targets with appropriate recovery plans implemented as necessary.
Cold Spell	— No specific risks identified.	
Lightning	— No specific risks identified.	
Gradual Warming	— No specific risks identified.	
Drought	— No specific risks identified.	

Appendices

Appendix 1 Customer Service

Key Current risk
2080s risk



Climate Change Risk	Impact and Consequence	Actions
Flooding (fluvial and pluvial)	— Increased number of substations at risk of flooding. Fault restoration times extended due to floodwaters.	— Policies for flood defending at risk substations. — Policies for emergency planning and major incident management. — All policies subject to regular review.
Coastal Flooding	— Increased number of substations at risk of flooding. Fault restoration times extended due to floodwaters.	— Policies for flood defending at risk substations. — Policies for emergency planning and major incident management. — All policies subject to regular review.
Ice and Wind	— Slow response times and increased fault durations due to large number of network faults and problematic access and travel.	— Policy for emergency planning and major incident management in place and subject to regular review.
Heavy Snow	— Slow response times and increased fault durations due to large number of network faults and problematic access and travel.	— Policy for emergency planning and major incident management in place and subject to regular review.
Hurricane and High Winds	— Slow response times and increased fault durations due to a large number of network faults. — Certain types of work prevented due to safety issues.	— Policy for emergency planning and major incident management in place and subject to regular review.
Heat Wave	— High staff absence due to sickness, leading to a reduced internal workforce.	— Policies to deal with pandemics, staff re-allocation etc. All subject to regular review.
Cold Spell	— Vulnerable customers need additional prioritisation.	— Vulnerable customer register maintained and policies in place. — Policies for dealing with customer welfare during outages. — All policies subject to regular review.
Lightning	— No specific risks identified.	
Gradual Warming	— No specific risks identified.	
Drought	— No specific risks identified.	

Appendices

Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.1 Overhead Lines (Risks AR1, AR2, AR3 and AR16)

Overhead Electricity Lines Background Information
Nearly all overhead lines owned by Northern Powergrid are constructed using wood poles or steel towers ("pylons"). A few exceptions use steel or concrete poles. Overhead lines structures are fitted with insulators that support wire conductors, carrying electrical current. The conductors are not normally insulated, are usually copper or aluminium based and are of different sizes to provide different current carrying capabilities.

As all electrical conductors have some electrical resistance, they heat up and expand when current is passed through them, causing them to sag. The amount of sag is impacted by the ambient air temperature, solar radiation and is offset by any cooling winds.

The amount an overhead line is permitted to sag is determined by the legal minimum heights of live electricity conductors over roads and other ground. Thus the current rating of an overhead line is determined by a heat balance equation:

> HEAT IN vs. HEAT OUT >

and based on a maximum conductor design temperature.

Northern Powergrid networks are designed such that overhead lines of 33kV and above normally connect one large substation to another, with no intermediate connections, hence the current flowing into the circuit is the same as that flowing out of the other end.

At 11kV and below, overhead lines radiate out from substations feeding small transformers or individual customers along the route. Consequently at these voltages, the current flowing in to the circuit gradually reduces as current is fed off to individual customers or small communities/businesses. It is important to make this distinction between the 11kV and below and 33kV and above because of the extent of impact of reduction in ratings caused by climate change.

Climate change will also impact on the structural integrity of overhead lines. Very high winds place structural wind loads on the poles, towers and conductors. These loads increase if there is ice build-up ("accretion") on the conductors as it increases the diameter subject to wind load. The wind loading increases as the square of the wind speed. The derivation of the wind load assesses either high wind or high ice conditions. Alternatively, a combination of the two may be used.

Climate Change and Overhead Line Ratings
The basic equations governing the derivation of overhead line current ratings are used globally. Typical international examples are set out in IEEE Standard 738 and Cigre Technical Brochure 207.

The above IEEE Standard was used to determine the impacts of changes in climate on ratings and the results of the Met Office ("EP2") research.

From a ratings perspective, the most challenging conditions prevail in high ambient temperatures, high solar radiation and low wind when there is minimum "leeway" between the ambient temperature and the rated conductor design temperature to allow for conductor heating due to the passage of current with little cooling influence.

Most wood pole overhead lines and steel tower lines at 132kV and below in the UK are designed to a 50°C design operating temperature.

The UKCP09 data and Met Office research has not currently identified a change in the prevalence of very low wind speeds (< 0.5 m/s) or in levels of solar radiation used in the current designs, but has identified a range of changes in ambient temperature across the UK in each decade, and for each emission scenario. Previous experience has shown that the limiting condition is the highest daily average ambient temperatures that have the greatest correlation with the highest electrical demands. Further research will be required in future years to check the ongoing validity of this, having regard, for example, to uptake of air conditioning.

Appendices

Appendix 2

A2.1 Overhead Lines (Risks AR1, AR2, AR3 and AR16) continued

Overhead Electricity Lines Background Information continued
The effects of any of the individual temperatures on a representative range of typical overhead conductor types is established by multiplying the °C value, by the % rating reduction per °C figures derived from the Met Office research and listed in Table 13 – Common Types of Overhead Line.

Conductor sizes on standard overhead lines range from 16mm² hard-drawn copper to 850mm² aluminium alloy, with rated temperatures varying from 50°C to 90°C and even up to 170°C. It would clearly be impractical to look at all these cases for the purposes of this assessment, so those in Table 13 have been selected as being representative of the most common types of overhead line along with the typical limiting rating season.

It is important to view the % de-ratings against past DNO experience in response to growth of electricity demand on their networks; effectively the same challenge. Table 13 indicates a range of de-ratings of distribution overhead lines (in the table, those of 175mm² and below) of up to 8.6% over the period having a centre point in 2055. That equates to a ratings impact of some 0.19% per annum. Recent demand growth has impacted these same networks at some 1.5% per annum.

The impacts of such reductions in ratings will vary from one circuit to another depending on how close the maximum demand on a particular circuit is to the circuit rating. In the case of 33kV and higher voltage circuits, when that limit is reached, the entire length of the circuit would have to be assessed to determine which locations required action to increase line height by changing supports (poles or towers) or by other action such as re-conductoring with higher operating temperature conductor and any consequential impacts on supports.

For 11kV and LV circuits it is necessary to determine what proportion of the circuit would need to be elevated or re-conductored. For all wood pole lines up to 33kV, sag increases would be fairly small (around 200mm per 5°C for a typical span) and in many spans there would be enough spare clearance to accommodate such an increase. Where clearance is unavailable, poles can be replaced with taller ones. It is unlikely that many additional poles would be needed in order to keep the existing conductors. Increasing the conductor size, however, will change pole loadings, which is likely to require more pole changes, and possibly additional poles if the wind loading limits of existing intermediate poles are exceeded.

Table 13 – Common Types of Overhead Line

Conductor & Operating Temperature	Rating	Existing Value	Reduction
25mm² Copper @50°C	Summer	126 Amps	1.6%/°C
100mm² Copper @50°C	Summer	316 Amps	1.6%/°C
175mm² Lynx ACSR @50°C	Summer	432 Amps	1.6%/°C
400mm² Zebra ACSR @75°C	Winter	1,230 Amps	0.81%/°C
500mm² Rubus AAAC @90°C	Winter	1,600 Amps	0.63%/°C

Appendices

Appendix 2

A2.1 Overhead Lines (Risks AR1, AR2, AR3 and AR16) continued

Overhead Electricity Lines Background Information continued
The 2009 price basis unit costs of pole/tower replacement and re-conducting of overhead lines in Ofgem's DPCR 5 assessment are shown in Table 14 – Overhead Line Data.

For steel tower lines (at all voltages), structure replacement and/or modification represents significant work. Where de-rating such lines would be problematic, the most practical solution would most often be replacement of the conductors. With the advent of new, low-sag conductor technologies, finding a larger replacement conductor that would minimise, if not eliminate, the need for structural reinforcement no longer presents an insurmountable technical challenge. Such conductors can, however, be relatively expensive compared to the current technology employed.

Table 14 – Overhead Line Data also includes costs for conventional (not low-sag) reconductoring of steel tower overhead lines on a per circuit km basis. Many designs have two circuits, one suspended on each side of the tower.

Table 14 – Overhead Line Data

Overhead Lines GB	Total circuit km	Total no of supports	Unit replace-ment cost	Full re-build	Conventional re-conducting
Pole Lines					
LV	64,874	1,710,926	Pole £1.4k	£28.4k/km	
HV (6.6,11,20kV)	168,962	2,113,339	Pole £1.8k	£33.5k/km	
EHV (33,66kV)	28,883	328,522	Pole £2.2k	EHV pole line re-build £42.0k/km	
132kV	1,774	7,807			
Steel Tower Lines					
EHV (33kV)	3,254	14,553	Tower £39.2k		£39.0k/km
EHV (66kV)			Tower £65.0k		£53.4k/km
132kV (DNO)	14,697	33,438	Tower £108.9k		£82.1k/km

Sources: Component numbers and circuit lengths supplied by Ofgem and are a summation of DNO regulatory returns submitted under the DPCR5 process (Table T4) for closing balances of all 14 licensed UK DNOs as at 31 March 2010.

Costs extracted from Tables 17 and 20 – Ofgem Electricity Distribution Price Control Review – Final Proposals – Allowed Revenue – Cost Assessment appendix Ref 146a/09 – 7 December 2009.

Appendices

Appendix 2

A2.1 Overhead Lines (Risks AR1, AR2, AR3 and AR16) continued

Climate Change and Structural Strength of Overhead Lines

It has always been recognised that the structural strength of overhead lines should reflect the exposed environment in which they operate. The physical capability of any overhead line is determined by the effect of a maximum probable expected wind force on the conductors usually, although not always, loaded with a maximum probable ice.

There have been UK statutory regulations controlling overhead line design since 1896, when the design criteria was required to be based on 125 mph winds with factors of safety of between 5 and 6 for conductors and between 6 and 12 for structures. A more realistic approach to design was applied in 1924 when the statutory design criteria were changed to reflect the contribution of ice loading; this allowed the wind contribution to be reduced to 50 mph, but this wind pressure was now applied to conductors covered with a ½" of radial ice (a reduced ice loading of 3/8" radial ice was applied to LV conductors). With these more realistic design criteria, the factors of safety were also reduced to 2 for conductors and between 2.5 and 3.5 for structures.

Further changes were made to overhead line design involving small section conductor in order to improve the economic viability of extending the electricity network to rural areas and the design standard BS1320:1946 allowed these lines to be constructed without an ice burden, but with 70 mph wind pressure and a 2.5 factor of safety. (In these calculations, factor of safety is the ratio of absolute strength (structural capacity) to calculated applied load). This resulted in a huge increase in overhead line construction.

Following severe storms in 1981 and 1982 it was recognised that the BS1320:1946 design standards were insufficient, but instead of prescribing further specific national criteria, the statutory Electricity Regulations of 1988 required that 'all works shall be sufficient for the purpose for, and the circumstances in which they are used'. This allowed regional variations to be applied and the use of semi-probabilistic designs based on combining the maximum hourly wind pressure likely to occur in a 50 year return period and the maximum radial wet snow accretion likely to occur in the same return period. The regional weather information is contained in ENA ETR111:1991, based on historic weather measurements at Met Office sites.

More recently there has been a return to deterministic overhead line design techniques based on International Standards; BSEN 50423 for lines up to 45kV, and BSEN 50341 for lines of 45kV and above. The adequacy of the overhead line designs introduced since the Electricity Regulations of 1988 has been tested over many years and is subject to post event review by Government.

UKCP09 does not provide information on future high wind speed events, but the Met Office presently advise that there is no evidence of an increase in the severity of high wind events, although there could be a possible increase in their frequency. This increased number of events has the effect of reducing the return period for the currently specified high wind events and will thus increase the wind pressure used in the calculations, if the same level of reliability is required. In respect of wet snow / ice loading, the UK DNOs are participating in COST 727 which is reviewing ice accretion models across the EU. It is currently anticipated that this research will indicate a reduction in the severity requirements used in UK overhead design criteria. Since the design criteria is based on the combined effect of wind and ice, it is expected that existing designs will probably have adequate structural strength and there will be no reason to modify existing networks or change the current design due to climate change impacts.

One related area which might however be affected by climate change is conductor clashing. This is directly related to the gusts associated with the probable wind speeds but, because of the uncertainty in predicting the change in future wind speeds, it is not currently possible to recommend any changes to existing overhead designs. These decisions will need to be reviewed once more accurate climate predictions on wind and ice accretion are available.

Appendices

Appendix 2

A2.1 Overhead Lines (Risks AR1, AR2, AR3 and AR16) continued

Limitations on available information
The following limitations have been identified in available information:

a) There is limited information on future changes in high wind speed events

b) There is no information on the combined probability of low wind speed (dead calm) events with high ambient temperatures. This combination has most effect on reducing overhead line capacity.

c) There is little probabilistic data on increased ambient temperatures generating light winds arising from convection currents generated from ground heating, though these conditions must already prevail in other global regions, albeit not necessarily in the coastal/island context of UK. The generation of winds under these conditions would ameliorate the effect of increased ambient temperatures on overhead line capacity.

d) Improved ice accretion data will be provided by the ”COST 727” EU research which should allow overhead lines to be designed more accurately to meet predicted ice loading.

e) Impacts of climate change on air conditioning demand and the timing relationship between peak ambient temperature and peak demand are not known and are subject to multiple other drivers such as building regulations, energy efficiency measures on both buildings and air conditioning units, and energy pricing. These in turn are impacted by “smart grid” technologies employed to mitigate low carbon economy impacts.

Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.2 Vegetation Growth and Climate Change (Risk AR 3)

Fundamentals
Overhead lines are susceptible to interference from the growth and frailty of vegetation and trees, which can cause a variety of power supply issues ranging from transient or persistent interruptions (due to vegetation touching the line) through to severe damage (due to falling trees or branches). Typically 25% of low voltage overhead interruptions and 6% of high voltage interruptions are related to vegetation induced faults. Under abnormal weather conditions falling trees can lead to large scale power outages.

Overhead lines are normally routed to reduce proximity to vegetation but this is not always possible. It is both socially and environmentally unacceptable to remove all vegetation in proximity to overhead lines and it is necessary to manage vegetation to maintain clearances.

An essential part of this management is understanding the risks associated with vegetation under both ongoing and abnormal conditions. It is important to understand the growth rates of different types of vegetation with respect to the environment at the location and to be able to assess the risks posed by the proximity to the overhead line, combined with the health and condition of the vegetation.

Northern Powergrid has always recognised the importance of efficient vegetation management in maintaining the performance of our overhead lines. Vegetation management is one of the largest annual recurring maintenance tasks that we undertake. We are obliged to carry this out in order to meet our statutory obligations under the ESQCRs, (as amended in 2006). We are required to ‘so far as is reasonably practicable, ensure that there is no interference with or interruption of supply caused by an insufficient clearance between any of his overhead lines and a tree or other vegetation.‘

Appendices

Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.2 Vegetation Growth and Climate Change (Risk AR 3) continued

Changes in Growing Season
External factors which influence vegetation growth include temperature and rainfall. Climate change will directly impact on growth rates – the number of days with a temperature over 5.6°C will impact the growing season, with an increase resulting in more and denser growth.

In 1999, German[20] research into changes in seasonal plant activity identified that the European growing season had extended by 10.8 days when compared with the early 1960s, with spring growth events (leaf unfolding) starting 6.0 days earlier and the autumn events (leaf colouring) delayed by 4.8 days.

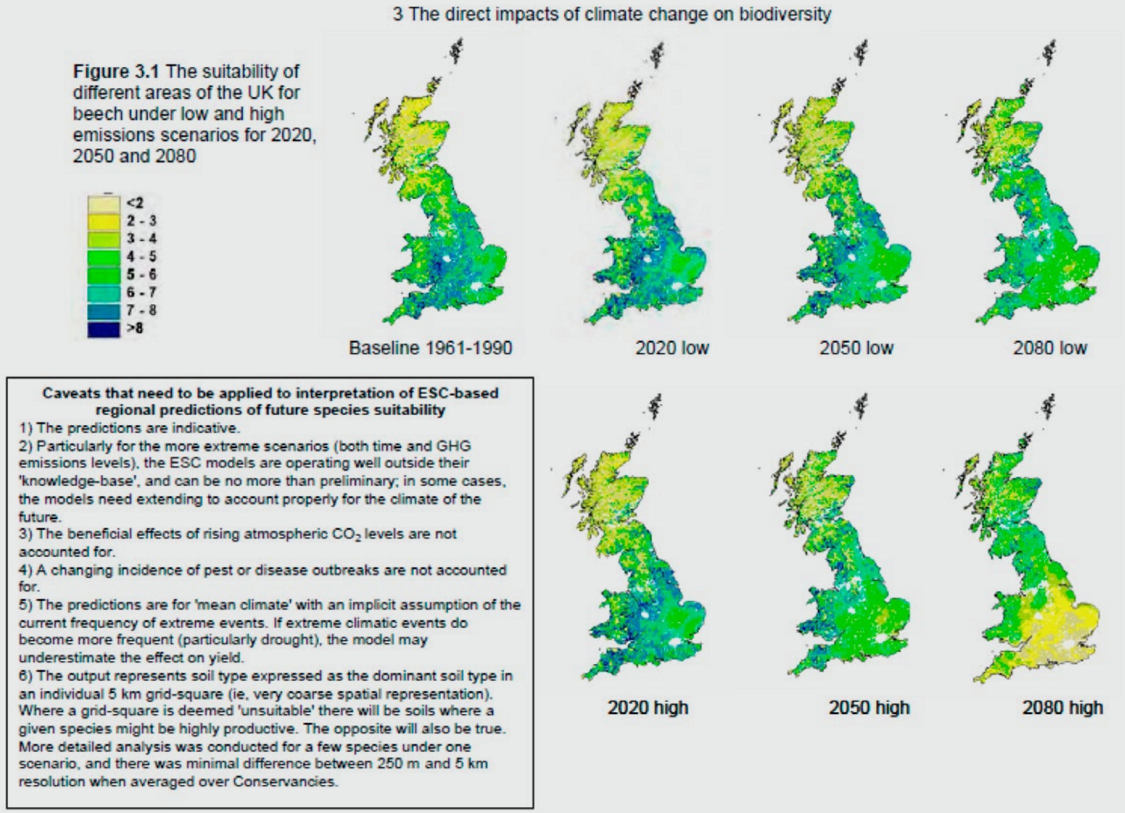
In 2001, American[21] research using NASA satellite data identified that plant life above 40 degrees latitude had been growing more vigorously since 1981. It concluded that the area of vegetation had not extended, but that existing vegetation had increased significantly in density. The timing of both the appearance and fall of leaves had shown dramatic changes over the two decades of recorded satellite data. In Eurasia, the growing season is now almost 18 days longer, with spring arriving a week earlier and autumn delayed by ten days.

The Met Office commented in 2006 that 'the longest thermal growing season in the 230-year daily Central England series occurred in 2000, when it extended for 328 days… The thermal growing season for this region of the UK is now longer than at any time since the start of the daily temperature series in 1772.'

Vegetation Growth – Changes in Habitat Suitability
In the longer term, the effect of a decrease in summer rainfall will also impact the growth of certain species which are sensitive to drought. One example given in a Defra Report[22] is lowland beech, identified as being particularly susceptible to climate change. Projections based on UKCP09 data are shown in Figure 17 – The suitability of different areas of the UK for Beech under low and high emissions scenarios for 2020, 2050 and 2080.

As habitats change, vegetation will gradually colonise new more suitable areas, but the health of existing susceptible vegetation species will deteriorate, resulting in an increased risk of these trees falling on to overhead lines.

Figure 17 – The suitability of different areas of the UK for Beech under low and high emissions scenarios for 2020, 2050 and 2080



20. Nature Vol. 397 Issue 6721 (1999) Growing season extended in Europe (A. Menzel and P. Fabian)

21. http://science.nasa.gov/science-news/science-at-nasa/2001/ast07sep_1/

22. Defra report England Biodiversity Strategy – Towards adaptation to climate change (May 2007)

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Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.2 Vegetation Growth and Climate Change (Risk AR 3) continued

Assessing The Impact of Climate Change
While the EP2 report did not include vegetation growth, the Met Office produced a report for the Department of Trade and Industry Network Resilience Working Group in August 2003 entitled ‘Extreme Weather Events likely to cause Disruption to Electricity Distribution’ which included the following predictions:

- In the south of the British Isles increased energy of storms may intensify and flash rates (lightning) may double.
- It is predicted that deciduous trees will be in leaf for longer periods of time resulting in increased risk from storm-related damage.
- In ENA ETR132, these predictions lead to the following comment: ‘It needs to be recognised that if the UK is presented with increasingly adverse climatic conditions over the coming decades, the reliability of the network is likely to become more difficult to manage. The consequence of this is that there will be a need for an increased level of funding and resource to keep network resilience, including vegetation management, at or above its current level.’

Between 1990 and 2006, prior to the improved management of vegetation, network fault statistics show that tree-related faults on the UK electricity network showed a significantly increased trend.

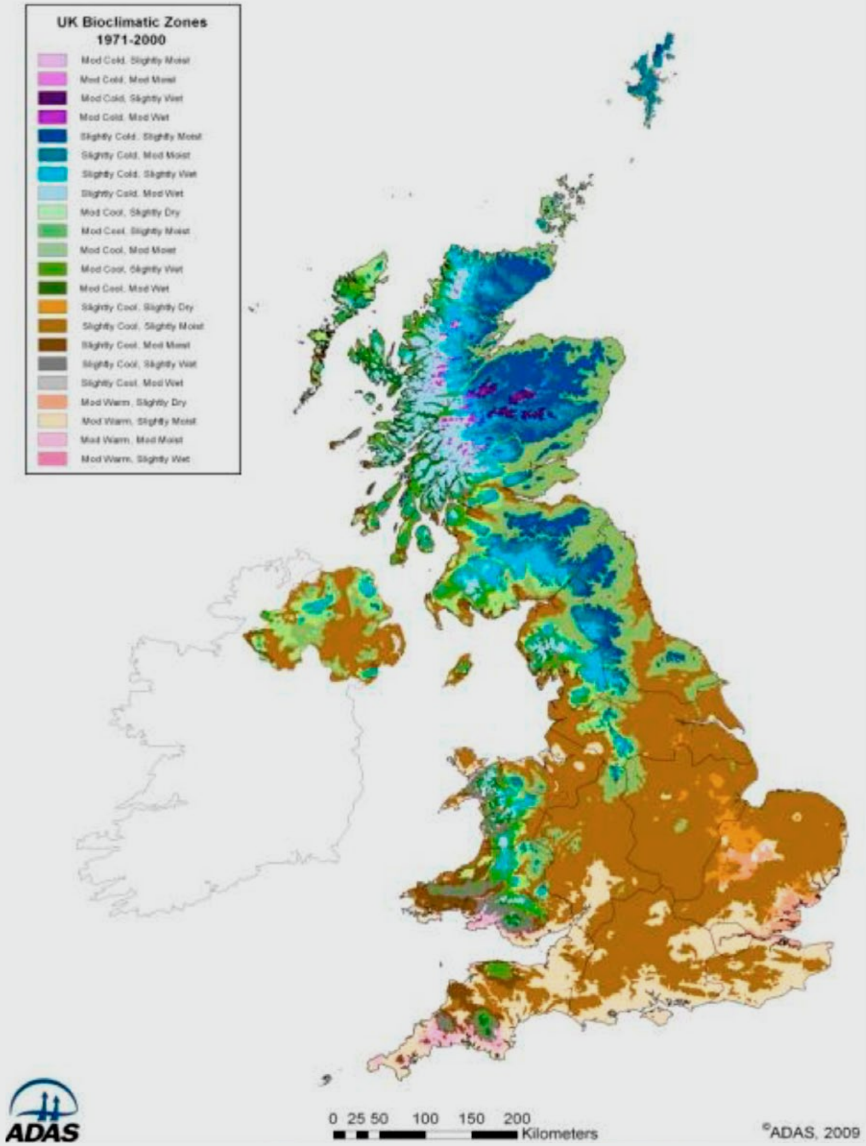
The introduction of the risk based approach to vegetation management under ENA ETR132 should improve network performance in abnormal weather conditions by the selected removal of high risk trees in the proximity of strategic overhead line circuits. This may have some benefit under normal weather conditions, but is unlikely to prevent further increases in the number of interruptions due to the expected increased vegetation growth rates.

This issue will need to be kept under review to confirm actual climate change impacts when maintenance can be adjusted accordingly.

Vegetation Growth Research Currently Underway
In 2008 several DNOs commissioned a four year research project with ADAS, an independent provider of environmental consultancy services, to quantify the impact of vegetation growth around overhead lines and in particular the manner in which the Utility Space (that is the physical volume around the utility’s apparatus including the volume necessary to ensure its safe and reliable operation) was degraded by vegetation growth over time.

The ADAS Vegetation Management Research Project established approximately 1,700 experimental sites across the country in representative bioclimatic zones determined by the temperature, rainfall and soil conditions (Figure 18 – ADAS Bioclimatic Zone).

Figure 18 – ADAS Bioclimatic Zone



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Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.2 Vegetation Growth and Climate Change (Risk AR 3) continued

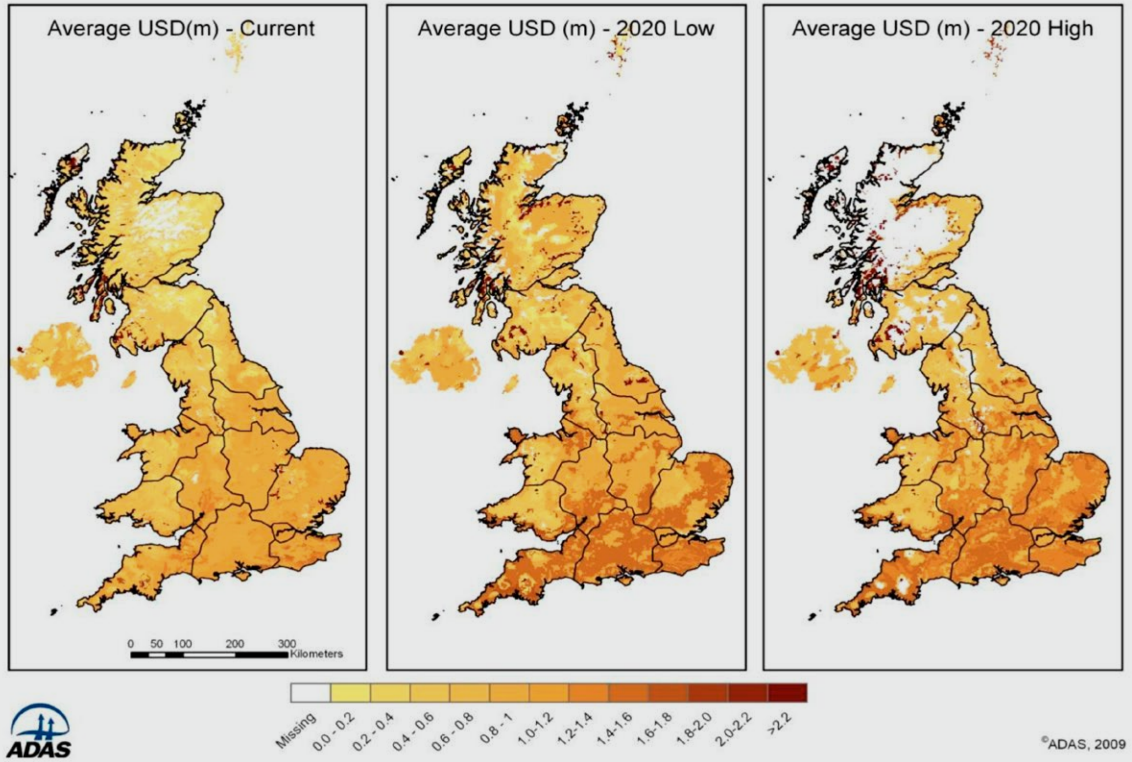
At each site the Utility Space derogation is being measured on a biannual basis. These measurements are used to infer the net integrated rate of growth at each site and will determine the spatial and temporal growth rates for each bioclimatic zone. The initial results have shown a marked variation in growth rates across the country, which follow the bioclimatic zone areas.

Using UKCP09 data, ADAS predicted the future changes in the size and locations of the bioclimatic zones under different emission scenarios. If the growth rates from the initial observations follow the expected trends then this points towards climate change having a substantial impact on vegetation growth over the next ten years. Figure 19 – Impact of Growth Rate on Annual Utility Space Derogation shows how growth rates will impact on the annual Utility Space Derogation in this period.

This research project is as yet incomplete, but the initial projections indicate that a significantly increased level of vegetation management will be necessary across most areas of the UK.

The potential impact of increase in vegetation cutting can be gauged from the fact that the allowed revenue for the industry set by Ofgem for the five year DNO price control from 2010 is £500m (at a 2007/08 price base).

Figure 19 – Impact of Growth Rate on Annual Utility Space Derogation



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Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.3 Underground Cables (Risks AR4 and AR5)

Underground Cables Background Information
In the UK, electricity cables are installed and operated at all voltages from low voltage (400/230 Volts) to 400kV. Cables are typically installed in more urban areas but can be used in rural areas where there are particular environmental issues that make them suitable. Lower voltage cables may be installed just 0.45m below the surface whilst higher voltage cables may be buried at depths of 1m or more.

The length of cable operated at the highest transmission voltages is limited due to the substantial costs involved, however as cable voltages reduce, the cost premium compared to an equivalent overhead line falls.

Cable construction typically comprises a central conductor(s) of copper or aluminium immediately surrounded by insulation (the dielectric) with an outer electrically earthed metallic screen. Older and lower voltage cables are typically of three, or at LV four, core construction whilst higher voltage, more recently installed cables are more likely to comprise three single core cables laid close together.

As with other electrical equipment, the rating of cables is typically limited by the maximum operating temperature of the insulation surrounding the conductors.

Older oil-impregnated paper insulated cables have a design maximum conductor temperature of 65°C whilst modern plastic insulated cables have a design maximum conductor temperature of 90°C. Exceeding the maximum operating temperature can have a significant impact on the expected life of the cable. The temperature of the cable is determined by four sources of heat generation:

- electrical current passing through the electrical resistance of the conductor(s)
- direct heating of the insulation caused by the alternating voltage, (only significant in higher voltage cables)
- heating caused by eddy currents which circulate within the earth sheath of single core cables
- other external sources of heat in the ground, i.e. adjacent cables.

Balanced against the conduction of heat away from the cable:

- The way cables are laid is a factor in this; cables laid in ducts are usually less able to dissipate the heat than those buried directly in the ground.
- The thermal resistivity of the ground surrounding the cable or duct is affected by the type of soil and the level of moisture it contains.
- The temperature of the surrounding soil is affected by ambient air temperature.

Climate Change
The basic equations governing the derivation of cable ratings have been understood for many years and, within the UK, have been incorporated into a comprehensive suite of cable rating tools called CRATER which can be used to model any range of scenarios in relation to soil temperature and resistivity.

Currently, cable ratings in the UK are based on assumptions of temperature (air and soil) and thermal resistivity (soil) made more than 50 years ago. Global warming is predicted to result in generally hotter, drier summers and milder, wetter winters in the UK. These changes will impact directly upon cable ratings due to the increase in ground temperature and the potential for increased soil thermal resistivity if soils become dry.

It is also likely that as soils dry out, particularly those rich in clay, that ground movement will occur which in turn may result in damage to cables and cable joints.

The Met Office EP2 report established the effect climate change will have on the industry's infrastructure and business. The main findings in relation to cable assets are that air and soil conditions are expected to change, resulting in higher temperatures and in seasonal differences in soil moisture content. This report recommended that:

- For every 1°C rise in air temperature, soil temperatures at depths of 0.45–1.2m can be expected to increase by 0.75°C.
- The effects are similar for different soil types; sand-rich soils offer slightly more resilience to temperature change than types rich in clay or silt, but the variations are small when compared to the effects of changes in the air temperature.
- Reduced precipitation levels will only impact ground resistivity values in extreme, prolonged drought conditions, otherwise the effect is small at 1.2m depth.
- Because of the small effect of soil type, climate change driven changes in air temperatures should be considered independent of soil type when calculating ratings.

The impact of these, more recent, climate change predictions as applied to cables using the guidance from the EP2 project are considered on the following page.

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Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.3 Underground Cables (Risks AR4 and AR5) continued

Impact of Climate Change on Cable Ratings
This section considers the general impact of the UKCP09 climate change predictions on the rating of a range of typical cables used throughout the UK. It is important to note that the predicted reduction in ratings may be exceeded in specific situations such as areas affected by Urban Heat Island effects or localised dry, sandy soil conditions which may be more prone to drying out as temperatures increase.

Table 15 – Common Types of Underground Cables considers a range of commonly used cable types and installation methods and shows the percentage reduction in rating per °C of air temperature change calculated using CRATER. A range of de-ratings of distribution cables (indicated in the table as 33kV and below) of up to 4.3% over the period having a centre point in 2055 are indicated. This equates to a ratings impact of some 0.10% per annum. Recent demand growth has impacted these same networks at some 1.5% per annum.

Table 15 – Common Types of Underground Cables

Description	Max °C	Time	Installation	Existing Rating (Amps)	Rating Reduction %/°C Air Temp
LV – 185 Cu Waveform	80	Summer	Direct Lay	339	0.590
LV – 185 AL PILC-STA	80	Summer	Direct Lay	335	0.597
11kV – 185 Al XLPE 1C	90	Summer	Direct Lay	370	0.507
11kV – 185 Al XLPE 1C	90	Summer	Ducted	360	0.521
11kV – 185 Al PICAS 3C	65	Summer	Direct Lay	270	0.787
33kV – 185 Al XLPE 1C	90	Summer	Direct Lay	457	0.492
33kV – 185 Al XLPE 1C	90	Summer	Ducted	430	0.494
33kV – 185 Cu PILC ‘H’	65	Summer	Direct Lay	355	0.775
132kV – 630 XLPE 1C	90	Summer	Direct Lay	881	0.511
132kV – 630 XLPE 1C	90	Summer	Ducted	879	0.512
132kV – 630 Cu Lead Sheath	85	Summer	Direct Lay	755	0.579
132kV – 630 Cu Lead Sheath	85	Winter	Direct Lay	827	0.544
400kV – 2000 XLPE 1C	90	Summer	Direct Lay	1,429	0.560
400kV – 2000 XLPE 1C	90	Summer	Ducted	1,448	0.570
400kV – 2000 XLPE 1C	90	Winter	Direct Lay	1,569	0.518
400kV – 2000 Cu Lead Sheath	85	Summer	Direct Lay	1,052	0.986

Appendices

Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.3 Underground Cables (Risks AR4 and AR5) continued

Impact of Climate Change on Cable Ratings continued

The impacts of such reductions in ratings will vary from one circuit to another depending on how close the maximum demand on a particular circuit is to the circuit rating. In the case of 33kV and higher voltage circuits, when that limit is reached, it is possible that the entire circuit may need to be replaced with a larger cable size or alternatively the capacity of the network increased by the installation of additional circuits or substations.

For 11kV and LV circuits, where the load on the circuit reduces over its length, it is necessary to determine what proportion of the circuit would need to be replaced with a larger cable size or again it may be possible to increase the capacity of the network by the installation of additional circuits or substations.

Where it becomes necessary to take action to replace an overloaded cable, an estimate of the likely costs can be calculated using a typical cost per installed kilometre. The estimated unit costs of cable replacement used in Ofgem's DPCR5 investment assessment (direct costs only) are shown in Table 16.

Table 16 – Extract from Ofgem Electricity DPCR, Final Proposals, Allowed Revenue, Cost Assessment App Ref 146a/09 – 7 Dec 2009 shows quantitative information supplied by Ofgem and is a summation of DNO regulatory returns submitted under the DPCR5 process (Table T4) for closing balances of all 14 licensed UK DNOs as at 31 March 2010 and Table 17 shows the amount of underground cable installed in the UK.

As with overhead lines it is important to consider de-ratings against past network operator experience in response to growth of electricity demand on their networks; effectively the same challenge.

Underground cable systems may also be affected by summer drought and consequent ground movement, leading to mechanical damage.

Table 16 – Extract from Ofgem Electricity DPCR, Final Proposals, Allowed Revenue, Cost Assessment App Ref 146a/09 – 7 Dec 2009

Cable Type	Cost/km
LV Main (UG Plastic)	£98.4
6.6/11kV UG Cable	£82.9
33kV UG Cable	£256.8
132kV UG Cable	£1,047.1
132kV Sub Cable	£1,966.7

Table 17 – Underground Cables Installed in the UK

Underground Cables GB	Total Circuit km
LV	328,038
HV (6.6, 11, 20kV)	153,884
EHV (33, 66kV)	21,188
132kV	3,190

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Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.4 Substation Earthing (Risk AR6)

Purpose
Earthing is essential to enable faults to be detected quickly and automatically made safe. When an earth fault occurs on the distribution network (See Figure 20):

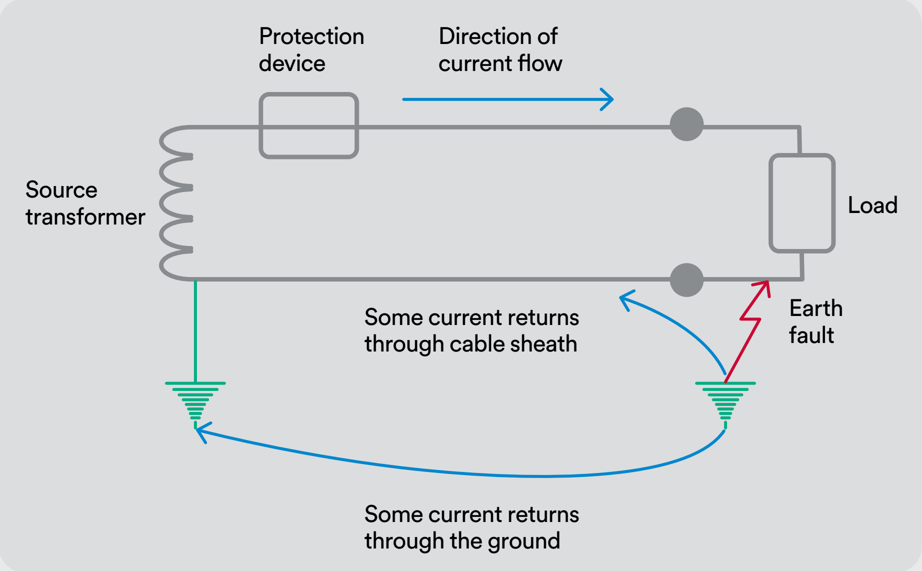
— A large current flows along the cable and returns to the source via the cable sheath and the general mass of earth.
— The current flows until the source protection disconnects the power supply.
— The current flowing through the earth causes a considerable rise in voltage – known as rise of earth potential or earth potential rise – on the ground and any metalwork near the fault, creating a possible danger (touch and step potential) to anyone in the vicinity if this becomes excessive.
— This rise in voltage may be transferred onto adjacent power and communication cables creating possible danger to anyone who might be in contact with them – this can be some distance from the actual fault.

The purpose of earthing is to pass the fault current during an earth fault back to the system neutral to ensure the source protection operates to disconnect supplies.

This will be achieved by an earthing system which is designed to:

— prevent dangerous voltages appearing on customer installations
— prevent dangerous voltages appearing at the substation and causing danger to staff or the public
— prevent damage to sensitive equipment (e.g. communications)
— discharge any lightning surges to earth.

Figure 20 – Earth Fault Current Path



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Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.4 Substation Earthing (Risk AR6) continued

Description of an Earthing System
An earthing system is a collection of one of more electrodes installed in the ground. It usually consists of a number of copper rods interconnected by copper tape or copper conductor. All metallic plant, equipment and structures on a site are then connected to this system. Where necessary some plant and equipment which might otherwise experience excessive rise of earth potential will be deliberately separated from the earthing system and could be provided with their own separate earthing system.

The size of earthing system will depend on the type of site and its complexity. A typical pole-mounted site will often have a single earth rod whereas a large substation will have an earth mat covering the complete site. The earthing system at most sites is based around a standard design. The design at larger substations requires measurements and complex calculations to be carried out prior to construction, whereas smaller substations and pole-mounted sites rely on measurements carried out during installation to achieve a satisfactory value of earth resistance. Typical values of earth resistance are given in Table 18 – Typical Earthing System Resistance Values.

Earthing systems require excavation for installation and are therefore, in order to minimise cost of construction, designed to provide resistance values which are safe and conservative but not over-engineered.

Impact of Climate Change on Earth Resistance
The resistance of an earthing system is mainly determined by the soil/geology both in contact with and in the immediate vicinity of the earthing system. Different soil/geology types exhibit different values of resistivity – some typical values are shown in Table 19 – Typical Soil and Geology Resistivity Values.

Earthing resistance changes with time as the resistivity of the ground varies in response to changes in water content and, for shallow installations, temperature. If the variations in moisture and temperature caused by climate change adversely affect the soil resistivity, the earth resistance could increase and the earthing installations would no longer satisfy the requirements of the original earthing design. Generally, earthing systems are designed to cater for a degree of seasonal and regional variations.

The important point is to understand the relative size of the effects that climate change might have with respect to these regional variations in soil/geology type and with respect to other contributing effects, such as change in soil moisture measurements when made in summer as opposed to winter.

Table 18 – Typical Earthing System Resistance Values

Substation Type	Typical Voltage Transformation Levels	Approximate number nationally	Resistance Value (Ω)
Grid	400kV to 132kV	380	
	132kV to 33kV	1,000	<0.1
Primary	33kV to 11kV	4,800	<0.1
Secondary ground-mounted	11kV to 400/230V	230,000	<1
Secondary pole-mounted	11kV to 400/230V		<10
LV system	400/230V	millions	<20

Table 19 – Typical Soil and Geology Resistivity Values

Soil/Geology Type	Typical Soil Resistivity (Ωm)
Loam	25 or less
Chalk	50 or less
Clay	100 or less
Clay/Sand/Gravel	150–300
Slate/Shale/Rock	500 or less
132kV	3,190

Appendices

Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.4 Substation Earthing (Risk AR6) continued

Risk and Mitigation
A standard risk assessment approach is used in earthing design to assess the risk and provide appropriate mitigation. This is based on the staff or customers being exposed to the risk, the likelihood, and the touch and step potentials generated. However to gain a better understanding of the effect of climate change on earthing and to identify the risks and determine a suitable mitigation strategy further research is necessary.

The National Soil Research Institute (NSRI) at Cranfield University and the British Geological Survey (BGS) have been working with UK Power Networks and E.ON (Central Networks) over the last couple of years to produce an earthing mapping system under the Ofgem Innovation Funding and Incentive (IFI) scheme. The earthing mapping system specifies the amount of earthing and the type of installation to obtain the required value of earth resistance.

Discussions have been held with NSRI and BGS to extend this work to account for the effects of seasonality and climate change on earthing. It is envisaged that this would include the following:

- An analysis of UKCIP climate models to assess climate variations – especially extended 'dry' periods, and extremes of drought.
- Use of the knowledge from earthing mapping system from phase 1 to highlight those soils and geology types most susceptible to climate change.
- Use of asset databases to cross match assets with 'sensitive' climate/season and soil-geology areas.
- Assess legacy (especially 'very shallow trench') installations to determine suitability for upgrade/remediation to deep drive.
- Provide a modified version of the earthing mapping system which incorporates an allowance for seasonality and climate change.

Mitigation measures are likely to be different for new installations and for existing installations.

For new installations, the mitigation measure will consist of updating design standards. New installations will need to be built to withstand greater temperature and moisture variations than the current seasonal cycle, in order to withstand expected changes to climate. Whilst design costs are unlikely to change, there is likely to be an incremental cost for additional materials and installation time where more rods need to be installed.

For existing installations, the mitigation measure is likely to consist of an inspection regime prioritised by risk. Although earthing is not something that is periodically renewed, the inspection regime would identify any potential risks that need addressing together with the timescales. The work carried out to date by NSRI and BGS provides a quantified basis on which to base the regime. An example inspection regime might be:

- targeting the type of substation (grid, primary, pole-mounted secondary, ground-mounted secondary or LV) representing the greatest risk, balancing the likelihood of exceeding earth potential due to climate changes with the number of people (staff and customers) exposed;
- refine this population by excluding those which are shielded from direct climate effects (such as indoor substations);
- refine this population of substations by targeting those with older earthing installations as a first priority;
- further refine this population by targeting those in areas with known poor soil resistivity;
- further refine this population by choosing a representative sample size to monitor.

Inspection visits would then consist of re-measuring the resistance of the earthing installation, and would need to pay due regard to the season and environmental conditions prevailing during the inspection in order to ensure readings can be correctly interpreted.

To give a context to this, sampling 1% of UK grid sites with 5-yearly inspections would involve a handful of inspections, and negligible cost. Sampling 1% of LV sites with 5-yearly inspections would involve hundreds of thousands of inspections and would be likely to incur several £ million in operating expenses.

Costs associated with monitoring by inspections, and replacement/upgrading would need to be recovered through the provision of appropriate allowances for this work via the regulatory regime.

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Appendix 2 Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.5 Transformers (Risks AR7 and AR8)

Transformers are used to transform voltage from one level to another. Within Northern Powergrid, the most common transformation steps are 132,000 Volts (132kV) to 33kV, from 33kV to 11kV and from 11kV to the low voltage (LV) supplies that feed homes and small businesses. Other voltage levels, such as 66kV and 22kV, are also in more limited use but the principles remain the same.

Transformers comprise an iron core with copper or aluminium insulated wire coils wrapped around that, further insulated with a mineral oil and housed in a steel tank, with external connection points to the system. The passage of current through the wire coils ("windings") causes heating, since no wire is a perfect conductor, and the insulating oil plays a major part in conducting that heat away.

The larger transformers used to transform down from 132kV, 66kV and 33kV are almost all "ground-mounted" and carry large amounts of power, necessitating the use of external radiator banks with pumps and fans to dissipate the heat.

The transformers that transform from 11kV down to LV have cooler radiators built into the sides of the tanks. Small capacity units can be mounted on poles ("pole-mounted distribution transformers") whilst others, typically feeding estates and semi-urban/urban businesses are slightly larger, ground mounted, and may be situated in an outdoor walled enclosure or within a building or Glass Reinforced Plastic type enclosure.

The load carrying capability of the transformer is primarily dictated by the maximum temperature at which the windings and insulation can be operated without causing damage or electrical fault. The greater the external ambient temperature the less heating can be permitted from the windings and consequently the rating is reduced. The pattern of demand loading during the day also has an impact.

Figure 21 – Ground mounted transformers with coolers

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Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.5 Transformers (Risks AR7 and AR8) continued

Northern Powergrid transformers have been purchased against British and International Standards extending back to the 1930s (see Appendix 3: Key Design Standards). These Standards have associated loading guides that provide a mechanism for assessing different loading levels and load patterns against ambient temperature, such as BS CP 1010 (1975) and most recently BSEN 60076-7. These provide a means of assessing the rating reduction impacts from increased ambient temperatures.

Whilst there are innumerable permutations that could be assessed, the objective here is to place some broad scales to the impact of climate change and the impact on continuous rated load represents a reasonable worst-case picture, when viewed against the 90% probability levels of the stated emission scenarios. BS CP 1010 provides a relatively straightforward tool and the analysis of a broad range of outputs indicates that 11kV distribution transformers are de-rated by some 1.0%/°C whilst the larger 33kV, 66kV and 132kV transformers that have external cooler banks with fans and pumps are impacted by some 0.7 %/°C.

Figure 22 – Pole-Mounted Distribution Transformer with External Cooling Tubes

Table 20 – % Reduction in Transformer Ratings

Transformer Type/Season	2010–39				2040–69				2070–2099					
	M		L		M		H		L		M		H	
	Mi n	Ma x	Mi n	Ma x	Mi	Ma x	Mi	Ma x	Mi	Ma x	Mi	Ma	Mi n	Ma Tx
11kV summer	1.8	2.9	2.6	4.5	2.8	4.8	3.3	5.4	3.2	5.3	4.1	6.8	5.0	8.0
11kV winter	1.6	2.3	2.2	3.2	2.4	3.5	2.5	3.9	2.7	4.1	3.0	4.8	3.5	5.8
33, 66, 132kV summer	1.3	2.0	1.8	3.2	2.0	3.4	2.3	3.8	2.2	3.7	2.9	4.8	3.5	5.9
33, 66, 132kV winter	1.1	1.6	1.5	2.2	1.7	2.5	1.8	2.7	1.9	2.9	2.1	3.4	2.5	4.0

Table 21 – Extract from Ofgem Electricity Distribution Price Control Review, Final Proposals, App Ref 146a/09 – 7 Dec 2009

Quantities of Transformers for UK DNOs as at 31 March 2010 and Replacement Costs		
Transformer Type	Numbers in Service	Replacement Cost £k
11kV pole mounted	348,647	2.9
11kV ground mounted	231,297	3.2
33kV pole mounted	1,588	7.9
33kV ground mounted	7,699	377.9
66kV ground mounted	612	440.2
132kV ground mounted	1,946	1,018.7

Appendices

Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.6 Substations (Risks AR9, AR10, AR11 and AR12)

Introduction
The relative importance of different types of substation are indicated in Table 1 – Types of Electrical Substation. Substations are key installations on the Northern Powergrid network and are built with considerable redundancy, as described below. However, network security requirements do not provide for the complete loss of a grid or primary substation, and in these circumstances, customers may be without supply until repairs or other work are carried out.

Typical Equipment Contained Within a Substation
Typically, a grid substation is made up of batteries, busbars, metering, relays, switchgear and transformers. Transformers ratings are considered in Section A2.5 of this appendix.

132kV system design generally establishes substations with duplicate 132kV/lower voltage transformers at practicable and convenient locations in the proposed zones of supply, having regard to current and possible future loadings together with environmental aspects.

33kV or 66kV substations are normally located at the centre of demand in the proposed zone of supply, having due regard to present loads

Figure 23 – 132kV Grid Substation Showing 132kV Terminal Tower and Start of 33kV Wood Pole Overhead Line

and possible future growth, future land use and environmental aspects. Care is always taken when siting substations close to residential property, public amenities or environmentally sensitive areas.

Substations are designed to occupy the minimum practicable site area to reduce future maintenance costs, subject to a reasonable provision for future extension and/or replacement of switchboards and transformers, and any planning requirements.

Wherever possible, new substations are situated on land which is not exposed to the risk of flooding. To establish whether a proposed substation premises is at risk from flooding and the potential scale of a flood event, a flood risk assessment should be carried out in line with risk based on Planning Policy Statement 25 (Development and Flood) as detailed in ETR138. Where it is necessary to site a substation on low-lying land, the site may need to be elevated or protected.

Distribution Licence Condition 9 requires Northern Powergrid to comply with a Distribution Code which 'is designed so as to permit the development, maintenance, and operation of an efficient, coordinated and economical system for the distribution of electricity'. The adoption of a standard range of plant and equipment across the 132kV system allows economies of scale and management of network risks by facilitating the interchangeability of plant under emergency situations.

Switchgear is to the standard specified in ENA TS 41-37 – switchgear for use on 66kV to 132kV Distribution Systems, or ENA TS 41-36 – distribution switchgear for use up to 36kV (cable and overhead conductor connected) which in turn specifies that switchgear will be to the standard specified by IEC 60694 – common specifications for high voltage switchgear and control gear standards. Details of the normal service conditions expected from switchgear can be found in Appendix 3: Key Design Standards. The selection of switchgear takes into account the following factors:

- total cost over the lifecycle of the asset
- risk of catastrophic failure
- substation security
- future availability of additional units
- available space
- environmental pollution.

Figure 24 – An Electricity Substation Protected by Flood Barriers in the 2007 Floods in the North East of England

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Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.6 Substations (Risks AR9, AR10, AR11 and AR12) continued

Substation Climate Change Risks

Flood Resilience

From a flood resilience perspective, the following guidance is given in the ETR138:

- Identify all substations (within scope) that lie within a flood plain using the best available current data from the EA.
- Establish the flood risk for each substation to identify predicted flood depth, where the flood depth is likely to cause damage to key parts of the substation resulting in the loss of supply to customers.
- For each substation deemed 'at risk', identify the flood impact for that site including societal impact.
- Establish if the site is to be protected under a flood protection scheme sponsored by an appropriate public authority.
- Establish the appropriate options for protecting the site with estimated costs. These should include:
  - provision of permanent or temporary barriers
  - protecting all the site or only key areas
  - providing a sufficient level of network interconnection
  - commissioning a replacement substation in an alternative location.
- Propose a solution based on flood risk and cost benefit assessment.
- Review information from EA on surface water flooding as the data becomes available. Ideally mitigation measures should be designed to protect against the 1 in 100 (river) or 1 in 200 (sea) for primary substations and 1 in 1,000 floods for grid supply points as appropriate to the practical limitations of the site and the outcome of the cost benefit assessment.

The flood plain is split into two different areas. These are:

- The area that could be affected by flooding, either from rivers or the sea, if there were no flood defences. This area could be flooded:
  - from the sea by a flood that has a 0.5% (1 in 200) or greater chance of happening each year, or
  - from a river by a flood that has a 1% (1 in 100) or greater chance of happening each year.
- The additional extent of an extreme flood from rivers or the sea.
- These outlying areas are likely to be affected by a major flood, with up to a 0.1% (1 in 1000) chance of occurring each year.

The predicted flood level for a substation asset will also need to take into account the uncertainties surrounding climate change. Based on current advice from EA, it is recommended in ETR138 that the potential flood depth is increased by the following amounts:

- Freeboard – By 300mm to allow for uncertainties in data modelling;
- Fluvial flooding – By 20% on the predicted flood depth to allow for climate change impacts;
- Sea Level – Increase by the corresponding amount in the table for climate change impact for the lifetime of the assets, nominally 60 years.

Table 22 – Defra Flood and Coastal Defence Appraisal Guidance, FCDPAG3

Region	Net Sea Level Rise (mm/yr)			
	1990–2025	2025–2055	2055–2085	2085–2115
East of England, East Midlands, London, SE England (south of Flamborough Head)	4.0	8.5	12.0	15.0
South West and Wales	3.5	8.0	11.5	14.5
NW England, NE England, Scotland (north of Flamborough Head)	2.5	7.0	10.0	13.0

At present, data is issued by EA solely for the current flood risks. It is anticipated that predictions on future risks, including pluvial flooding, will be available in future and it will be necessary to re-assess flood mitigation plans and expenditure in line with this data. In addition, the second generation of National Shoreline Management Plans are now available. These include projections for coastal erosion and will also be considered in the assessment of flood risks.

Appendices

Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.6 Substations (Risks AR9, AR10, AR11 and AR12) continued

Substation Climate Change Risks continued

For existing major substation sites where there are no short-term plans for substantial asset replacement work, one of the following options may be adopted, bearing in mind the cost benefit assessment of the design.

- Construction of a subterranean “wall” around the perimeter of the substation site (including compound and buildings, extending above ground (e.g. concrete, sheet piling)).
- Construction of a waterproof wall within the site to protect critical assets. This option may be adopted where only specific assets are at risk and may be used in conjunction with option 3. Any of the following measures may be used where the flood height is not great, usually 300mm or less:
- Installation of flood protection to door openings;
- Raising ventilation holes;
- Raising walls; and
- Sealing cable troughs.
- Deployment of a temporary flood barrier around the perimeter of the substation site (or specific assets).
- Relocation of the substation.

Where a substation has been identified for asset replacement, an assessment of the flood risk shall be undertaken. Should this analysis result in the substation being identified as being at risk, the substation may be built at an elevated level. Standard designs are available for indoor distribution substations elevated at 600mm and 1200mm above ground level.

The cost of providing resilience will vary greatly between different sites, depending on the flood depth, work needed to protect the site, the availability of alternative sources of supply if a site is lost and the degree of protection offered by other schemes such as those defences provided by the EA.

ETR138 states that DNOs should carry out cost benefit assessments for each substation at risk in order to determine which resilience level is appropriate in any given case. This will include consideration of customers’ “willingness to pay”. The cost benefit assessments will take into account the societal aspects identified in ETR138 and other reviews into recent floods, including the Pitt review, as well as the more usual considerations of reducing customer supply losses and protecting assets.

For grid substations the target level of resilience should be Level 1 unless cost benefit analysis determines that Level 2 resilience is appropriate. If, in exceptional circumstances, a company determines that neither Level 1 nor Level 2 resilience is appropriate for a grid substation, it will provide such level of resilience as is reasonable practicable in the circumstances. If a company is uncertain about the level of resilience, it may consider consulting with government departments and the relevant flood protection authority as a means of resolving such uncertainty.

Table 23 – Resilience Levels

Resilence Levels Without Relying on Temporary Flood Protection Measures	
Level of flooding that may occur within a 1:1,000 year flood contour	Level 1
Level of flooding that may occur within a 1:100 year fluvial flood contour (1:200 in Scotland) and within the 1:200 contour for sea flooding throughout the UK	Level 2
Other flood protection measures (not meeting Level 1 or Level 2 above) including provision of limited alternative supplies.	Level 3

For primary substations the target level of resilience should be Level 2 unless cost benefit analysis determines that Level 3 resilience is appropriate. However, where substantial additional protection can be provided for a primary substation at marginal additional cost, e.g. protection increased from Level 2 to Level 1, then companies should consider providing this enhanced level of protection.

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Appendix 2
Details on Technical Risks from First and Second Round Climate Change Adaptation Reports

A2.7 Lightning Resilience

The Met Office Project EP2 details likely changes in lightning activity, including a projected change in future UK lightning faults by the 2080s, ranging from a decrease of 3% to an increase of 75% with a regional variation in the estimates.

Lightning storms may cause damage, latent damage, flashovers and transient interruptions to electricity networks. The effects of lightning can be minimised by including both shielding measures and suppression devices.

Metallically enclosed ground-mounted substations have inherent protection from direct lightning strikes, but can be affected by nearby strikes. These can cause surges in connected circuits either by a direct strike, or by inducing current in these lines. To guard against these effects, shield wires are installed on grid circuits supported by metal structures to provide a preferential path, reducing the probability of flashovers to the phase conductors. Unearthed circuits mounted on wooden poles form the majority of overhead high-voltage circuits and their physical properties provide a degree of electrical isolation from earth (reducing the likelihood of a direct strike). There are frequent earthed positions which tend to be associated with more vulnerable equipment such as overhead/cable interfaces and pole mounted plant/transformers. At these positions surge arresters are used to protect the equipment by clamping the voltage below values that can cause damage.

Flashovers caused by lightning normally result in high levels of power follow-through current, causing circuit protection to operate. To minimise the effects to customers, auto-recloser devices are installed on the network to rapidly reconnect circuits automatically.

Increased lightning activity could result in:

- reduction in life of surge arrestors due to increased exposure to lightning strikes;
- requirement to upgrade/modify lightning protection to maintain system performance;
- requirement to upgrade/modify lightning protection to cover assets not currently protected;
- reduced network performance with increased likelihood of supply interruptions in spite of improved lightning protection.

In view of the wide range of likely change in lightning activity and the uncertainty of the overall change in lightning risk, further investigation is require to provide sufficient evidence to support firm recommendations on adaptation requirements.

Appendices

Appendix 3 Key Design Standards

This appendix provides some background on the most relevant applicable design standards, together with some illustrations relating to the historical usage of older British Standards in a global context.

Whilst present day standards are dominated by those issued by the International Electrotechnical Commission (IEC) and European Norms (EN), it should be recognised that much electricity network infrastructure still in use was designed according to British Standards (BS) issued many decades ago. It is thus appropriate to briefly describe the climatic conditions used as the basis for equipment ratings in those old standards.

The UK was a major manufacturing base of electricity network equipment from the 1920s, supplying a global market dominated by a British sphere of influence. Consequently both British Standards and equipment designs were arranged to meet climatic demands covering the Middle East, India, Malaysia, South Africa and Australasia, as evidenced by references to peak ambient temperature requirements of 40°C as far back as 1923.

Table 24 – Key Design Standards

Standard etc.	Date	Title	Comment on Climate Content
BS116	1923	Oil immersed switches and circuit breakers for AC circuits	Ambient air temperature up to 40°C.
Electricity Supply Acts 1882 to 1936	1931	Electricity Commissioners 1931 design requirements	
BS171	1936	Electrical performance of transformers for power and lighting	Peak air temperature 40°C, average over any 24 hour period not greater than 35°C. Also refers to tropical 45°C options.
BS116	1937	Oil circuit breakers oil switches etc for AC circuits	Ambient peak up to 40°C with average over any 24 hour period not greater than 35°C.
BS137	1941	Insulators of ceramic material or glass for overhead lines with nominal voltages greater than 1,000V	Lightning withstand, pollution performance and temperature cycling.
BS1320	1946	High Voltage overhead lines on Wood Poles for line voltages up to and incl. 11kV	Design for wind load of 16 lb/sq ft (766 N/m²) with factor of safety. Conductor temperature 22 to 122F.
Electricity Supply Act ELC53	1947	Overhead line Regulations (differs from 1931 ELC53 in ref to BS1320)	Lines to withstand simultaneous 50mph wind and (57 lb/cu ft) ice load with factor of safety. Max conductor temperature 122F.
BS116	1952	Oil circuit breakers for AC systems	Ambient peak up to 40°C with average over any 24 hour period not greater than 35°C.
BS171	1970	Power transformers	Not greater than 30°C average air temperature in any one day or average greater than 20°C in one year.
Statutory Instrument 1355	1970	The Electricity (overhead line) regulations 1970	Design for 760N/m² wind load for conductors up to 35 sq mm and for 380N/m² simultaneous with augmented (ice/snow load) for conductors >35 sq mm.

Appendices

Appendix 3
Key Design Standards continued

Standard etc.	Date	Title	Comment on Climate Content
BS137	1973	Insulators of ceramic material or glass for overhead lines with nominal voltages greater than 1,000V	Lightning withstand, pollution performance and temperature cycling.
BS171	1978	Power transformers	Ambient air not greater than 40°C, not below -25°C outdoor or -5°C indoor, not greater than 30°C average in any one day or more than 20°C average in any one year. Lightning withstand.
BS7354	1990	Design of HV open terminal substations	Wind speed, ice thickness, pollution and lightning withstand.
PD IEC TR61774	1997	Overhead lines – Meteorological data for assessing climatic loads – mainly ice models but links to IEC 60826 that includes ref to wind and coincident (work fed into BS EN 50341 and 50423 also COST 727 project on icing) temperature.	Discusses icing models for glaze, rime ice and wet snow. Draws on test span information from Canada, Czech Republic, Germany, Japan, Hungary, Iceland, Norway, UK, USA and Italy.
IEC60265-1	1998	HV switches for rated voltages 1kV to less than 52kV	
IEC60076-1	2000	Power Transformers	Ambient temperature max 40°C minimum -25°C. Lightning withstand.
IEC60694	2002	Common specification for switchgear and control gear (superseded by BS EN 62271-1)	Sets ambient temperatures, pollution etc. E.g. outdoor equipment for -25°C and 10mm ice coating. Also sets lightning overvoltage performance levels. The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24h, does not exceed 35°C.
ANSI/IEEE C37.60	2003	American national standard for overhead line pole mounted, dry vault and submersible automatic circuit reclosers and fault interrupters for AC systems	Ambient not greater than 40°C or less than -30°C.

Appendices

Appendix 3
Key Design Standards continued

Standard etc.	Date	Title	Comment on Climate Content
BSEN62271-105	2004	High-voltage alternating current switch-fuse combinations	Links to 60694. The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24h, does not exceed 35°C. Minimum -5°C indoor -25°C outdoor.
IEC60076-7	2005	Loading guide for oil immersed power transformers	Normal service conditions.
BSEN62271-200	2005	AC metal-enclosed switchgear and control gear for rated voltages above 1kV and up to and including 52kV	Links to 60694. The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24h, does not exceed 35°C. Minimum -5°C indoor -25°C outdoor.
BSEN50423	2005	Overhead electrical lines 1kV up to and including 45kV	Design standard for new overhead electricity lines <45kV, covers wind and ice load structural strength of supports, conductors, foundations and factors of safety.
IEC60947	2007	Low voltage switchgear and control gear	Ambient not greater than 40°C and its average value, measured over a period of 24h, does not exceed 35°C.
IEC61462	2007	Composite insulators – hollow insulators for use in outdoor and indoor electrical equipment	
BSEN62271-102	2007	High-voltage alternating current disconnectors and earthing switches	Links to 60694. The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 h, does not exceed 35°C. Minimum -5°C indoor -25°C outdoor.
IEC60137	2008	Insulated bushings for alternating voltages above 1,000V	Standard for bushings (the external connections into transformers, circuit breakers etc) – covers ambient temperature, ice accretion.
IEC60815	2008	Guide for selection of insulation in respect of polluted conditions	
IEC60529	2009	Degrees of protection provided by enclosures (IP guide)	Ability to withstand driven rain/immersion etc.

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Appendix 3
Key Design Standards continued

Standard etc.	Date	Title	Comment on Climate Content
BSEN62271-100	2009	High voltage circuit breakers	Links to 60694. The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 h, does not exceed 35°C. Minimum -5°C indoor -25°C outdoor.
BS EN61936-1		Draft standard on substation design	
ENA TS43-40		High voltage single circuit lines on wood poles	Design includes ref to maps showing combined wind/ ice severity by altitude across UK.

Appendices

Appendix 3
Key Design Standards continued

Extract From IEC60694
IEC 60694 lays out the normal service conditions expected from switchgear. The following are the service conditions relevant to the climate in which the switchgear operates:

Indoor switchgear and control gear:

- The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 hours, does not exceed 35°C.
- The minimum ambient air temperature is -5°C for class “minus 5 indoor”, -15°C for class “minus 15 indoor” and -25°C for class “minus 25 indoor”.
- The influence of solar radiation may be neglected.
- The altitude does not exceed 1,000m.
- The ambient air is not significantly polluted by dust, smoke, corrosive and/or flammable gases, vapours or salt.
- The conditions of humidity are as follows:
  - The average value of the relative humidity, measured over a period of 24 hours, does not exceed 95%.
  - The average value of the water vapour pressure, over a period of 24 hours, does not exceed 2,2kPa.
  - The average value of the relative humidity, over a period of one month, does not exceed 90%.
  - The average value of the water vapour pressure, over a period of one month, does not exceed 1,8kPa.

Outdoor switchgear and control gear:

- The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 hours, does not exceed 35°C.
- The minimum ambient air temperature is -10°C for class “minus 10 outdoor”, -25°C for class “minus 25 outdoor” and -40°C for class “minus 40 outdoor”. Rapid temperature changes should be taken into account.
- Solar radiation up to a level of 1,000 W/m² (on a clear day at noon) should be considered.
- The altitude does not exceed 1,000m.
- The ambient air may be polluted by dust, smoke, corrosive gas, vapours or salt. The pollution does not exceed the pollution level II – medium according to Table 1 of IEC 60815.
- The ice coating does not exceed 34m/s (corresponding to 700 Pa on cylindrical surfaces).
- Account should be taken of the presence of condensation or precipitation.
- Vibration due to causes external to the switchgear and control gear or earth tremors are negligible.

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Appendix 4
Standards and Specifications

Table 25 – Standards and Specifications

Transformers			
	Northern Powergrid Specification	**External Design Standard**	**Climate Conditions**
Temperature			
Max Ambient Temp Outdoor			40°C
Max Ambient Temp Indoor			40°C
Min Ambient Temp Outdoor			-25°C
Min Ambient Temp Indoor			-5°C
Overload Ratings Ambient Temp			40°C
Solar Radiation			
Solar Radiation			1000 W/m²
Lightning			
Lightning Impulse LV	NPS/003/0111	ENA TS 35-1	8kV
Lightning Impulse 11kV			95kV
Lightning Impulse 20kV			Ground Mounted – 123kV Overhead Connected – 200kV
Lightning Impulse 33kV	NPS/003/012 NPS/003/021	ENA TS 37-5	Ground Mounted – 170kV Overhead Connected – 200kV
Lightning Impulse 66kV			350kV
Lightning Impulse 132kV			650kV

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Appendix 4
Standards and Specifications continued

Switchgear			
	Northern Powergrid Specification	**External Design Standard**	**Climate Conditions**
Temperature			
Max Ambient Temp Outdoor			40°C
Max Ambient Temp Indoor			40°C
Min Ambient Temp Outdoor			-25°C
Min Ambient Temp Indoor			-5°C
Overload Ratings Ambient Temp			40°C
Ice Loading			
Ice Loading Class			Class 10
Ice Loading			10mm
Solar Radiation			
Solar Radiation			1000 W/m²
Lightning			
Lightning Impulse LV	NPS/003/005	ENA TS 37-2	8kV
Lightning Impulse 11kV	NPS/003/006 NPS/006/014	ENA TS 41-34	95kV
Lightning Impulse 20kV	NPS/003/006 NPS/006/014	ENA TS 41-34	Ground Mounted – 125kV Overhead Connected – 200kV
Lightning Impulse 33kV	NPS/003/004	ENA TS 41-36	Ground Mounted – 170kV Overhead Connected – 200kV
Lightning Impulse 66kV	NPS/003/007 NPS/003/008	ENA TS 41-37	350kV
Lightning Impulse 132kV	NPS/003/007 NPS/003/008	ENA TS 41-37	650kV

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Appendix 4
Standards and Specifications continued

Overhead Lines			
	Northern Powergrid Specification	External Design Standard	Climate Conditions
Mechanical Design Ratings			
LV lines	NSP/004/041 & NSP/004/041/001	ENA TS 43-12	Wind Pressure: 380 n/m² Ice: 4.75mm diameter
11 – 33kV	NSP/004/042 NSP/004/044	ENA TS 43-40 ENA TS 43-121 BS EN 50341	Wind Pressure: Normal altitude = 380 n/m² High altitude = 570 n/m² Ice: Normal altitude = 19mm dia High altitude = 25mm dia
66kV – 132kV Wood Pole	NSP/004/045	BS EN 50341 ENA TS 43-50	Wind Pressure: Normal altitude = 380 n/m² High altitude = 570 n/m² Ice: Normal altitude = 19mm dia High altitude = 25mm dia
66 – 132kV Steel Towers	NSP/004/030	BS EN 50341 ENA TS 43-125 ENA TS 43-7	Wind Pressure: 380 n/m² Wind Speed: 25m/s Ice: Not < 60mm radial or 10mm radial (wind & ice)
Line Ratings			
LV lines 11 – 33kV 66kV – 132kV Wood Pole 66 – 132kV Steel Towers	IMP/001/011	ENA Eng Rec P27 (New weather model with new seasonal ambient temperature values) Once adopted this will change the rated values in IMP/001/011	Min line design temp: -5.6°C Max line design temp: 75°C Wind Speed: 0.5m/s Ambient Temperatures: Winter 2°C Spring/autumn 9°C Summer 20°C No longer considered

Appendices

Appendix 4
Standards and Specifications continued

Overhead Lines			
	Northern Powergrid Specification	External Design Standard	Climate Conditions
Lightning Performance			
LV lines			
11 – 33kV lines	IMP/001/909	BS EN 60071	Lightning Impulse: 11kV = 95kV 20kV = 125kV 33kV = 200kV
66kV – 132kV Wood Pole			Lightning Impulse: 66kV = 325kV 132kV = 650kV
66 – 132kV Steel Towers			Lightning Impulse: 66kV = 325kV 132kV = 650kV Shielding Angle: 45°
Transformers	IMP/007/011		Withstand Impulse Voltage Level kV 11kV = 95kV 20kV ground mounted = 125kV 20kV overhead mounted = 145kV 33kV ground mounted = 170kV 33kV overhead connected = 170kV 66kV = 325kV
Switchgear			Withstand Impulse Voltage Level kV 11kV = 95kV 20kV ground mounted = 125kV 20kV overhead mounted = 145kV 33kV ground mounted = 170kV 66kV = 325kV
Cables			Withstand Impulse Voltage Level kV 11kV = 95kV 20kV ground mounted = 125kV 33kV ground mounted = 194kV 66kV = 345kV

Appendices

Appendix 5
Innovation and Research Case Studies

A5.1 Drones

In 2018, Northern Powergrid began trialling the use of drones to monitor and survey the network within the line of visual sight. This proved to be successful and the use of drones has now become part of our business as usual process. All flights are carried out in line with appropriate Civil Aviation Authority legislation. The drones are employed in a number of ways both as a monitoring tool and an aid following major events.

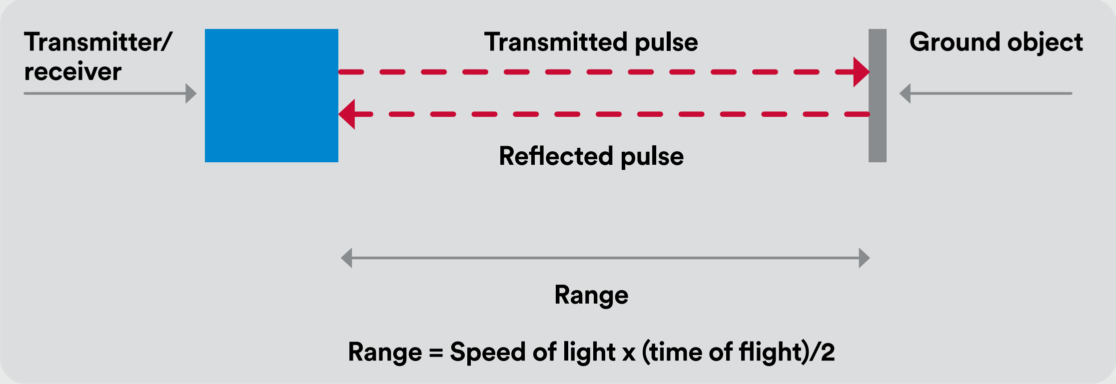
Monitoring of a Changing Landscape:
During a drone flight, many images can be captured which then allows 3D modelling to take place. We are currently monitoring overhead lines in Northumberland which are in close proximity to a river. The river bank is known to be eroding and we are capturing images so that we can ensure the safety of our assets and look to relocate if necessary.

Inspections During and After Major Events:
We employ drones to inspect lengths of overhead line for storm damage following a major event. This allows us to quickly locate any damage. Additionally, we use drones to monitor the situation at substations where there is a danger of flooding. This prevents any risks to staff from entering flood waters. Photos gathered on site can be transferred directly to the phone or tablet of the pilot, allowing key images to be shared at the earliest opportunity.

Figure 25 – Drone Footage of Overhead Line in Northumberland

Figure 26 – Drone Footage of Substation at Risk From Flood Water

Figure 27 – LiDAR



A5.2 LiDAR (Light Detection and Ranging)

Northern Powergrid has been exploring the use of LiDAR in order to carry out more effective and efficient clearance and vegetation management. A successful trial of the technology was carried out over a 300km² area of the network in the Rothbury area of Northumberland and we are now looking to implement the use of LiDAR as business as usual. LiDAR is a method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor.

The pulsed laser beam is reflected from objects such as buildings, poles, conductors, vegetation etc. The return pulses are recorded and the distance between the sensor and the object is calculated. The data produced is in a 'point cloud' format, which is a 3-dimensional array of points, each having x, y and z positions relative to a chosen coordinate system. The points can be colour coded, tagged or grouped into objects to facilitate the running of semi-automated processes to code and analyse distances from conductors to ground or other objects like vegetation or buildings.

Appendices

Appendix 5 Innovation and Research Case Studies

A5.2 LiDAR (Light Detection and Ranging) continued

LiDAR was initially considered to identify and deal with overhead line ground clearance issues. The option to employ for vegetation management is seen as a very effective side benefit for identifying vegetation encroachment.

Data from LiDAR surveys will be able to provide the following:

- Proximity Zones: Client-defined clearance profiles modelled around the network and powerline conductors and pole objects to assess and model the distance and volume of any vegetation encroachments.
- Encroachment Assessment: Model of vegetation identified within proximity zones including encroachment attributes such as distances and volumes.
- Risk Analysis: Risk report and map of areas requiring treatment by network spans (e.g. pole to pole) or management regions; set by client-defined standards for encroachment and risk category.

Access to LiDAR data acquired through flying the complete network at the beginning of each major cutting phase should provide vegetation management contractors with the opportunity to prioritise the cutting responses, as currently the network is surveyed in a serial manner with permissions and cutting following on accordingly. This serial approach inevitably results in higher priority cutting being missed as the contractor may not be aware of its urgency until the network receives its first vegetation inspection (on foot).

Use of LiDAR will provide an overview of the whole network in respect to the following clearances:-

- Conductor to ground
- Conductor to roads
- Conductor to buildings/objects
- Conductor to vegetation

In the case of the first three sets of clearance data, as vegetation is not involved, the issue of clearances will be fairly static as there either is an issue or not. Once a list of inadequate clearances is defined a programme of work can be established to work through and correct them.

Clearances to vegetation, however, require a totally different intervention frequency as trees and shrubs are growing constantly and therefore the clearances continue to decrease until, and indeed after, they are cut. This means the process will need to be repeated, thereby requiring more frequent inspections with LiDAR than the first three clearance types.

Appendices

Appendix 5 Innovation and Research Case Studies

A5.3 OHL Ratings

Distribution overhead line ratings are based on CEGB research work and further assumptions described in ENA ACE 104 and ENA ER P27 published nearly 30 years ago. Recent work testing these assumptions has found some of them to be erroneous, with the result that existing distribution line ratings are now considered out of date. In the meantime, changing demands on networks are increasing the pressure to maximize overhead line capacity. In addition, existing ratings take no account of regional differences in climate, nor of any changes in climate that may have occurred over the last 30 years. Taken in conjunction, this means that load-related decisions to replace or reinforce lines are currently based on inaccurate ratings. Future climate change is predicted to put further pressure on line capacity. Distribution Network Operators (DNOs), therefore, need a cost-effective, up-to-date and robust methodology (supported with the necessary tools) for calculating and optimizing overhead line ratings at both the regional and line specific level, both for today and the future.

A previous DNO collaborative project under the Innovation Funding Incentive established an overhead line test rig to monitor weather conditions and temperatures of different conductors at various current levels. A second project was undertaken by WPD – "Improved Statistical Ratings for DNO Overhead Lines" (Ref. 41 WPD_NIA_008) [N2] – which set up a test rig at WPD's Stoke depot, and over a period of 24 months, the temperatures of a number of All Aluminium Alloy conductors were monitored and recorded. The test rig comprised four separate circuits, each continuously energised to give a range of design temperatures representative of the UK's distribution networks. The data captured assisted in determining an up-to-date, robust, statistical relationship between thermal ratings and the risk of a temperature exceedance which would be applicable to all UK distribution networks. A revision to EREC P27 has now been issued which employs the findings taken from the test rig, and provides data to enable a Network Operator to more accurately decide an appropriate rating for any distribution overhead line. A stand-alone computer program is also available to assist in assessing ratings.

A5.4 Small Section Conductor

Evidence suggested that we were experiencing a high volume of 11kV and 20kV overhead line faults due to the failure of cadmium copper (CaCu) conductors. 13mm/.017" CaCu conductors are unique to the Northeast area; where there is circa 4,863km of this conductor installed on the 11/20kV overhead line network, representing circa 49% of the total length of installed conductor. The following observations have been made:

- CaCu was used on the Northeast network from 1939 until 1989. It was initially used with oak crossarms, then later with steel crossarms when BS1320 construction was introduced in the 1950s to facilitate the electrification of the network.
- CaCu lines were typically constructed with twice the span lengths allowed by modern line designs and often used light grade poles rather than medium grade poles. This means that rebuilding these lines to modern standards typically requires them to be interpoled with its subsequent wayleave implications.
- CaCu lines were originally constructed using narrow crossarms. In combination with the long spanning, this led to a very poor clashing performance, often resulting in damaged or broken conductors.
- A CaCu conductor has a UTS value of 7,918N and compares with 6,761N for 16mm HDBC, 12,989N for 32mm HDBC and 17,660N for 50mm AAAC. By modern design standards, 50mm AAAC is the weakest which could withstand heavy ice loading conditions. When CaCu does break, its relatively low UTS tends to result in limited or no related pole failures, allowing faults to be quickly resolved. Unfortunately, this ease of repair has resulted in a large number of automatic joints (non-compression) being installed into the system which have subsequently proven themselves to be very unreliable when subjected to ice load shedding conditions.
- CaCu lines tend to be located in scarcely populated rural locations which mean they impact a limited number of customers. However, these faults can sometimes be off for long periods due to access restrictions in bad weather.

A line strengthening work program made a step change in the reliability of light lines. The combinations of wider crossarm installations and/or the use of limited contact spacers have removed the majority of conductor clashing faults. As a result, conductor breakages are now generally restricted to heavy icing events or the failure of automatic mid-span joints. It is still an old asset and we can expect pole failures but that's nothing to do with the installed conductor type.

A 2018 study considering failure rates of CaCu conductor shows that it is comparable with other conductor types, with line strengthened circuits performing well. However, it is recommended that we re-enforce the need for the replacement of all auto midspan connectors installed in this conductor type and that we consider the replacement of circa 5% of network where the basic span is >100m and the line is located >270m above sea level.

Appendices

Appendix 5 Innovation and Research Case Studies

A5.5 Self-Sealing Cables

Northern Powergrid has participated in a project funded under the Network Innovation Allowance to develop and test an additive to cable oil that allows Self-Sealing of certain leaks. This project was carried out in collaboration with UK Power Networks, the Energy Innovation Centre and Kinectrics. The objective of the project was to develop a new cable fluid that can seal itself when exposed to air and to demonstrate that Self-Sealing Cables are suitable for use in commercial, large-scale projects. To date an additive has been identified and taken through laboratory tests and field trials within the Northern Powergrid region are to take place.

The additive is made from Tung oil which is used in wood finishing, wood waterproofing caulking, inks and paints. The primary constituent is a fatty acid with a chain of 18 linked carbon atoms or methylene units containing three conjugated double bonds. They are especially sensitive to autoxidation which encourages cross linking of neighbouring chains and hence hardening of the base resin. Tung oil cures upon exposure to air within 24 to 48 hours and is environmentally safe and sustainable. It does not change the properties of the cable oil in a sealed airtight system.

Once this system has been proven to work, it can be considered for rollout as part of our programmes of work. This will provide environmental protection against cable leaks and will improve the reliability of our cables.

A5.6 Foresight

The Foresight project aimed to improve our understanding of indicative pre-fault behaviour of low-voltage (LV) cable networks and our ability to develop management options for it.

Northern Powergrid has a population of networks based on Consac and Aluminium waveform cables which are more prone to some particular fault types than other cables. This project focused on these to observe real, active pre-fault behaviour. The intended outcome was that the learning would reduce the level of technology deployment required to capture faults and contribute to keeping project costs down. The learning developed is relevant to all types of LV cable networks and their management.

As a result of mature cable designs installed over the last 50 years, LV fault management is becoming increasingly difficult. Restoration times can be lengthy, as the majority of the LV network is neither comprehensively monitored nor controlled automatically. Responses to faults tend to be reactive as the condition of LV cable systems at any point in time is unknown and there is no capability of predicting the timing and location of faults before the event.

Northern Powergrid intends to reduce the number and duration of customer interruptions, where possible taking action before network issues impact customers. Foresight is an extensive programme of work that developed and tested a low-cost sensing system to enable active and sophisticated remote monitoring of the LV networks, the identification of developing LV faults, and locating those potential defects which are likely to develop into LV faults. The intention was to achieve this identification and intervention before supply interruptions occur with their consequent impact on customers.

The programme of work included development of equipment and field trials with the aim of verifying the efficacy of the system, identifying any practical ‘business as usual’ issues associated with wide-spread deployment of the system and to identify associated costs. The development of such a system will also require changes in operational practice to facilitate the change from reactive to proactive management. The trial will identify the changes needed and the practicalities of implementing those changes.