SSE Power Distribution

(including: Scottish Hydro Electric Transmission)

Climate Change Adaptation Report

Appended Version 3.1, June 2011

This document specifically produced by SSE Power Distribution encompasses, qualifies and expands on the Climate Adaption Report produced by the Energy Networks Association for Electricity Transmission and Distribution Companies.

Where a response is required, this is shown opposite to the corresponding position of the ENA response in blue border.

Adaptation to Climate Change Task Group

Electricity Transmission and Distribution Network Companies

Climate Change Adaptation Report

Final Draft Version 5
21 January 2010

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1 Executive Summary

SSE Power Distribution (SSEPD) believes the management of network assets requires constant review and revision to reflect changing technology, regulatory requirements, network demands and environmental variables.

These principles, amongst others, are reflected in our **Asset Management System**. SSEPD have now been accredited to **BSI PAS 55 - Asset Management** for the past 4 years

The management of risk from climate related events has been central to SSEPD for a considerable period of time. SSEPD have been early adopters of many practices that have over the years resulted in an increasingly resilient network as can be demonstrated by the dramatic improvements in network performance over the last 10 years.

Examples of these early adoptions include:

- Covered Conductor (termed BLX) on High Voltage overhead wood pole lines.
- Aerial Bundled Conductor on Low Voltage overhead wood pole lines.
- Adoption of cable ploughing techniques to improve the economics and environmental impact of underground cable laying.
- Network automation and storm management systems, for example, have also enhanced our ability to respond to extreme weather events that are likely to typify climate change.

It is recognised that there is a high probability of climatic change over the next 100 years but it must also be recognised that assets have a life varying from 25 to 80 years and as such, in conjunction with appropriate mitigation, the need to replace assets purely for climate change is relatively low.

When assets are replaced SSEPD aim to ensure that the replacements conform to the latest standards. In addition where relatively low cost changes can assist with the mitigation of potential impacts SSE will adopt these practices as a matter of course, examples of this include the specification of lightning protection and the level of ground clearance built into the construction of new overhead lines in arable ground.

We have, and will, continue to maintain a flexible and diverse range of research and development work to forecast prepare for and mitigate against climate change both as SSEPD and in collaboration with the rest of the sector. This approach allows the re-assessment of migration risks (as future information on climate change is realised) to be factored in to our Asset Management Strategy at an early stage.

In conclusion SSEPD have a good understanding of the risks associated with climate change. The management of these risks is already embedded into our Asset Management System. Should climate change accelerate then SSEPD would strive to modify or re-design assets during the maintenance cycle.

1. Executive Summary

Energy Networks Association (ENA) is the industry body for UK wires and pipes companies that carry electricity and gas to UK homes and businesses. This ENA Engineering Report (ERep) has been developed in response to the requirements placed on Reporting Authorities by the Climate Change Act and concerns:-

- Identification of climate change impacts on the functions of licensed electricity distribution and transmission companies
- Proposed mechanisms for monitoring and actions to respond to the likely impacts of climate change "adaptation".

This "core" assessment has been prepared by a task group of electricity distribution and transmission network operator members of ENA. The task group included the Department of Energy and Climate Change (DECC) and received inputs from the Office of Gas and Energy Markets (Ofgem), Defra, Environment Agency (EA), the Met Office and other organisations.

This ERep follows the structure set out by Defra and considers those issues that are common to companies across the UK. It is intended that companies can use this ERep as the basis for their individual reports which will also include company specific information. This ERep does not address the means by which risk is managed within member companies, which will be dealt with within their individual reports.

Transmission and Distribution companies in Great Britain are regulated businesses and operate under licences issued by Ofgem and are also are subject to common statutory requirements which are overseen by DECC and the Health and Safety Executive (HSE). Allowed revenues for the industry are currently set by Ofgem every five years and therefore any costs associated with Adaptation to Climate Change (ACC) would need to be agreed with Ofgem.

Transmission and Distribution companies are responsible for transporting electrical power from generating plants to customers over their extensive networks. These networks comprise a mixture of overhead lines and underground cables and include points on the system called substations, where voltage transformation takes place and switching and control equipment are located.

Overall levels of supply security are agreed by Ofgem and these 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.

Whilst every effort is made to ensure network security, companies have 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 Network Operators are Category 2 responders and work closely with other Utilities, The Emergency Services and Local Authorities. They are also active participants in the DECC Energy Emergencies Executive Committee (E3C).

Electricity transmission and distribution systems are made up of many different types of equipment including overhead lines, cables and transformers, which all comply with appropriate British and International Standards. These standards are also used in parts of the world which already experience the climatic conditions predicted for the UK. Consequently it is expected that these existing standards may provide the appropriate functionality for the changes forecast for the UK during this century.

Electricity Network Companies across the UK have experience in operating in a range of weather conditions and have always used the latest information when considering current threats and potential climate change impacts. For Climate Projections this was initially UKCP02, which was used by the Met Office in a report commissioned by energy companies and published in 2008. The report, EP2, investigated the potential impact of climate change on energy companies. UKCP02 has now been superseded by UKCP09, which is used in all current research.

The EP2 Report was a groundbreaking initiative that brought climate science closer to business applications. This was the first project sponsored by an entire sector to review the specific impacts of climate change on their industry. Supported by climate scientists, experts from the industry worked together to understand their precise requirements and developed practical applications and business strategies for a changing world.

Further work has recently been commissioned with the Met Office to build a risk model that quantifies the relationship between climate and network faults, and also the vulnerability and exposure of the network to these faults. This model can be driven with climate projections to assess how network resilience may be affected by climate change.

This ERep considers all other available evidence from a variety of sources including EA, SEPA, Cranfield University, UK Climate Impacts Programme (UKCIP) and those involved in the National Climate Change Risk Assessment programme.

The main impacts on electricity networks from the current climate change projections are:

- Temperature—predicted increase.
- Precipitation—predicted increase in winter rainfall and summer droughts.
- Sea level rise—predicted increase.
- Storm surge—predicted increase.

At present there is no firm climate change evidence to support increased intensity of wind or ice storms both of which can cause extensive damage to overhead electricity networks.

The ERep considers each component of Transmission and Distribution Systems and uses current industry techniques to calculate the effects of climate change to 2099.

For example in the case of overhead lines, the maximum current that can be carried (known as the rating) reduces as the ambient temperature increases. This ERep presents calculated reductions in rating for Low, Medium and High emission levels to 2099. In the case of overhead distribution lines the maximum current is reduced by typically 10% and for transmission lines by typically 3%. A similar approach is taken for underground cables and transformers.

Table 1 - Typical reductions in asset capacity for High Emissions at 90% Probability Level

Typical reductions in asset capacity for High Emissions at 90% Probability Level		
Equipment		UKCP09 Period 2070 - 2099
Overhead lines	Transmission	3%
	Distribution	10%
Underground Cables	Transmission	5%
	Distribution	4%
Transformers	Transmission	5%
	Distribution	7.5%

A reduction in capacity can be seen as equivalent to an increase in load and these are relatively small capacity reductions compared with recent historical load growth.

Increased precipitation, sea level rise and storm surge can all lead to flooding and the report considers the consequent risks. There has been recent experience of flooding in the North East, South Midlands and South Yorkshire during the summer of 2007 and Carlisle in 2005 which all highlighted the potential vulnerability of electricity substations to major flood incidents from current levels of flooding. In response to the floods and subsequent reports a Task Group was established to develop an industry response to flooding risk.

Photograph 1 - An electricity substation protected by flood barriers in the 2007 floods in the North East of England

The Task Group which comprised representatives from Networks Companies, DECC, OFGEM, EA, SEPA, Met Office and the Pitt Review Team produced ENA Engineering Technical Report 138 (ETR 138). The report was accepted by E3C and companies have begun a circa ten year programme of work to improve substation resilience to flooding.

ETR 138 is based on current flood risk and also provides an allowance for climate change adaptation and this will be improved by new data being made available by EA. The essential aspects of ETR 138 dealing with adaptation are also dealt with in this ERep.

The ERep also considers possible impacts from:-

- Drought and the potential impact on safety electrical earthing systems.
- Accelerated vegetation growth and its impact on overhead line performance.

Other possible impacts are also reviewed including, electricity markets, finance, logistics and staff absence. Reference is also made to potential relationships with items on the National Risk Register.

As required by the Defra guidance this ERep includes a risk matrix showing the relative likelihood and impact of all the identified risks and this is included in the Executive Summary for easy reference.

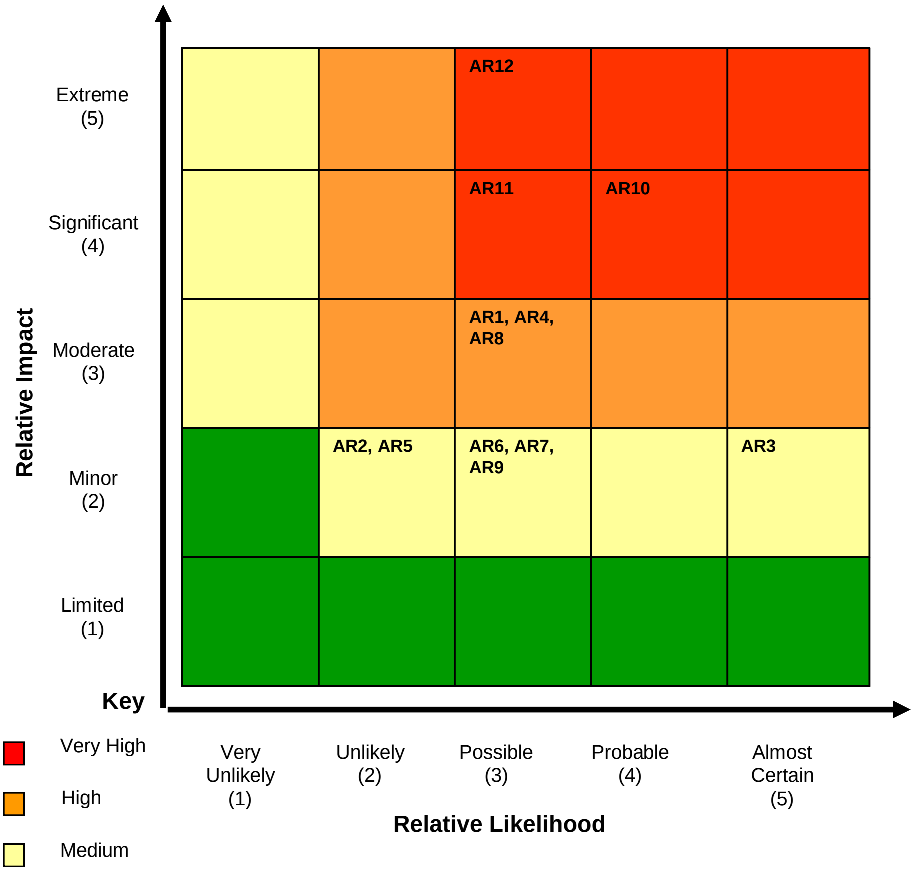
This ERep sets out all these issues in some detail and makes proposals for adapting networks to climate change effects within the business planning cycle.

Finally, the ERep deals with the main uncertainties and assumptions in the development of this adaptation programme.

In addition to adaptation to climate change, there are also a wide range of activities being pursued by Government and society in general to "mitigate" climate change by reducing-greenhouse gas emissions in order to slow the rate of global warming.

These mitigation actions will have significant effects on electricity networks. The changes that will be needed to electricity networks to transform them into smart, low carbon networks may also address a number of the climate change adaptation requirements.

Risk Matrix (if no adaptation measures taken)



AR1 Overhead line conductors affected by temperature rise, reducing rating and ground clearance.
AR2 Overhead line structures affected by summer drought and consequent ground movement.
AR3 Overhead lines affected by interference from vegetation due to prolonged growing season.
AR4 Underground cable systems affected by increase in ground temperature, reducing ratings.
AR5 Underground cable systems affected by summer drought and consequent ground movement, leading to mechanical damage.
AR6 Substation and network earthing systems adversely affected by summer drought conditions, reducing the effectiveness of the earthing systems.
AR7 Transformers affected by temperature rise, reducing rating.
AR8 Transformers affected by urban heat islands and coincident air conditioning demand leading to overloading in summer months.
AR9 Switchgear affected by temperature rise, reducing rating.
AR10 Substations affected by river flooding due to increased winter rainfall.
AR11 Substations affected by flash flooding due to increased winter rainfall.
AR12 Substations affected by sea flooding due to increased sea levels and/or tidal surges.

Low = updated specification of new assets, Med = Minor up-rating
High = Major up-rating, Very high = specific replacements

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

2. Foreword

ENA is the industry body for UK wires and pipes companies that carry electricity and gas to UK homes and businesses.

This "core" assessment has been prepared by a task group of electricity distribution and transmission network operator members of ENA which also included government regulators with inputs from Defra, EA, the Met Office and other organisations.

The assessment is in response to the requirements placed on Reporting Authorities by the Climate Change Act. This assessment concerns the identification of climate change impacts on the functions of licensed electricity distribution and transmission companies and the proposed mechanisms for monitoring and actions to respond to the likely impacts of climate change; "adaptation".

Although companies have to provide individual reports to Defra, this assessment considers those issues that are common to companies across the UK. Because of national equipment designs based on International, European and British Standards, many of the issues of Climate Change Adaptation are common to all companies. Companies can use this ENA report as the basis for their individual reports which will also include any company specific information.

Defra has issued statutory guidance to Reporting Authorities which includes instructions on the content of company reports. This report follows the structure set out by Defra in the Guidance.

In addition to adaptation to climate change there are also a wide range of activities being pursued by Government and society in general to "mitigate" climate change, by seeking to slow down global warming by reducing greenhouse gas emissions. Examples include:

- Measures to increase the amount of renewable generation connected to the electricity system
- De-carbonising transport through take-up of electric road vehicles and trains
- De-carbonising heating through energy efficiency, use of solar heating and heat pumps

These mitigation actions have significant knock-on effects to electricity networks. The DECC and Ofgem joint chaired Energy Networks Strategy Group (ENSG) and work by Imperial College London with ENA provide useful background[1]. The latter has pointed to a doubling in UK electricity peak demand from some 60GW to almost 120 GW if "smart" network technologies are not employed to intelligently control and time shift demands. It is not the purpose of this adaptation report to cover this subject, though the changes that will be needed to electricity networks to transform them into smart networks will also serve to address a number of the climate change adaptation requirements. These are discussed further in section 7.1 of this ERep.

[1] These documents are available at http://2010.energynetworks.org/smartmeters/

3. Functions impacted by climate change

3.1. Electricity Network Companies' organisation's functions, mission, aims, and objectives

3.1.1. 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 and operate under licences issued by Ofgem and are subject to a common Regulatory Framework set by Ofgem. They also are subject to common statutory requirements including The Electricity Act and Electricity Safety Quality and Continuity Regulations (ESQCRs) which are overseen by DECC and the HSE.

As a consequence of these common drivers, UK Electricity Network Operators have worked together for many years across a wide range of activity including:

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

This basis of a common background, asset standards and regulatory processes means that UK Electricity Network Operators 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 °C, can be established using common methodology, as set out in this report.

Allowed revenues for the industry are currently set by Ofgem with individual Network Operators every 5 years and these reviews govern all expenditure which includes resilience against natural hazards and emergency planning. This provides common oversight and accountability to Ofgem and DECC.

Therefore any costs associated with Adaptation to Climate Change (ACC) would need to be discussed with and allowances set by Ofgem. This would include costs directly associated with the network, e.g. overhead lines, underground cables and substations. It would also include costs linked to the supply chain and "softer" issues concerning potential climate impacts on staff.

3.1.2. Description of Networks

In the UK, electrical power is transported from generating plants to customers over networks managed by Transmission and Distribution companies. The Transmission System operates at typically 400,000volts (400kV) or 275kV (and 132kV in Scotland) and the Distribution system operates at voltages from 132kV to the normal household voltage of 230V. This is shown diagrammatically below.

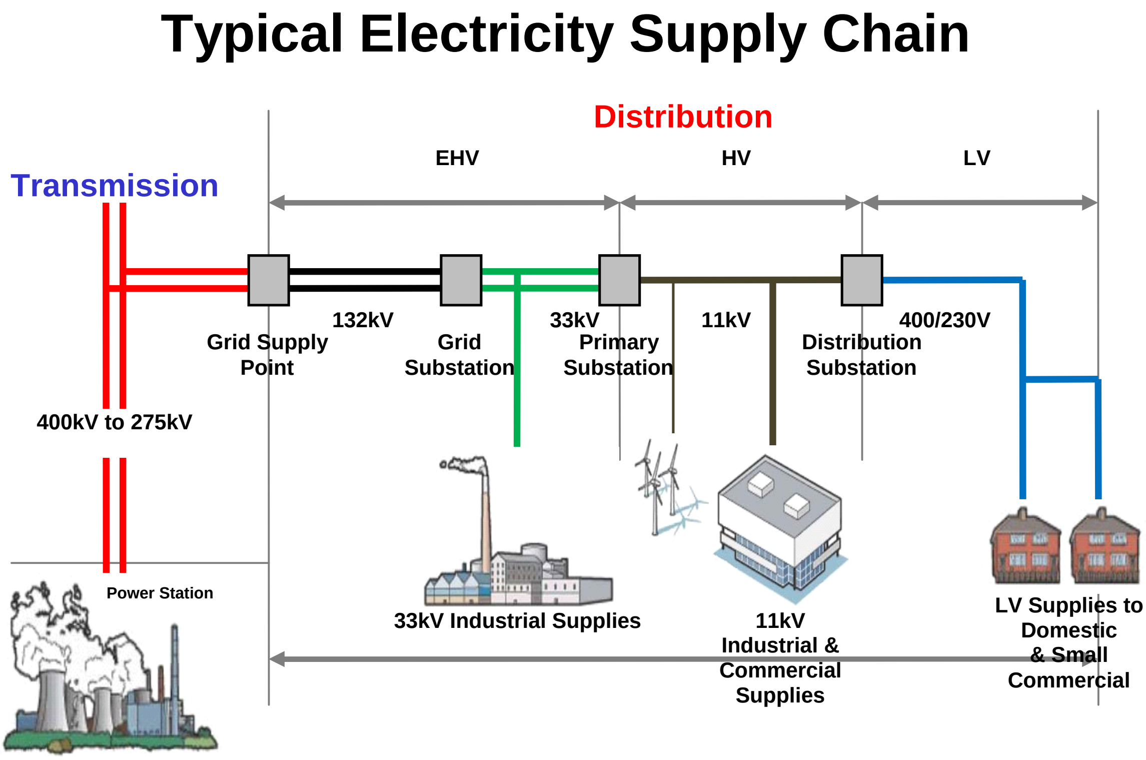


Figure 1 - Typical Electricity Supply Chain

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.

In England and Wales, National Grid own and operate the Transmission System and the interface between transmission and distribution systems takes place within grid substations at 132kV. In Scotland the Transmission Networks are owned by Scottish Power and Scottish and Southern Energy but operated by National Grid and the interface between transmission and distribution systems takes place within grid substations at 33kV.

The characteristics of different types of substation are described in Table 2 below and the photographs in Appendix 1 illustrate the substations and overhead line connections. Circuit lengths are shown in Appendix 2.

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.

Table 2 - Types of Electrical Substation

Substation Type	Typical Voltage Transformation Levels	Approximate number nationally	Typical Size	Typical Number of Customers Supplied
Grid	400kV to 132kV	380	250m by 250m	200,000/500,000
	132kV to 33kV	1,000	75m by 75m	50,000/125,000
Primary	33kV to 11kV	4,800	25m by 25m	5,000/30,000
Distribution	11kV to 400/230V	230,000	4m by 5m	1/500

3.1.3. Levels of service

The Grid Code covers all material technical aspects relating to connections to, and the operation and use of, the GB electricity transmission system and is approved by Ofgem.

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

Overall levels of supply security are agreed by Ofgem and contained in:

- Transmission systems
  The National Electricity Transmission System Security and Quality of Supply Standard
- Distribution Systems
  ENA Engineering Recommendation P2/6 in England and Wales and Scottish Distribution Planning Standard (mirrors P2/6)

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.

As part of the current 5 yearly price review process, Ofgem sets standards of service targets for companies which directly relate to the reliability of supply experienced by connected customers. These targets include:

Guaranteed Standards covering

- Payments to customers without supply for more than 18 hours.
  (Subject to exceptional event exclusions such as storms)
- Payments to customers suffering frequent interruptions.
- Financial incentives/penalties for companies covering performance against targets for the number and duration of supply interruptions experienced by customers.

The aim of this report is to set out a managed mechanism for adapting to climate change which allows companies to continue to deliver the reliability of supply currently expected.

3.1.4. International and National Standards

As mentioned above, electricity transmission and distribution systems are made up of many different types of equipment including overhead lines, cables and transformers. Current equipment complies with appropriate International and British Standards (see appendix 5).

Given that more onerous climate conditions than those predicted in the UK are already being experienced now in parts of the world where these standards apply, it is apparent that the assets built to these standards will be able to remain in service, albeit with a potentially reduced capacity, even allowing for the changes forecast for the UK by 2100.

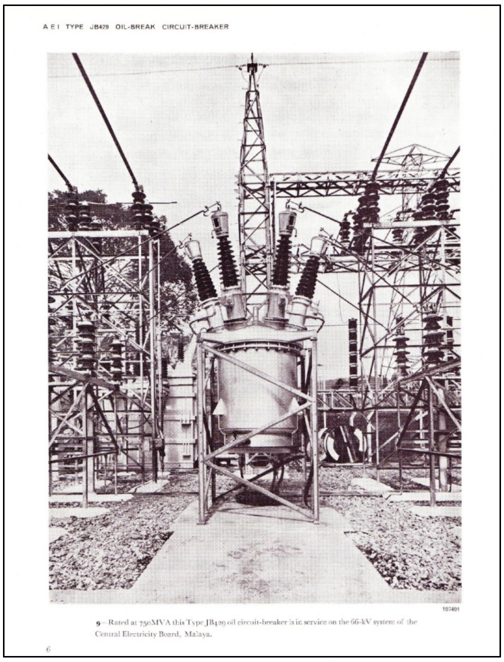
Equipment in the UK normally complies with industry standards that have been developed and enhanced over many years to ensure that UK networks are built using high specification, safe equipment that is fully interchangeable and can be installed and operated in a similar manner across the UK.

These industry standards and engineering practices have been established over the years through ENA and predecessor organisations and therefore, because UK networks are built on a common basis, they will all experience similar impacts from similar changes in climate. This underlines the reason for a common approach to national issues in adaptation.

The production of new ENA documents and the updating of existing documents is covered by an agreed process involving ENA transmission and distribution network operators. Some ENA documents are annexed or are appendices to the Grid or Distribution codes and therefore any modifications are subject to governance by the Grid or Distribution Code Review Panels.

The development and review of National and International Standards is subject to well established procedures and UK electricity network operators, via ENA, have experience of leading and influencing this work through BSI and European and International standards organisations.

The photographs below show equipment installed in different environments and over some 40 years during which time the relevant standards have evolved.



Photograph 2 - EHV 1950s UK manufactured oil circuit breaker (similar to that still operated in the UK) in service in Malaysia where ambient temperature can exceed 30°C

Photograph 3 - 132kV Grid Transformer and circuit breakers in service in the UK

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3.1.5. Emergency Planning

Emergency planning issues of shared interest to the government, industry and the regulator are reviewed and managed through the framework of the Energy Emergencies Executive (E3). The Executive is made up of a senior representative from DECC, 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, DECC and Ofgem. The committee 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.

Whilst every effort is made to ensure network security, network companies have well developed emergency plans to ensure an effective response to a range of events that can affect both Transmission and Distribution networks. Overhead line systems are susceptible to severe weather conditions such as wind storms and lightning and consequently companies are required to implement their emergency response procedures on a regular basis which ensures they are tested and practiced. These plans also cover other incidents such as flooding. Customer communication for problems affecting customers' supplies is the responsibility of Distribution Network Operators and they have sophisticated telephony systems that are capable of answering very large numbers of simultaneous customer calls. Through ENA, Network Operators, meet regularly to review emergency planning and response arrangements covering issues ranging from wind storms to flu pandemics.

Network companies are all members of a mutual aid consortium called the "North East West South Area Consortium" (NEWSAC). In an emergency, affecting one or more member companies, the NEWSAC group representatives will assess the availability of resources from those companies least affected and agree the allocation of these resources based on the level of damage. The NEWSAC agreement has been in place and utilised over many years, most recently during the 2007 floods when CE Electric received assistance from ScottishPower and Central Networks.

Under the terms of the Civil Contingencies Act Network Operators are Category 2 responders and work 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 ESQCRs already includes powers for the Secretary of State in relation to continuity of supply, including powers to give directions for preserving security of electricity supply. The Minister twice exercised these powers in 2002 in the setting up of independent reviews of "Resilience of the Electricity Supply Industry".

However, whilst Emergency Planning is vital for managing serious incidents it is not appropriate for controlling climate change risks.

3.2. Effect of current and possible future impacts of climate change

3.2.1. Current Position

Electricity Network Companies across the UK have experience in operating in a range of weather conditions and have always used the latest information when considering current threats and potential climate change impacts. For Climate Projections this was initially UKCP02 which has now been superseded by UKCP09 (see below). Other information included:

- ENA Engineering Technical Report 111 which provides the theoretical background to the data and diagrams produced in Technical Specification 43-40 (Specification for single circuit overhead lines on wood poles for use at high voltage up to and including 33 kV). ETR 111 quantifies appropriate snow accretion loadings on overhead lines in different areas of the UK.
- Department of Energy – 'Review of Technical Standards for Overhead Lines following Storm Damage in December 1981 and January 1982' – the Baldock Report.
- COST 727, a European project addressing the measurement and forecasting of atmospheric icing on structures.

To address these matters, companies have adopted a common approach, usually through ENA, and therefore have considerable experience in successfully managing issues in this way.

3.2.2. UK Climate Projections

The UK Climate Projections (UKCP09) provide climate information for the UK up to the end of this century. Projections of future changes to our climate are provided, based on simulations from climate models.

The Projections show three different scenarios representing high, medium and low greenhouse gas levels. The types of climate information provided are:

- observed climate data (20th and 21st century historical information about temperature, precipitation, storminess, sea surface temperatures and sea level)
- future climate projections (for temperature, precipitation, air pressure, cloud and humidity)
- future marine and coastal projections (for sea level rise, storm surge, sea surface and sub-surface temperature, salinity, currents, and waves).

3.2.3. Impact on electricity networks

The table below shows possible current and future impacts different types of climate change event on network components or services.

Table 3 - Possible current and future impacts of climate change

Climate Change Risks		Network Component/Function at Risk													
Risk Type	**Specific Risk**	**Substations**	**Transformers**	**Circuit Breakers**	**Overhead Lines**	**Cables**	**Protection**	**Earthing**	**Logistics**	**Vegetation Management**	**Spares**	**Resources**	**Communications**	**Operations Centres**	**Customer Service**
Extreme Events	Flooding (Fluvial)	H	M	M	L	NE	H	NE	M	NE	M	H	M	M	H
	Flooding (Pluvial)/ Heavy Rain	M	M	M	L	NE	M	NE	L	NE	L	M	L	L	M
	Flooding (Sea Breach including erosion risks)	H	M	M	L	NE	H	NE	M	NE	M	H	M	L	H
	Dam Inundation	H	H	H	H	NE	H	NE	M	NE	NE	L	L	L	L
	Ice & Wind	L	L	L	H	NE	NE	NE	H	H	NE	H	H	L	H
	Hurricane and other high wind events	L	L	L	H	NE	NE	NE	H	H	NE	H	H	M	H
	Extreme prolonged temperature periods	L	M	L	M	M	NE	NE	L	L	NE	H	H	M	H
	Lightning	M	M	L	H	NE	NE	NE	NE	L	NE	NE	NE	NE	NE
Gradual Warming	Temperature Increase	NE	L	L	L	L	NE	NE	NE	M	NE	M	M	NE	NE
	Drought (Soil Drying and Movement)	M	L	L	M	L	L	M	NE	M	NE	NE	L	NE	NE
	Demand increase due to Mitigation and HVAC	NE	H	NE	H	H	NE	NE	NE	NE	NE	L	NE	NE	NE

H = High Impact, M = Medium Impact, L = Low Impact, NE = None Expected

High Network component/function temporarily disabled. Function severely disrupted.
Medium Network component/function substantially reduced in capacity or damaged. Function disrupted.
Low Network component/function reduced in capacity or suffers minor damage. Function suffers minor disruption.

However, this report focuses on the main impacts on electricity networks from the current climate change projections which are:

- Temperature—predicted increase.
- Precipitation—predicted increase in winter rainfall and summer droughts.
- Sea level rise—predicted increase.
- Storm surge—predicted increase.

The potential impacts are described briefly below and are covered in more detail this section. Other potential climate impacts are discussed in Section 3.2.7.

3.2.4. Temperature effects

Electrical current passing through electrical plant causes the equipment to heat up. The maximum current rating of electrical plant is generally governed by the equipment's maximum permissible operating temperature. This temperature is usually determined by the type of conductor/insulation material involved but there may be other considerations.

For example:

- the sag of overhead line conductors increases with temperature and this could compromise statutory ground clearances if too much sag occurs
- ambient air temperature affects soil temperature which in turn affects its ability to conduct heat away from underground cables.

Once the ambient and maximum temperatures in which the equipment is operating are agreed, the maximum temperature rise is set and this determines the amount of current that a given piece of equipment can carry. Clearly, if the ambient temperature increases the available temperature rise decreases and the maximum current rating is reduced.

3.2.5. Precipitation

Increased winter rainfall will result in increased river flow rates and a potential increase in flood levels. Overhead lines and underground cables are generally not susceptible to flooding but there is a potential for statutory safety clearances to be affected in flood conditions. However, the type of equipment operating at substations can be vulnerable to flooding if water reaches certain critical depths. The loss of supply incidents in 2007 in Yorkshire and Gloucester all occurred as a result of substation flooding when the exceptionally high water levels reached critical depths at some substations.

Increased rainfall also brings the risk of surface water and ground water flooding which could again threaten substations.

Summer drought conditions can lead to a reduction in the ability of the ground to conduct heat from underground cables. This can result in the maximum current rating of cables being reduced or cable faults developing that could interrupt customers' supplies if cables are allowed to operate at higher temperatures. This latter issue can be a particular concern for higher voltage cables.

Droughts can also lead to ground movement that may damage underground cable systems or structures.

3.2.6 Sea Level Rise and Storm Surge

SSEPD do no see any significant threats from sea level rise or storm surge with the exception of some specific sites in the North and West of Scotland for which contingency plans are in place.

Account will be taken of environmental changes when assets are being renewed to ensure adequate protection is provided.

The major 1953 North Sea storm surge did not significantly affect either the South or the North of Scottish and Southern Energy's geographical area. Hence it is unlikely that any similar storm surge will present any issues.

3.2.7 Other Climate Treats

In addition to ice storms a predicted increase in atmospheric moisture could lead to more Rime (in-cloud) icing events occurring in Scotland. This could lead to failures of lines constructed to early post-war designs using small diameter conductors. Severe icing on lines with a larger diameter conductor could see them being switched out due to low ground clearance. New designs for transmission circuits allow them to operate under ice loading whilst still maintaining a safety clearance, these standards are being adopted for new construction work.

The installation of covered high voltage conductors in the South, low voltage insulated conductors and the lightning protection enhancements in the South and North are already showing benefits in reducing lightning damage.

It is not clear if lightning strike intensity will increase, if so this could lead to an increase in localised damage. This would be captured by our existing and planned investment in advanced automation such as the Pulse Closing Protection installed on the Isle of Wight.

As a general precaution against lightning damage SSEPD took the option, at no increase in overall cost, to standardise on class 2 surge arresters which give better overall protection on our wood pole overhead lines.

3.2.6. Sea Level Rise and Storm Surge

These types of incident would have a similar effect to river flooding except the volumes of water are potentially far greater with more widespread flooding, greater damage to infrastructure and a longer recovery period.

3.2.7. Other Climate Threats

The most common current weather threats to electricity networks are wind storms, lightning and to a lesser extent ice accretion. Wind storms and ice accretion have the potential to cause widespread devastation and there are recent examples across the world of extensive damage to electricity infrastructure.

- **Wind Storms**

  Widespread interruptions to customer supplies have occurred on a number of occasions including in 1987, 1990, 1997, 1998 and 2002. Although this type of incident can be very disruptive, repairs can normally be carried out relatively quickly and most customers' supplies are usually restored within a few days apart from more remote rural areas. However there have been two recent incidents in France where restoration times were extended due to the extent of the damage.

- **Ice Storms**

  There is limited recent experience of ice storms in the UK, with incidents occurring mainly in Scotland and Northern England, but they have the potential to interrupt customers' supplies for longer periods than wind storms and there have been a number of incidents abroad notably affecting Canada in 1998. The photographs below show the effect of icing on an 11,000 volt rural overhead line in North West England in January 2010, with ice accretion on the conductors and a broken pole.


- **Lightning**

  Lightning storms are regular occurrences in the UK and can damage overhead lines and connected equipment. Distribution circuits are more difficult to protect against lightning and generally suffer more damage than transmission equipment.

- **Heat Waves/Drought**

  Heat waves can lead to equipment being damaged due to high operating temperatures. In addition, localised drying of subsoil can increase ground resistivity, reducing the ability of cables to dissipate heat into the ground which can lead to rapid degradation and failure. This type of situation occurred in Auckland, New Zealand in 1998.

3.2.7 Other Climate Treats

Over the last 20 years SSEPD has noticed a considerable increase in vegetation growth which has led to an enhanced tree cutting programme to reflect this change.

In addition, the use of low voltage insulated conductor (Aerial Bundled Conductor) has allowed the clearance of foliage to be reduced through growth without a corresponding impact on safety or network reliability.

We are undertaking a number of projects to explore new vegetation growth management techniques.

3.3.1 Temperature Effects

Comments are entered later in specific sections

At present UKCP09 does not provide any guidance on the potential effects of climate change on these weather threats. Electricity companies are maintaining close contact with the Met Office, as indicated in Section 2, and this will ensure that companies have the most up to date information on these potential threats enabling companies to plan ahead and develop adaptation schemes if this becomes necessary. Recent work with the Met Office (Project EP2) concludes that there is no need to change current ground resistivity figures when calculating cable ratings.

- **Vegetation**
  Increased vegetation growth rates and extended growing seasons are already affecting overhead lines resulting in higher costs.

3.3. Assessment of climate thresholds above which climate change and weather events will pose a threat

These thresholds are generally determined by the standards and specifications to which items of plant and equipment have been designed and constructed. These are normally based on international standards that take into account a wide range of climatic conditions e.g. including both hot and cold climates. Appendix 5 provides further information**.**

3.3.1. Temperature effects

Increased ambient temperature can reduce plant and overhead line ratings. This can be a particular problem with transformer ratings in urban areas where air conditioning load is likely to have a coincident peak. Network Operators now experience a substantial proportion of their circuits with maximum loading occurring in summer hot spells as opposed to winter cold spells Current security standards are based on maintenance being carried out during historically relatively lightly loaded summer conditions and increased summer loadings are likely to cause increasing operational difficulties.

3.4. Potential impacts of climate change on key stakeholders

For the purposes of the Adaptation Programme, the following sectors/organisations have been identified as electricity network companies' key stakeholders:

- Connected customers
- Generators
- Ofgem (also concerned with mitigation)
- DECC (also concerned with mitigation)
- HSE
- Defra
- EA
- SEPA
- Regional and Local Resilience
- Other utilities
- Regional Development Agencies
- Local Authorities
- Devolved Administrations
- Supply Chain

- Contractors
- Land owners and farmers

In developing Adaptation Plans it is important that they are co-ordinated with key stakeholders to ensure a consistent and effective approach. For example it is essential that companies' plans and Ofgem's plans are in harmony and that equipment providers' plans will enable companies to deliver any reinforcement or replacement projects that may be required to safeguard the electricity system.

Under Ofgem regulatory requirements, companies are required to consult with key stakeholders. These include Local Resilience Forums and Regional Resilience Teams with whom companies work to develop Local and Regional Risk Assessments.

4. Approach used to assess risk

4.1. Evidence, methods and expertise used to evaluate future climate impacts including sources and references

The majority of the evidence base for this report is centred on UKCP09 and considers the 90% probability level with High, Medium and Low emission scenarios to test sensitivity.

One of the main advances in UKCP09 is that it provides probabilistic projections. This means that different future climate outcomes are described in probabilistic terms, based on the strength of evidence associated with them. As such, probability levels associated with a given change should be interpreted as indicating the relative likelihood of the projected change being at or less than the given change.

For example, if a projected temperature change of +4.5°C is associated with the 90% probability level at a particular location in the 2080s for the UKCP09 medium emission scenario, this should be interpreted as it is projected that there is a 90% likelihood that temperatures at that location will be equal to or less than 4.5°C warmer than temperatures in the 1961–1990 baseline period. Conversely, there is a 10% likelihood that those temperatures will be greater than 4.5°C warmer than the baseline period.

The emission scenarios are described in UKCP09 as a plausible representation of the future development of emissions of substances (e.g. greenhouse gases and aerosols that can influence global climate. These representations are based on a coherent and internally consistent set of assumptions about determining factors (such as demographic and socio-economic development, technological change) and their key relationships. The emissions scenarios used in UKCP09 do not include the effects of planned mitigation policies, but do assume different pathways of technological and economic growth which include a switch from fossil fuels to renewable sources of energy.

Information has also been considered from EA and SEPA. In addition, companies have been engaged in a number of initiatives related to climate change impacts, which are described below.

4.1.1 Work on flooding resilience

Comments are entered later in specific sections

4.1.1. Work on flooding resilience

The serious incidents of flooding in the South Midlands and South Yorkshire during the summer of 2007, and the incident at Carlisle in 2005 highlighted the potential vulnerability of electricity substations to major flood incidents from current levels of flooding. The ESQCRs Section 3 (1) (b) state that “Generators, distributors and meter operators shall ensure that their equipment is so constructed, installed, protected (both electrically and mechanically), used and maintained as to prevent danger, interference with or interruption of supply, so far as is reasonably practicable.” However, in the absence of any specific guidance on the level of acceptable flood risk or regulatory impact assessment, it was recognised that the extent of the duty has been unclear. Since the introduction of the ESQCRs far greater information on flood levels has become available to assess flood risk to substations and the respective mitigation options and costs. This facilitated the development of an industry Engineering Technical Report, ETR 138, setting out a common approach to the assessment of flood risk and the development of target mitigation levels that are subject to cost benefit assessment.

The Task Group that produced ETR 138 comprised representatives from Networks Companies, DECC, Ofgem, EA, SEPA, Met Office and the Pitt Review Team. The report was accepted by the E3C and companies have begun a circa ten year programme of work to improve substation resilience to flooding. Ofgem set allowances of approximately £110 million which Distribution companies agreed as part of the current five year DPCR5 package. Transmission companies have already started their resilience work and expect to formally agree a programme with Ofgem at their next Price Review in 2013.

ETR 138 is based on current flood risk and also provides an allowance for climate change as indicated in the section on substations below.

4.1.2. Work with the Met Office

A number of UK energy companies recently commissioned the Met Office to carry out a project to investigate the potential impact of climate change and this report was published in 2008. The Executive Summary is attached as Appendix 3.

Background to the Met Office Project EP2

This was an industry-funded project involving 11 UK energy companies focussing on the priorities identified by an earlier scoping study. It was a groundbreaking initiative that brought climate science closer to business applications. This was the first project sponsored by an entire sector to review the specific impacts of climate change on their industry. Supported by climate scientists, experts from the industry worked together to understand their precise requirements and developed practical applications and business strategies for a changing world.

The project covered the following areas:

- Developed innovative new techniques that apply climate models to energy applications so that the industry is better placed to adapt to climate change.
- Investigated future wind resource, enabling the industry to understand the continued uncertainty of future wind power. This will assist risk management and investment decisions.
- Modelled future soil conditions and their impact on cables so that companies can understand the cost and benefits of installing cables for a more resilient future network.
- Built a tool to enable UK coastal and marine sites of interest to be screened to assess if sea level rise should be considered in more detail.

- Investigated how the urban heat island effect may change in the future so that Networks can develop plans for their infrastructure in cities.
- Produced guidance to help make best use of public domain information on climate change such as the United Kingdom Climate Impacts Programme new scenarios of climate change (UKCP09). UKCP09 provides a probabilistic presentation of future climate and enhanced regional detail.
- Delivered new site-specific climatologies of temperature, wind speed and solar radiation that account for climate change so that decisions can be based on realistic climate expectations.

Latest project with Met Office addressing network resilience

Introduction

Following the completion of a feasibility study, a further contract was placed with the Met Office to build a risk model to quantify the relationship between weather and network faults, and also the vulnerability and exposure of the network to these faults. This model was then driven with climate projections to assess how network resilience may be affected by climate change.

That research examined some 5.6 million individual faults on a national basis recorded in NaFIRS (National Fault and Interruption Reporting Scheme) over a 20 year period to identify those that were weather related and then analysed the fault incidence versus the severity of the related weather event, to provide a baseline from which to establish future fault trend impacts arising from changes in frequency and severity of weather events.

The results of this work were presented at an ENA Workshop on 25th November 2010 attended by Defra, DECC and Ofgem.

The following weather effects were considered:

- Wind damage to overhead line systems due to gales and severe storms, normally arising from trees or windblown debris, but in very severe conditions breakage due to exceeding mechanical load capability.
- Lightning damage to overhead line systems caused by very high voltages being generated in overhead conductors and connected equipment.
- Ice accretion damage to overhead line systems caused by ice build up on conductors or supports causing extreme sag or breakage due to very high mechanical loading.
- Solar heat faults causing damage to equipment due to overheating.
- Flooding, which is referred to elsewhere in this report and is a particular threat to substations.

Baseline climate risk assessment: key conclusions

Hazard and vulnerability are considered where hazard is defined as the occurrence of a fault on the electricity network caused by weather and vulnerability as the magnitude of impact on the network measured in the numbers of customers whose supplies are interrupted by the fault.

Baseline hazard

- Wind and gale is the primary cause of weather-related faults. A non-linear relationship was found between wind and gale faults and maximum gust speeds. Networks are not susceptible to faults unless wind gusts speeds are greater than a certain threshold.

- Lightning is the second most common cause of weather-related faults. The meteorological quantity “convective available potential energy” (CAPE) was found to be a good proxy for lightning occurrence.
- The third dominant cause of weather-related faults was snow sleet and blizzard (SSB). An analysis of England and Wales SSB faults identified that strong wind gusts in addition to snow were necessary to cause a fault.

Baseline vulnerability: key conclusions

- The greatest numbers of weather-related customer interruptions (CIs) in the historical record are caused by wind and gale and lightning faults.

Although rain and flooding faults occur infrequently they can have a significant impact on the network.

Combining the hazard and vulnerability assessment to measure risk, the Baseline risk key conclusions are

- Wind and gale faults pose the greatest risk to the low voltage distribution network, whilst lightning faults pose the greatest risk to the high voltage distribution network.
- Irrespective of the type of faults, the transmission network is at low risk from weather-related faults because the equipment is more resilient to weather. However, when a fault occurs it may cause many more interruptions than the low or high voltage networks. These can be low probability, high impact events.

Future Climate Risk Assessment for the UK Electricity Network: National findings

Using the relationships established in the baseline risk assessment between asset fault rates and severity of specific types of weather conditions, future risk was then assessed for climate change out to the 2080s

Wind and gale faults

- For all future time periods throughout the UK on both the distribution and transmission networks, estimates of wind and gale faults range from changes that are negative to changes that are positive, therefore it is possible that these faults may increase or decrease in the future.
- In the 2080s the projected change in future UK wind and gale faults ranges from a decrease of 23% to an increase of 20% on the distribution network, and from a decrease of 30% to an increase of 25% on the transmission network.
- Regionally there is more evidence of a reduction in faults in Northern England and Scotland compared to the South; however, this signal is not consistent over all the regional climate model runs.

Lightning faults

- Lightning faults are projected to increase in the future as a consequence of more days with higher convection.
- In the 2080s the projected change in future UK lightning faults ranges from a decrease of 3% to an increase of 75% at most, on both the distribution and transmission networks.

- There is regional variation in the estimates; in particular the change may be smallest in the Midlands and the South East of England and greatest in North England, North Wales and Scotland.

Snow, sleet and blizzard (SSB) faults (including ice)

- SSB faults are projected to decrease. This signal is due to a decrease in the number of days when snow falls; this highlights a decrease in the frequency of SSB fault days, but not necessarily a decrease in the intensity of events when snow does fall.
- In the 2080s the projected change in future SSB faults is for a decrease of approximately 50% to 90% on both the distribution and transmission networks. Regionally, the North of Scotland projections exhibit a smaller reduction than the rest of the UK.

Solar heat faults (analysis for distribution network only)

- For all future time periods throughout the UK, the incidence of solar heat faults is expected to increase, due to projected increases in maximum temperatures.
- The future fault distribution for solar heat faults has not been estimated – their rare occurrence in the baseline period means that statistically robust relationships between fault numbers and weather parameters cannot be determined. Instead, a threshold exceedance analysis based on maximum daily temperature has been used as an indicator of the direction of change in the incidence of solar heat faults in future.
- In the 2080s the projected change in future exceedance of the 90th percentile maximum temperature across the UK ranges from an increase of 88% to an increase of 246%, and the projected change in future exceedance of the 98th percentile maximum temperature across the UK ranges from an increase of 137% to an increase of 707%. The 90th and 98th percentiles of maximum temperature vary regionally (e.g. higher values in South East England than in Scotland would be expected), so there is little evidence for significant regional variations in the frequencies of exceedance of these thresholds.

Flooding faults (analysis for distribution network only)

- A UK-wide event-based analysis has been conducted for flooding. In the 2080s, for all events considered, projections show a mean increase in exceedance of rainfall amounts which have caused significant flooding events in the baseline period. The possibility of decreases cannot be ruled out, however, as some model runs still project slight decreases in exceedance for some of the rainfall events.
- The absence of a flooding event in a particular licence area during the baseline period does not mean that that area is not vulnerable to flooding events. Major flooding events are statistically rare and the baseline period is short in terms of the occurrence of these events. The general increase in heavy rainfall projected by this analysis should therefore be considered as relevant to all licence areas.

4.1.3. Other activities related to Climate Change Risk Assessment

As a result of the establishment of an ENA Task Group to develop this report, electricity network operators have made a number of new contacts with Defra, EA, Cranfield University, UKCIP and those involved in the National Climate Change Risk Assessment programme. These new contacts have helped the Task Group test the industry's current evidence base and ensure all relevant sources of evidence are presented in this report.

Finally, under the requlator Ofgem's Innovation Funding Incentive (IFI) companies have carried out a number of projects that provide knowledge about potential climate change impacts and these are listed in Appendix 4.

4.1.4. Other Evidence

- **Air Conditioning**
  Air conditioning is now widely available for commercial and domestic use and has had an increasing level of adoption in the UK, particularly in city environments such as London where summer peak loads are now similar to winter peaks.

  Evidence on the future impacts of increased temperature is available from countries with similar infrastructure to the UK such as Australia and New Zealand. Recent information from an electricity utility in South East Queensland, Australia provides information on the impacts of air conditioning and the potential to manage these impacts by the development of Smart Grids. This provides a clear relationship between a mitigation initiative, Smart Grids, and a potential adaptation requirement to address consumer behaviour as a result of increased temperatures.

  More work is required in the UK to fully understand the potential impact of air conditioning load.

- **Standards**
  Current International Standards provide good evidence of the requirements for operating in hotter climates and UK equipment being purchased at present will normally comply with these Standards.

- **Wind Storms**
  According to UKCIP, predictions for wind are very uncertain. Also, information provided by the Met Office at the DECC Resilience workshop on 22 February 2010 clearly indicated that UKCP09 did not provide any conclusive evidence that climate change is likely to increase the severity of high wind events, although there could be a possible increase in their frequency.

- **Seasonal Demand Curve**
  Milder winters are expected to reduce winter peak demand and air conditioning load is expected to increase summer demand, resulting in a flattening of the seasonal demand profile As mentioned above, at present networks are designed with a level of security that ensures that circuits can be taken out of service at more lightly loaded times in the summer to allow maintenance or construction activities. With a flatter demand curve, this will be more difficult to achieve and current security standards may need to be enhanced.

4.2. Estimation of the impact and likelihood of risks occurring at various points in the future

The Met Office EP2 Project found that because of climate change:

- With a few exceptions, such as the thermal ratings of equipment and apparatus, there is currently no evidence to support adjusting network design standards.
- The risk profile for transformers will be affected. Design thresholds of temperature will be exceeded more often and there will be more hot nights in cities.

- Soil conditions will change; higher temperatures and seasonal differences in soil moisture are expected. Future conditions could be included in cable rating studies by increasing average summer soil temperatures in the models by approximately 0.5°C per decade.
- Wind resource is uncertain and understanding future resource represents a significant challenge. Although we don't yet have the answers, this project has highlighted possible strategies for improving our knowledge.

4.3. Evaluation of the costs and benefits of proposed adaptation options

4.3.1. Introduction

The main options for adaptation are:

a) Electricity Network equipment
   - Modifying the specification of assets subject to normal replacement criteria to ensure they can meet predicted adaptation requirements during their asset life.
   - Minor adaption or up rating of current assets
   - Major adaption or up rating of current assets
   - Replacing current assets specifically to meet an adaptation requirement

b) Other issues including human factors and supply chain
   - Adaptation of internal processes including safety requirements
   - Adaptation of relationship with other organisations including suppliers.

It is expected that required adaptation actions will be introduced gradually over the coming century. During the same period electricity network companies will be updating their networks as part of the move to the Low Carbon Economy, whilst at the same time replacing aging assets and building new ones. Any necessary adaptation measures will be built into the specifications and designs for the new plant.

In considering these options it is important for Network Operators to ensure they carry out cost/benefit assessments for each potential issue to determine which course of action is appropriate. This should include consideration of customers' "willingness to pay" for this type of adaptation as assessed by Ofgem and the cost/benefit assessments should also take into account societal aspects.

This type of approach has recently been agreed with Ofgem and DECC regarding current and future substation resilience to flooding in ETR 138. An extract of this report showing the approach to cost/benefit assessments is included as Appendix 7 and this type of approach may be adopted by companies in their response to Climate Change risk.

5. Summary of risks which affect functions, mission, aims, and objectives

A summary of risks is shown in the two tables below, following which these risks are considered by asset type. Replacement cycles provide an opportunity to build adaptation at an incremental cost and this is discussed under each asset.

Table 4 shows the expected impact of different types of event on network components or functions and Table 5 shows the overall impact of these events.

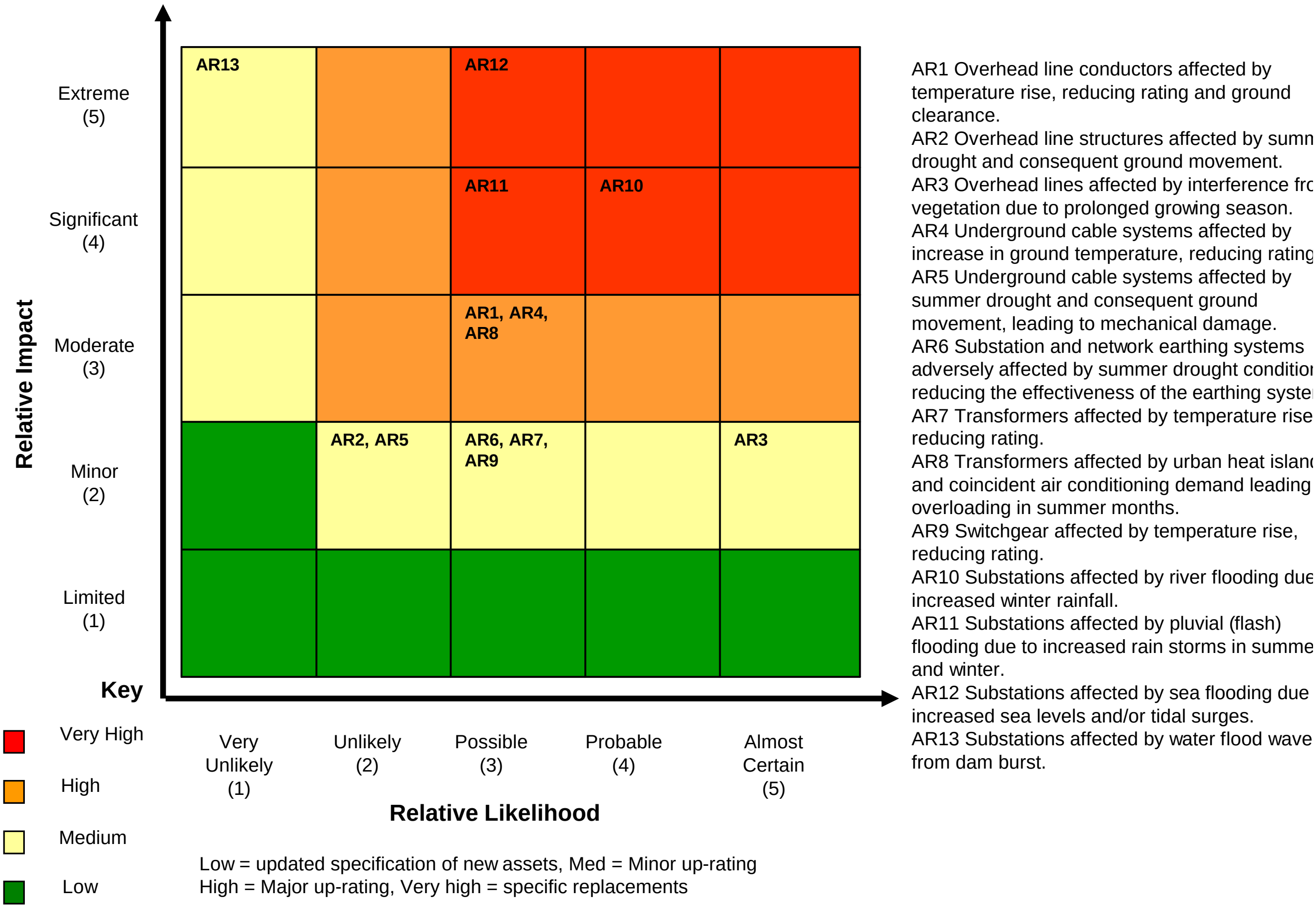
Table 4 - Possible current and future impacts of climate change which affect functions, missions, aims and objectives

Climate Change Risks		Network Component/Function at Risk													
Risk Type	**Specific Risk**	**Substations**	**Transformers**	**Circuit Breakers**	**Overhead Lines**	**Cables**	**Protection**	**Earthing**	**Logistics**	**Vegetation Management**	**Spares**	**Resources**	**Communications**	**Operations Centres**	**Customer Service**
Extreme Events	**Flooding (Fluvial)**	H	M	M	L	NE	H	NE	M	NE	M	H	M	M	H
	Flooding (Pluvial)/ Heavy Rain	M	M	M	L	NE	M	NE	L	NE	L	M	L	L	M
	Flooding (Sea Breach including erosion risks)	H	M	M	L	NE	H	NE	M	NE	M	H	M	L	H
	Dam Inundation	H	H	H	H	NE	H	NE	M	NE	NE	L	L	L	L
	Extreme prolonged temperature periods	L	M	L	M	M	NE	NE	L	L	NE	H	H	M	H
Gradual Warming	**Temperature Increase**	NE	L	L	L	L	NE	NE	NE	M	NE	M	M	NE	NE
	Drought (Soil Drying and Movement)	M	L	L	M	L	L	M	NE	M	NE	NE	L	NE	NE
	Demand increase due to Mitigation and HVAC	NE	H	NE	H	H	NE	NE	NE	NE	NE	L	NE	NE	NE

H = High Impact, M = Medium Impact, L = Low Impact, NE = None Expected

High Network component/function temporarily disabled. Function severely disrupted.
Medium Network component/function substantially reduced in capacity or damaged. Function disrupted.
Low Network component/function reduced in capacity or suffers minor damage. Function suffers minor disruption.

ENA Adaptation to Climate Change Risk Matrix Showing Overall Impact (if no adaptation measures taken)



Relative likelihoods
Probability of a climate change effect having an impact under the change scenarios considered ion the report.
Definitions of relative impacts[2]

Extreme:	Regional area affected with people off supply for a month or more OR asset de-rating exceeds ability to reinforce network leading to rota disconnections on peak demand.
Significant:	County or city area affected with people off supply for a week or more OR asset de-rating requires a significant re-prioritisation of network reinforcement and deferment of new connection activities.
Moderate:	Large town or conurbation off supply for up to a week OR significant increase in cost of network strengthening.
Minor:	Small town off supply for a 24 hour period OR significant increase in cost of network maintenance requirements.
Limited:	Limited impact - can be managed within “business as usual” processes.

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

[2] Areas affected can be as a result of single or multiple events.

Note regarding Confidence Levels and Thresholds (Also covers Appendix 8)

Confidence Levels

The report considers the predicted effects of climate change in accordance with the UKCPO9 projections for the 90% confidence level at Low Medium and High emissions. The report demonstrates a high level of confidence in the predicted performance of networks under those conditions.

Thresholds

Risks AR1, AR2, AR4, AR5, AR6, AR7, AR8, AR9

Warmer drier summers generally have a gradual impact and there are no particular thresholds. However, individual sites/equipment may be subject to thresholds that dictate when reinforcement or replacement is necessary and this will be monitored as part of the forward CAPEX programme.

Risks AR10, AR11, AR13

Warmer wetter winters result in increased flood risk from rivers and surface/ground water and the thresholds in this case relate to the height of any flood waters compared with the height/protection at any substations at risk as set out in ETR 138.

Risk AR12

Regarding the increased risk of sea flooding, the thresholds in this case again relate to the height of any flood waters compared with the height/protection at any substations at risk as set out in ETR 138.

Note: For all potential flooding scenarios it will be necessary to monitor actual flood levels to check that the planned remedial action is appropriate.

RiskAR3

A warmer climate with wetter winters leads to a longer growing season with vegetation interfering with overhead lines. Again this is expected to be a gradually increasing impact. Thresholds will be linked to the frequency of inspections and tree cutting.

5.1.2 Climate Change and Overhead Line Ratings

SSEPD rate distribution lines in accordance with ENA Engineering Recommendation P27. This is a probabilistic method of rating which allows exceedances in conductor temperature above the design temperature. An increase in ambient temperature will change the rating changeover points for summer, winter, spring and autumn and would increase the number of exceedances. This is mitigated at present by using lines which operate on a load cyclic and at less than their full rating (utilisation factor<1). The effects of climate change may be shadowed by changes to the load cycle and utilisation factor. These will most probably result in a reduction of the ratings of the conductors due to the increase in exceedances if existing ratings are maintained.

Where there is a redundancy of circuits, in other words, 2 or more circuits feeding the same substation then climate change will have little effect on the normal operation of the circuits. However under fault situations it may become necessary to look at load management. Under Registered Power Zones, Innovation Funding Incentive and Low Carbon Networks Fund SSEPD are exploring a number of technical options for managing load including dynamic line rating, active network management and demand side management.

SSEPD continuous rate transmission circuits in accordance with a probabilistic pre-fault rating. This method guarantees that there will be no exceedances above design temperature which would result in a reduced ground clearance.

A rise in ambient temperature, could lead to the reduction in the pre-fault continuous rating. Initiatives such as monitoring of line ratings are being explored as a mitigation of this risk.

Longer drier summers could see an increase in the daytime ratings of overhead lines (rather than a decrease). Sunshine is normal coupled with an increase in wind speed. The effects of ambient temperature rise could be negated by the cooling effect of the wind.

This proves to be a potential benefit, however night time ratings could be reduced as the wind drops off at a greater rate than the reduction in ambient temperature. SSEPD are conducting a trial on monitoring temperature of an overhead line, load and weather related data to formulate an enhanced strategy for line loadings

These sensors will facilitate methods such as Dynamic Line Rating but will also allow us to see the impacts of climate change develop and allow a timely response.

5.1. Overhead Lines (Risks AR1, AR2 and AR3)

Typical overhead line types are illustrated in Appendix 1. Appendix 2 shows circuit lengths.

5.1.1. Overhead electricity lines background information

Nearly all overhead lines in the UK are constructed using wood poles or steel towers ("pylons"), though there are a few that use steel or concrete poles, but in the context of climate change, this is not relevant.

The overhead lines structures are fitted with insulators that support wire conductors that carry electrical current. The conductors are not normally insulated and are usually copper or aluminium based and of different sizes to provide different current carrying capabilities. Because 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, heating from the sun (solar radiation) and offset by the amount of cooling winds. The amount an O/H line is permitted to sag is determined by the legal minimum heights of live electricity conductors over roads and over other ground. Thus the current rating of an O/H line is effectively determined by a heat balance equation – heat in vs. heat out, and based on a maximum conductor design temperature.

The design of UK electricity networks is such that overhead lines of 33,000 volts (33kV) and above normally connect one large substation to another, with no intermediate connections, such that the current flowing into one end of the circuit is the same as that flowing out of the other end. At 11,000 volts (11kV) and low voltage, overhead lines radiate out from substations feeding small transformers or individual customers along the route. Consequently at these lower voltages, the current flowing in at one end of the circuit gradually reduces along the line as current is fed off to individual customers or small communities / businesses. It is important to make this distinction between the 11kV and lower voltage lines and 33kV and higher voltage overhead lines because of the extent of impact of reduction in ratings caused by climate change.

The above paragraphs outline the relationship between climate and overhead line ratings, but there are also climate impacts on the structural integrity of overhead lines. Very high winds place structural wind loads on the overhead line poles, towers and conductors. These loads are also increased if there is ice build up ("accretion") on the overhead conductors because 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 and this issue is covered in more detail in Section 5.1.3.

Further details on the above processes are given in sections 5.1.2 and 5.1.3 below.

5.1.2. Climate change and overhead line ratings

The basic equations governing the derivation of overhead line current ratings have been well known for almost a century and 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 and little cooling influence. Most wood pole O/H lines and steel tower lines at 132kV and below in the UK are designed to a 50°C design operating temperature, whilst 275kV and 400kV higher voltage steel tower O/H lines normally have 75°C or higher design operating temperatures.

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 present basis of UK design, 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 etc.

The diagrams attached as Appendix 9 show, from UKCP09, the spread of changes in average daily maximum summer temperature for the high emission scenario for the periods 2010-2039 2040-2069 and 2070–2099. Additional maps are available showing the other scenarios and seasons.

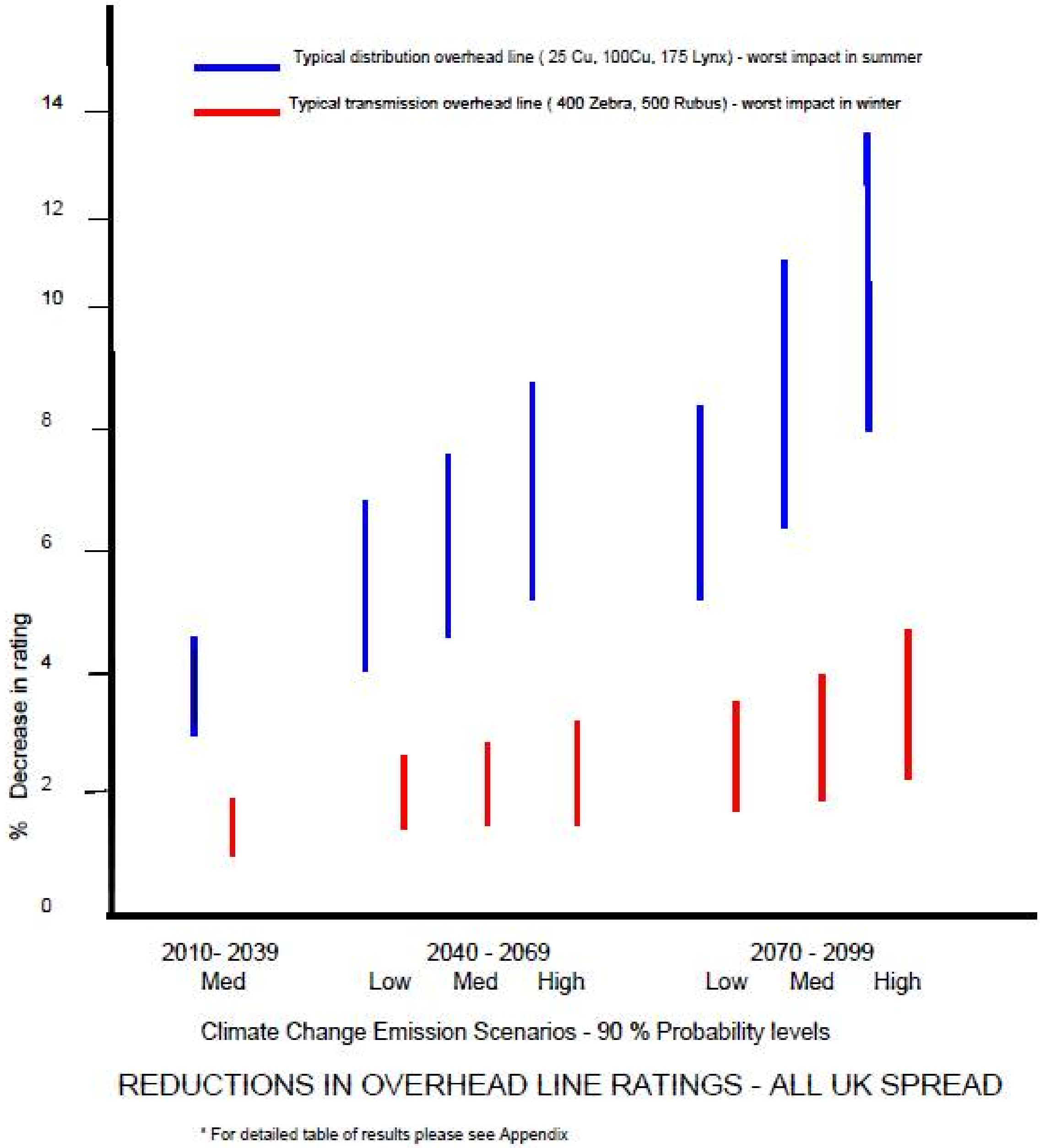
The effects of any of the individual temperatures on a representative range of typical O/H conductor types is established by multiplying the °C value, by the % rating reduction per °C figures derived from the Met Office research and is listed below.

Conductor sizes on standard overhead lines range from 16mm^2 hard-drawn copper to 850mm^2 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 the following have been selected as being representative of the most common types of overhead line in the UK, along with the typical limiting rating season:

Table 5 - Common types of overhead line

Conductor & Operating Temperature	Rating	Existing Value	Reduction
25mm^2 Copper @50°C	Summer	126 Amps	1.6% /°C
100mm^2 Copper @50°C	Summer	316 Amps	1.6% /°C
175mm^2 Lynx ACSR @50°C	Summer	432 Amps	1.6% /°C
400mm^2 Zebra ACSR @75°C	Winter	1,230 Amps	0.81% /°C
500mm^2 Rubus AAAC @90°C	Winter	1,600 Amps	0.63% /°C

Figure 2 - Ranges of % de-ratings across UK



It is important to view the above % de-ratings against past network operator experience in response to growth of electricity demand on their networks; effectively the same challenge. The above table indicates a range of de-ratings of distribution overhead lines (in the table, those of 175 mm^2 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, whereas 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 of 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 for 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.

The 2009 price basis unit costs of pole/tower replacement and re-conductoring of overhead lines in Ofgem DPCR 5 assessment are shown in Table 6 below.

Table 6 - Overhead Line Data

Overhead Lines GB	Total circuit km	Overhead Lines GB (Total numbers of supports)	Unit replacement cost	Full Re-build	Conventional re-conductoring
Pole lines					
LV	64,874	1,710,926	LV pole £1.4k	£28.4k /km	
HV (6.6,11, 20kV)	168,962	2.113,339	HV pole £1.8k	£33.5k /km	
EHV (33, 66kV)	28,883	328,522	EHV (33kV pole) £2.2k	EHV pole line rebuild £42.0k /km	
132kV	1,774	7807			
Steel tower lines					
EHV (33kV)	3,254	14,553	33kV tower replace £39.2k		33kV £39.0k /km
EHV (66kV)			66kV tower replace £65.0k		66kV £53.4k /km
132kV (DNO)	14,697	33,438	132kV tower replace £108.9k		£82.1k /km
132kV NGC					
275kV NGC					
400kV NGC					

Sources:
Component numbers and circuit lengths 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 31st 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 - 7th December 2009

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.

The above Ofgem reference also includes costs for conventional (not low sag) re-conductoring of steel tower overhead lines on a per circuit km basis also shown in Table 6. Note that many designs have two circuits, one suspended on each side of the tower).

5.1.3 Climate change and structural strength of overhead lines

SSEPD now design new tower lines and assess existing tower lines being refurbished or reconductored to BS EN 50341. This standard takes probabilistic weather related data to produce structural loadings. In the case of existing lines this has led to strengthening of tower components. Tower line conductors are replaced every 25 to 40 years and the opportunity can be taken, before it is has it conductor replaced, to access the design integrity to the latest standards.

5.1.3. 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 during the 1950's and early 1960's.

Following severe storms in 1981/82 it was recognised that the BS1320:1946 design standards were insufficient, but instead of proscribing 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 subject to post event review by Government (DTI / BERR now DECC).

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 network operators are participating in EU research (COST 727) which is reviewing ice accretion models across EU. It is currently anticipated that this research will indicate a reduction in the severity requirements used in UK O/H design criteria. Since the design criteria is based on both 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.

5.1.4 Limitations on available information

SSEPD is currently championing an EA Technology Ltd Strategic Technical Programme project to produce new weather maps, based on the latest European predictive models which will support the future design of overhead lines. These enhanced weather maps will allow a better understanding of the types of weather to be expected and hence more appropriate designs for towers and poles to be produced. These weather maps will be factored into BS EN 50341(Overhead electrical lines 1kV up to and including 45kV), BS EN 50423 (Overhead electrical lines above 45kV) and Energy Networks Association Technical Standard 43-40 (Probabilistic design of wood pole lines up to and including 33kV).

5.2.1 Fundamentals

SSEPD installed high voltage covered conductor (BLX) on a third of its 11kV network in the South. This has shown benefit in the reduction of normal tree related faults.

The structural integrity of this covered conductor system can also resist, to a certain extent, the falling of trees directly onto the line.

In suburban and rural areas a significant proportion of our Low Voltage networks have been replaced with Aerial Bundled Conductor (ABC).

The net effect of ABC and BLX on the network has been to increase the resilience of the network to tree related damage and increase the amount of vegetation growth that can be sustained between tree cutting visits.

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.

5.1.4. 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. However, there is much ongoing work in this area – see sections below.

5.2. Vegetation Growth and Climate Change (Risk AR 3)

5.2.1. Fundamentals

Overhead lines are susceptible to interference from the natural 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 trees or branches falling onto the lines). Typically 25% of all low voltage overhead interruptions and 6% of all high voltage interruptions are related to vegetation induced faults and under abnormal weather conditions falling trees can lead to large scale power outages.

Overhead lines are normally routed to reduce proximity to vegetation which may cause interference with the lines, but this is not always possible and it is both socially and environmentally unacceptable to remove all vegetation in proximity to overhead lines. Thus it is necessary to maintain electrical clearances between overhead lines and vegetation by vegetation management.

5.2.2 Changes in Growing Season

SSEPD have noticed that the growing season has increased, especially in the South. This had led to an increase in tree-cutting.

A secondary impact on the industry of increase tree growth rates is an impact on the structural strength of the wood used to manufacture poles.

The structural attributes of wood poles have been reduced due to the accelerated growth period at latitudes where historically trees for wood poles are grown.

SSEPD are currently assessing the reduction in strength of new poles – this could result in shorter spans, larger diameter or new materials for poles being required.

An essential part of this management involves 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.

Electricity Network Operators have always recognised the importance of efficient vegetation management in maintaining the performance of their overhead power lines and vegetation management is one of the largest annual recurring maintenance tasks undertaken by Network Operators, accounting for a substantial proportion of their budgets. Network Operators are obliged to carry this out in order to meet their statutory obligations under the ESQCRs, as amended in 2006. This requires Network Operators 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.'

5.2.2. Changes in Growing Season

The external factors which can influence vegetation growth include temperature and rainfall. Climate change will therefore directly impact on growth rates, in particular the change in the number of days with a temperature over 5.6°C will impact the growing season, resulting in more and denser growth. Over the past decade a number of studies have confirmed this effect.

In 1999, German research[3] 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 research[4] using NASA satellite data identified that plant life above 40 degrees latitude had been growing more vigorously since 1981. They concluded that the area of vegetation had not extended, but that the existing vegetation had increased significantly in density and that 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, on average, 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 from 29th January to 21st December. The thermal growing season for this region of the UK is now longer than at time since the start of the daily temperature series in 1772.'

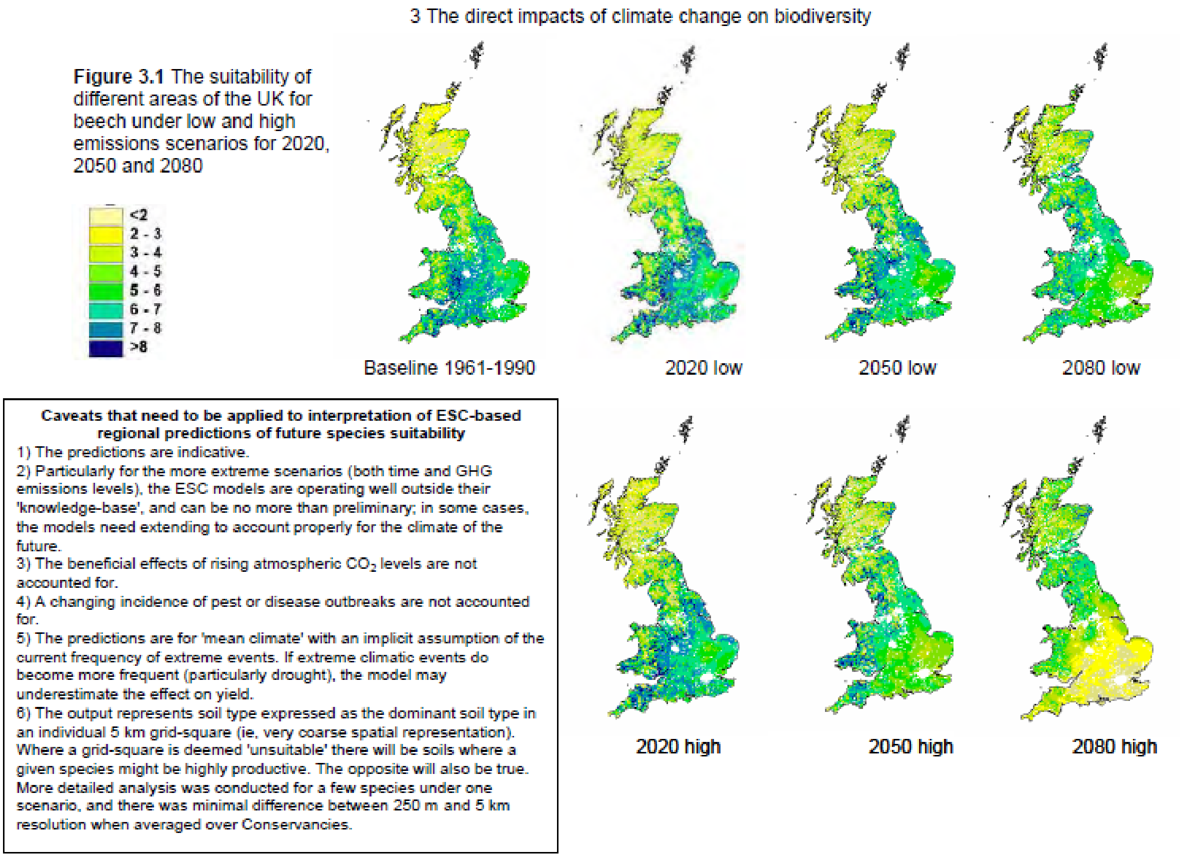
5.2.3. Vegetation Growth – Changes in Habitat Suitability

In the longer term, the effect of a decrease in summer rainfall will also start to impact the vegetation growth of certain species, which are sensitive to drought. One example given in a Defra Report[5] is lowland beech, which has been identified as being particularly susceptible to climate change. Below are the projections in the future suitable habitats based on the UKCP09 data.

[3] Nature Vol. 397 Issue 6721(1999) Growing Season extended in Europe (A. Menzel and P. Fabian)
[4] http://science.nasa.gov/science-news/science-at-nasa/2001/ast07sep_1/
[5] DEFRA Report England Biodiversity Strategy – Towards adaptation to climate change (May 2007)

5.2.4 Assessing the Impact of Climate Change

SSEPD supported the compiling of ETR 132 and its relation to the 2005 amendments to the Electricity Safety, Quality and Continuity Regulations. However it is recognised that the need to ensure that the network is made resilient over the next 25 years will have little impact on improving overall reliability in the short term.



As habitats gradually 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.

5.2.4. Assessing the Impact of Climate Change

While the EP2 report did not include vegetation growth, the Met Office produced a report for the DTI 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.

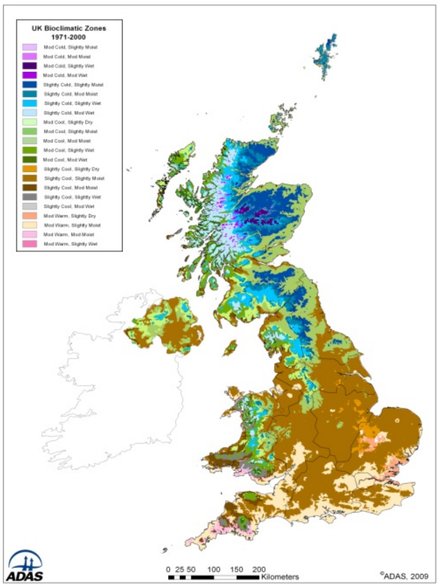
In ENA ETR132[6], these predictions lead to the following comment: ‘It needs to be recognised that if the UK is presented with increasingly adverse climatic conditions over the coming decades, the reliability of the Network is likely to become more difficult to manage. The consequence of this is that 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.’

This view is supported by the fact that between 1990 and 2006 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 ETR 132 should improve network performance in abnormal weather conditions, by the selected removal of high risk trees in the proximity of strategic overhead line circuits and this may have some consequential 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.

5.2.5. Vegetation Growth Research Currently Underway

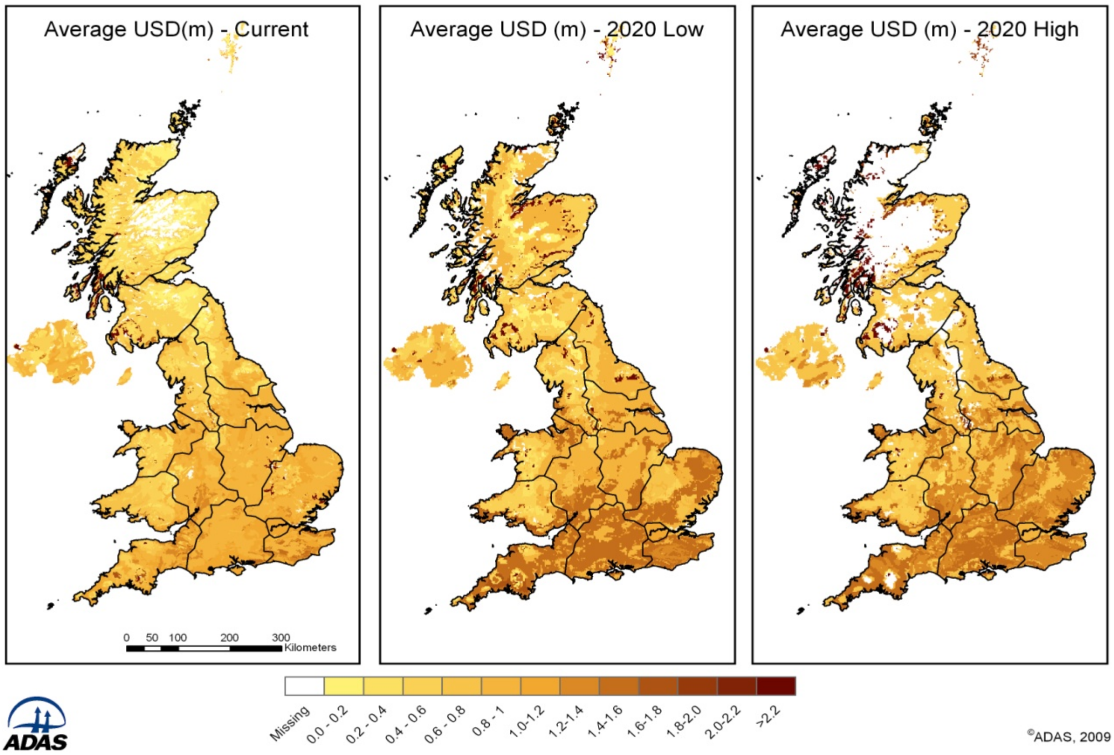


In 2008 several Network Operators commissioned a four year research project with ADAS to quantify the impact of vegetation growth around overhead lines and in particular the manner in which the Utility Space (that is the physical volume around the utility’s apparatus including the volume necessary to 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 (see map). At each site the Utility Space derogation is being measured on a biannual basis and 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.

[6] Energy Network Association Engineering Technical Report 132 – Vegetation management near overhead lines for the purpose of improving network performance under abnormal weather conditions

Using UKCP09 data, ADAS have 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. The maps below show how growth rates will impact on the annual Utility Space Derogation (USD) in this period.



This research project is as yet incomplete, but the initial projections indicate that a significant 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 set by Ofgem for the five year DNO price control from 2010 is £500m (at a 2007/08 price base).

5.3. Underground Cables (Risks AR4 and AR5)

5.3.1. Introduction

Typical underground cable types are illustrated below and Appendix 2 shows circuit lengths.



5.3.2. Underground electricity cables background information

In the UK electricity cables are installed and operated at all the common voltages used on the electricity network 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. Appendix 2 shows installed circuit lengths for the various operating voltages.

Cable construction typically comprises a central conductor or conductors of copper or aluminium, immediately surrounded by insulation (the dielectric) with an outer electrical 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 electrical insulation caused by the alternating voltage, this is 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 such as other adjacent cables.

Balanced against this is the conduction of heat away from the cable:

5.3.3 Climate Change

The impact of climate change is uncertain as the factors which lead to a cable route design are based on deterministic values. In general these factors are still suitable and the slight increases in ground temperature may not have any significant effect. However, smoothing of load curves and increases in load utilisation factor could lead to a more significant effect. Cables will be re-laid on average every 60 years and for distribution cables the average reduction in rating is about 2% over the lifetime of the cable. Further work is required to verify the thermal model of the cables currently being used. .

The effect on transmission cables is less certain as they are already rated to run continuously, however there could be a reduction of about 3% over the lifetime of the cable. Further work is required to verify the thermal model of the cables currently being used.

- 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. Thermal resistively itself is affected by the type of soil and the level of moisture it contains.
- The temperature of the surrounding soil, which is itself affected by ambient air temperature.

5.3.3. 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.
- Reduced precipitation levels will only impact ground resistivity values in extreme, prolonged drought conditions otherwise the effect is small at 1.2m depth.
- 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.
- 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 diagrams attached as Appendix 9 show, from UKCP09, the spread of changes in average daily maximum summer temperature for the high emission scenario for the periods 2010-2039 2040-2069 and 2070–2099. Additional maps are available showing the other scenarios and seasons.

The impact of these, more recent, climate change predictions as applied to cables using the guidance from the EP2 project are considered in section 5.3.4.

5.3.4 Impact of Climate change on Cable ratings

It has to be proven that the projected rise in temperature will affect cable laid in an urban environment, where the soil conditions remain reasonably constant. The greater use of unfilled ducted systems at high voltage restrict cable ratings and so the effect of drying out of soils not so important.

5.3.4. 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. These predictions will apply to the majority of cables installed in the UK however 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 7 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.

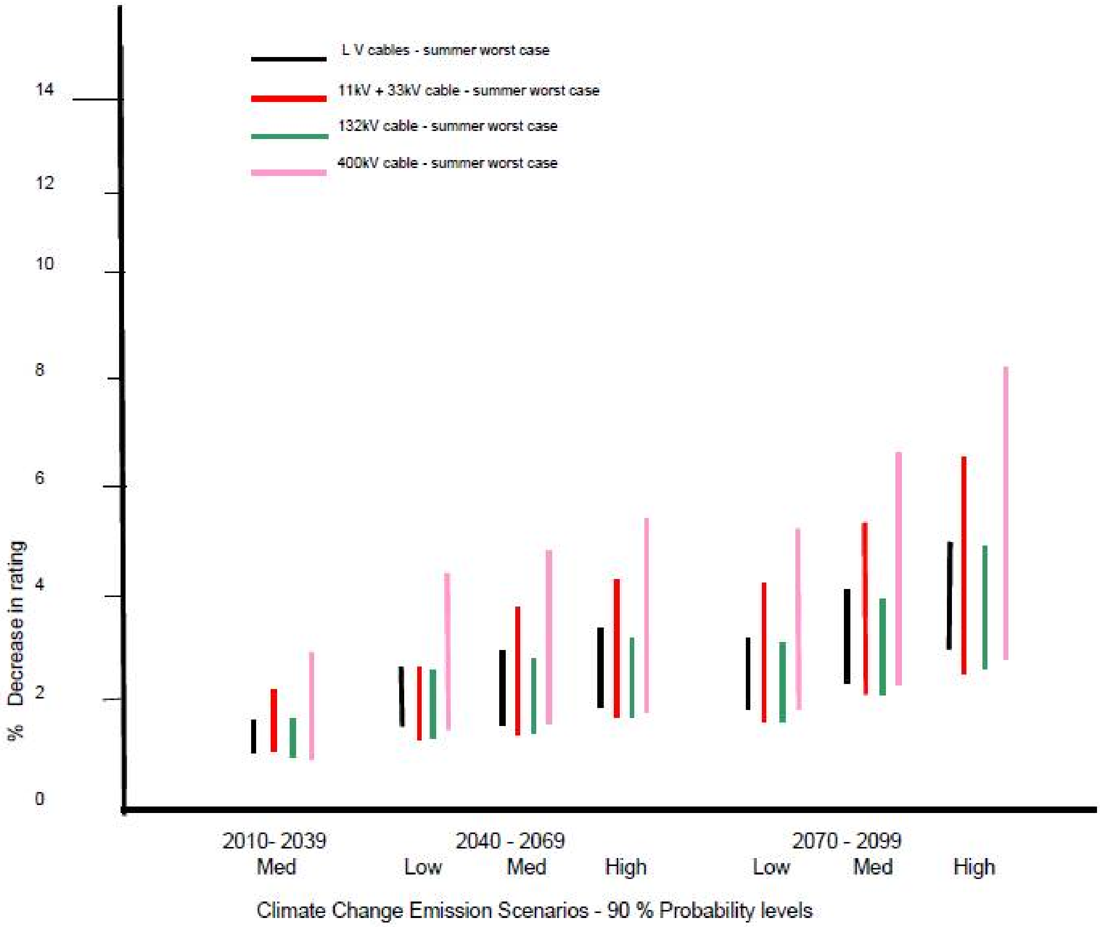
Table 8 shows the range of de-ratings for the 7 climate change scenarios extracted from UKCP09.

Table 7 - Common types of underground cable

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	1429	0.560%
400kV - 2000 XLPE 1C	90	Summer	Ducted	1448	0.570%
400kV - 2000 XLPE 1C	90	Winter	Direct Lay	1569	0.518%
400kV - 2000 Cu Lead Sheath	85	Summer	Direct Lay	1052	0.986%

Table 8 - Ranges of % summer de-ratings across UK from UKCP09

Cable Type		2010–39		2040–69		2040-69		2040-69		2070-99		2070-99		2070-99	
Emission Scenario		M		L		M		H		L		M		H	
Range		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Air Temp Increase Range °C		1.8	2.9	2.6	4.5	2.8	4.9	3.3	5.4	3.2	5.3	4.1	6.8	5.0	8.4
Soil Temp Increase Range °C		1.3	2.2	2.0	3.4	2.1	3.6	2.4	4.1	2.4	4.0	3.1	5.1	3.8	6.3
LV - 185 Cu Waveform	Summer - Direct Lay	1.0%	1.7%	1.5%	2.7%	1.7%	2.9%	1.9%	3.2%	1.9%	3.1%	2.4%	4.0%	3.0%	5.0%
LV - 185 AL PILC-STA	Summer - Direct Lay	1.1%	1.7%	1.6%	2.7%	1.7%	2.9%	1.9%	3.3%	1.9%	3.2%	2.4%	4.1%	3.0%	5.0%
11kV - 185 Al XLPE 1C	Summer - Direct Lay	0.9%	1.5%	1.3%	2.3%	1.4%	2.5%	1.7%	2.8%	1.6%	2.7%	2.1%	3.4%	2.5%	4.3%
11kV - 185 Al XLPE 1C	Summer - Ducted	0.9%	1.5%	1.4%	2.3%	1.5%	2.5%	1.7%	2.8%	1.7%	2.8%	2.1%	3.5%	2.6%	4.4%
11kV - 185 Al PICAS 3C	Summer - Direct Lay	1.4%	2.3%	2.1%	3.5%	2.2%	3.8%	2.6%	4.3%	2.5%	4.2%	3.2%	5.3%	3.9%	6.6%
33kV - 185 Al XLPE 1C	Summer - Direct Lay	0.9%	1.4%	1.3%	2.2%	1.4%	2.4%	1.6%	2.7%	1.6%	2.6%	2.0%	3.3%	2.5%	4.1%
33kV - 185 Al XLPE 1C	Summer - Ducted	0.9%	1.4%	1.3%	2.2%	1.4%	2.4%	1.6%	2.7%	1.6%	2.6%	2.0%	3.4%	2.5%	4.2%
33kV - 185 Cu PILC 'H'	Summer - Direct Lay	1.4%	2.2%	2.0%	3.5%	2.2%	3.8%	2.5%	4.2%	2.5%	4.1%	3.2%	5.3%	3.9%	6.5%
132kV - 630 XLPE 1C	Summer - Direct Lay	0.9%	1.5%	1.3%	2.3%	1.4%	2.5%	1.7%	2.8%	1.6%	2.7%	2.1%	3.5%	2.6%	4.3%
132kV - 630 XLPE 1C	Ducted	0.9%	1.5%	1.3%	2.3%	1.4%	2.5%	1.7%	2.8%	1.6%	2.7%	2.1%	3.5%	2.6%	4.3%
132kV - 630 Cu Lead Sheath	Summer - Direct Lay	1.0%	1.7%	1.5%	2.6%	1.6%	2.8%	1.9%	3.2%	1.9%	3.1%	2.4%	3.9%	2.9%	4.9%
400kV - 2000 XLPE 1C	Summer - Direct Lay	1.0%	1.6%	1.5%	2.5%	1.6%	2.7%	1.8%	3.0%	1.8%	3.0%	2.3%	3.8%	2.8%	4.7%
400kV - 2000 XLPE 1C	Summer - Ducted	1.0%	1.6%	1.5%	2.6%	1.6%	2.8%	1.9%	3.1%	1.8%	3.0%	2.3%	3.9%	2.9%	4.8%
400kV - 2000 Cu Lead Sheath	Summer - Direct Lay	1.7%	2.9%	2.6%	4.4%	2.8%	4.8%	3.2%	5.4%	3.2%	5.2%	4.0%	6.7%	4.9%	8.3%



REDUCTIONS IN UNDERGROUND CABLE RATINGS - ALL UK SPREAD

* For detailed table of results please see Appendix

The above table indicates 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. That equates to a ratings impact of some 0.10% per annum, whereas 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, 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 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.

5.4 Transformers (Risks AR7 and AR8)

Large and medium power transformers may be less effected by an increase in ambient temperature. Most large and medium power transformers are normally run at utilisation factors less than 1 (with the exception of generator transformers). Monitoring of the winding temperature is used to introduce forced cooling. Where the transformers have separate radiators there is some scope for increasing the size of the radiators to cope with the excess heat. Another method is to use a water cooling spray to reduce the temperature of the transformer. Both of these methods have been used by SSEPD. Providing the current cyclic rating is used a rise in ambient temperature will only have a slight reduction in predicted life.

Ground mounted distribution transformers are less accommodating to being modified to allow for additional cooling. Most SSEPD distribution substations are being installed in some form of housing (Glass Reinforced Plastic, brick, basement). These can mitigate to some extent the increase in ambient temperature, for example, they shield the transformers from solar gain, however can form a microclimate which can lead to higher average ambient temperatures. Running transformers above their design temperatures will lead in general to a reduction in asset life.

Although this is an impact SSEPD are focussing heavily on the monitoring of the network in its Smart Grid programme. This will allow the thermal models of transformers to be verified against actual operating conditions of load and temperature, and, where necessary allow asset replacement, or, other load management programmes to be introduced to compensate for the small changes in asset life.

Pole Mounted Transformers may be less, or not, affected by ambient temperature rise. Hotter, drier summers with more sun can lead to an increase in the wind strength, which cancels out the solar gain and increases the cooling effect.

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. In 2009 the estimated unit costs of cable replacement used in Ofgem's DPCR5 investment assessment (direct costs only) were:

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

Source – Tables 17 - Ofgem Electricity Distribution Price Control Review – Final Proposals – Allowed Revenue – Cost Assessment appendix Ref 146a/09 - 7th December 2009

The following quantitative information was 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 31st March 2010.

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

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

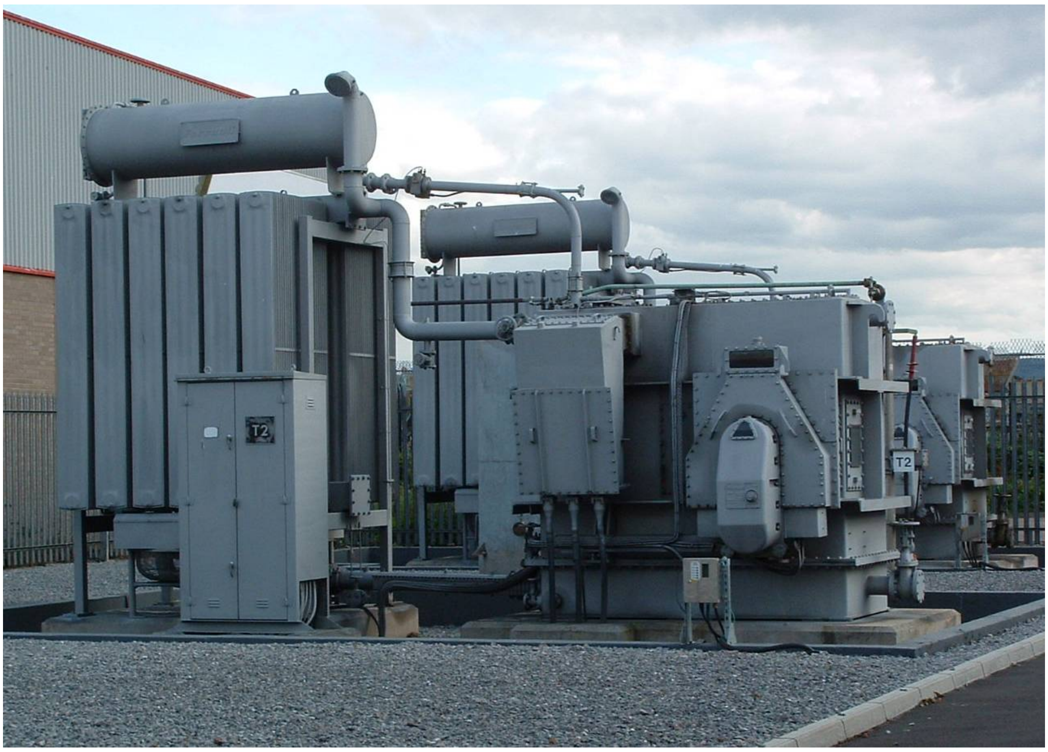
Underground cable systems may also be affected by summer drought and consequent ground movement, leading to mechanical damage.

5.4. Transformers (Risks AR7 and AR8)

Transformers are used to transform voltage from one level to another. Within DNO systems 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. Some other voltage levels are also in more limited use, such as 66kV and 22kV, but the principles remain the same.

Transformers basically 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 (GRP) type enclosure. Examples are shown below:



Examples of 33k / 11kV ground mounted (GM) transformers (two visible in photo) with coolers shown to the left of the picture.

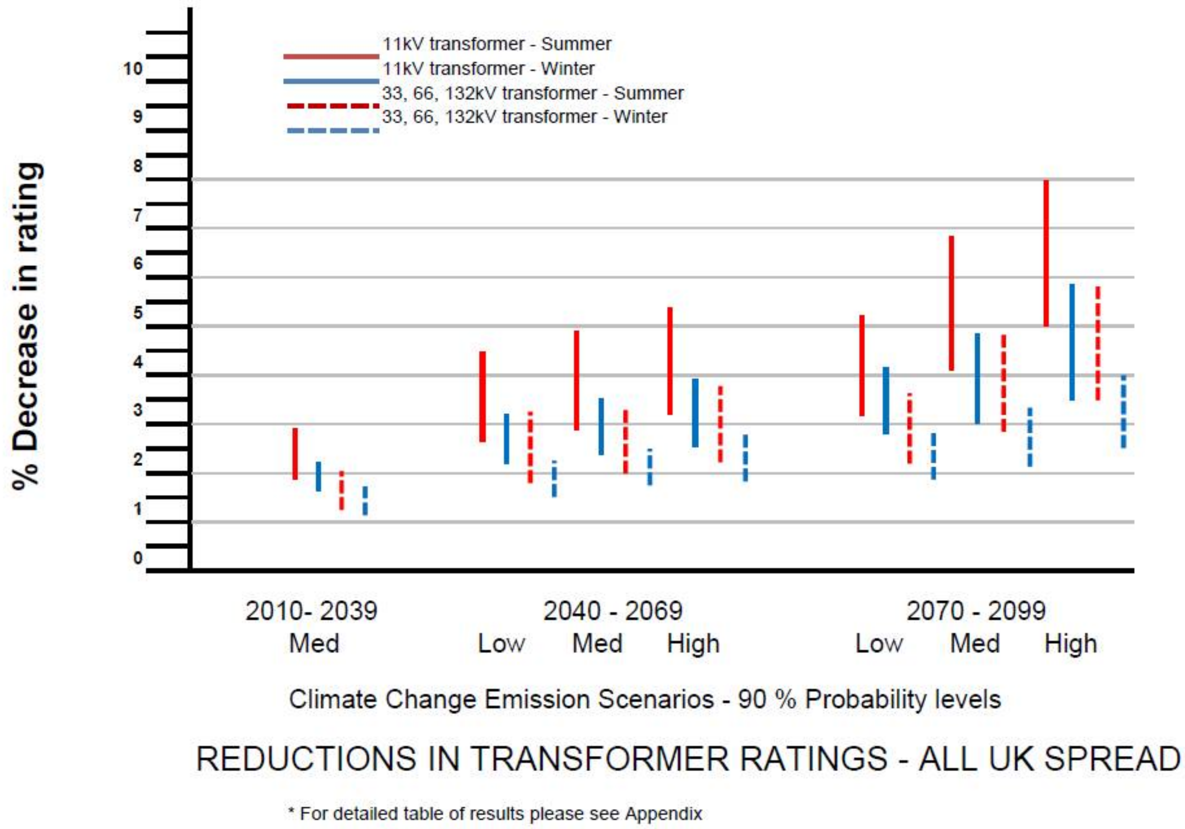

A pole mounted distribution transformer with external cooling tubes.

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 and an 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.

UK DNO transformers have been purchased against British and International Standards extending back to the 1930s (see Appendix 5). These Standards have for many years had 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

Ranges of % de-ratings across UK from UKCP09 are as follows -



Transformer type / season	2010-39 M	2040-69 L	2040-69 M	2040-69 H	2070-99 L	2070-99 M	2070-99 H
11kV summer	[1.8–2.9°C] 1.8–2.9%	[2.6–4.5°C] 2.6-4.5%	[2.8-4.8°C] 2.8-4.8%	[3.3–5.4°C] 3.3-5.4%	[3.2–5.3°C] 3.2–5.3%	[4.1–6.8°C] 4.1-6.8%	[5.0–8.4°C] 5.0-8.0%
11kV winter	[1.6-2.3°C] 1.6-2.3%	[2.2–3.2°C] 2.2–3.2%	[2.4-3.5°C] 2.4-3.5%	[2.5–3.9°C] 2.5-3.9%	[2.7-4.1°C] 2.7-4.1%	[3.0–4.8°C] 3.0-4.8%	[3.5–5.8°C] 3.5-5.8%
33, 66, 132kV summer	[1.8–2.9°C] 1.3–2.0%	[2.6–4.5°C] 1.8–3.2%	[2.8-4.8°C] 2.0–3.4%	[3.3–5.4°C] 2.3–3.8%	[3.2–5.3°C] 2.2–3.7%	[4.1–6.8°C] 2.9–4.8%	[5.0–8.4°C] 3.5-5.9%
33, 66, 132kV winter	[1.6-2.3°C] 1.1–1.6%	[2.2–3.2°C] 1.5–2.2%	[2.4-3.5°C] 1.7–2.5%	[2.5–3.9°C] 1.8–2.7%	[2.7-4.1°C] 1.9–2.9%	[3.0–4.8°C] 2.1-3.4%	[3.5–5.8°C] 2.5-4.0%

Note: Figures in square brackets denote range of projected temperature increases.

Quantities of transformers for UK DNOs as at 31st 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	1018.7

*Source Ofgem – Aggregated Price Control returns (Table T4) [- 132kV excludes Scottish DNO quantities which are captured by Ofgem under Transmission – need to add in]
**The Ofgem Electricity Distribution Price Control Review (Final Proposals document 146a/09 Table 17 FP cost)

5.5. Substation earthing (Risk 6)

5.5.1. Purpose

Earthing is essential to enable faults, to be detected quickly and automatically made safe.

When an earth fault occurs on the electricity distribution network (See Figure 3):

- A large current will flow along the cable and return to the source via the cable sheath and the general mass of earth.
- The current will flow until the source protection disconnects the power supply.
- The current flowing through the earth will cause a considerable rise in voltage - known as rise of earth potential (ROEP) or earth potential rise (EPR) - 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.

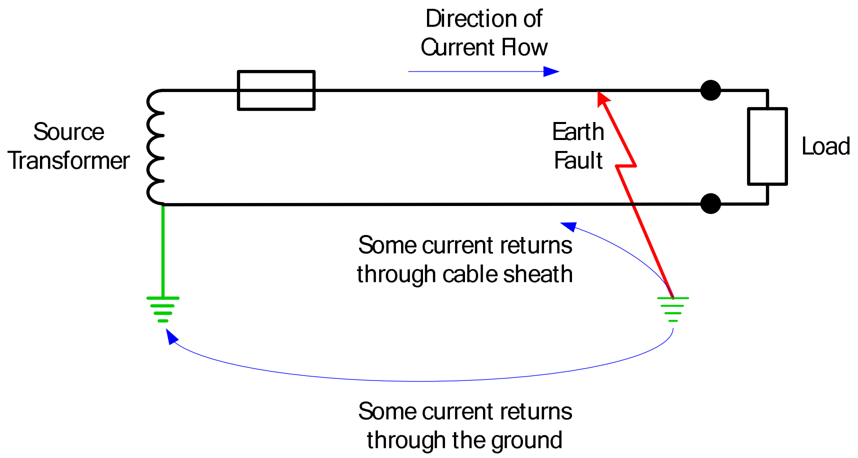


Figure 3 - Earth fault current path

Therefore the purpose of earthing is:

- To pass the fault current during an earth fault back to the system neutral to ensure the source protection system 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.

5.5.2. Description of an Earthing System

An earthing system is a collection of one of more electrodes installed in the ground. The earthing system 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 the earthing system. Where necessary some plant and equipment which might otherwise experience excessive rise of earth potential will be deliberately separated from this 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 9.

5.5.3 Impact of Climate Change on Earthing Resistance

Changes in ground resistance naturally occur throughout the year and the lifetime of the earthing system. The greatest risk is to networks which only support a return path through the ground (such as overhead lines). Those with a metallic path back to source (underground cables) are less affected.

SSEPD undertake regular earth resistance measurements and are able to identify trends brought about by climate change such as changes in land use, water extraction or drainage.

Increases in the value of earth resistance can result in protective equipment taking longer to operate. This is more of an issue at primary and secondary levels where the protection is less sophisticated., On overhead line circuits SSEPD have, for a number of years been installing sensitive earth fault protection which is less susceptible to changes in soil resistance.

The effect on lightning arresters could be more profound. These devices rely on a low impedance path to ground to ensure protection of the equipment. Longer, drier summers resulting in increased soil resistivity, coupled with increases in lightening could see more equipment failures. However, to have any significant effect the ground resistance would have to double its design value.

SSEPD have been verifying the resistance of pole mounted equipment for a number of years. This has not resulted in a significant number of installations being found above their design resistance. These transformers have been in service for periods of up to 40 years. It can therefore be concluded with some confidence that there will be little effect. SSEPD have always used segregated earthing on Pole Mounted Transformers and as such any increase in either the LV or HV earth will have little affect on the safety of Stakeholders.

It should be noted that soil resistivity is more likely to be affected by local effects rather than climatic changes, for example, changes in water table, agriculture practices, surfacing of the land and naturally changes throughout the year.

Table 9 - 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

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

5.5.3. Impact of Climate Change on Earth Resistance

The resistance of an earthing system is mainly determined by the soil/geology in contact with the earthing system and the soil/geology in the immediate vicinity of the earthing installation. Different soil/geology types exhibit different values of resistivity - some typical values are shown in Table 10. Figure 4 provides an indication of the effect of the soil/geology on the earthing installations for the UK Power Networks and Central Networks areas.

Table 10 - Typical soil and geology resistivity values

Soil/Geology Type	Typical Soil Resistivity (Ω/m)
Loam	25 or less
Chalk	50 or less
Clay	100 or less
Clay/Sand/Gravel	150-300
Slate/Shale/Rock	500 or less

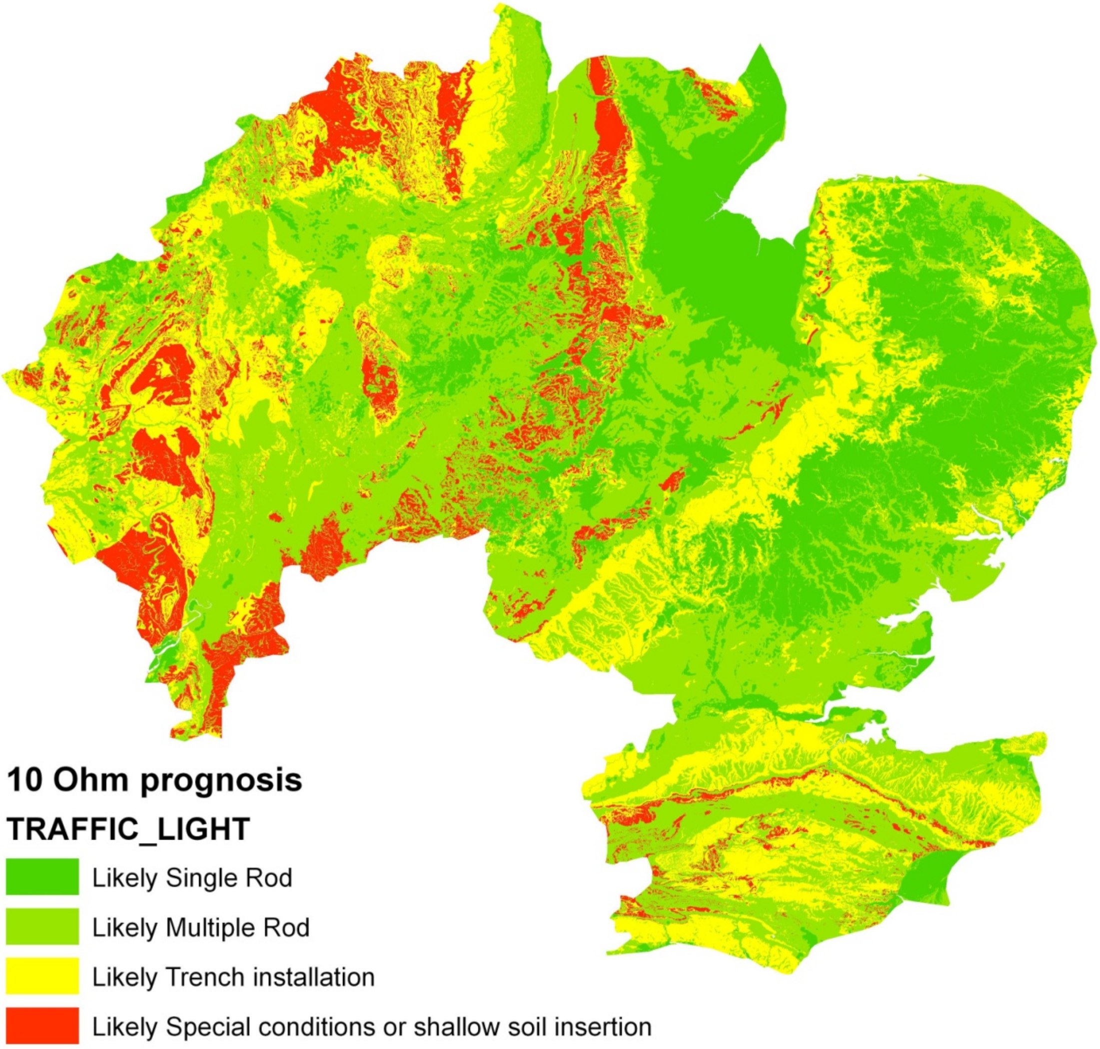


Figure 4 - Typical effect of soil/geology variations on earthing installations

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.

5.5.4. Risk & 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 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 the knowledge from earthing mapping system from phase 1 to highlight those soils and geology types most susceptible to climate change.
- Use 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 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 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 consist of:

- 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 designed to legacy design standards 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.

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5.6.1 Introduction

To some extent grid and primary substations can be sited outside of flood plains. However, where this is unavoidable they are designed to take account of Energy Networks Association Technical Report (ETR) 138, which includes elevated switchrooms for instance. Before purchasing a primary or grid substation site, a detailed Flood Risk assessment (FRA) is carried out as part of the site assessment for suitability, and also to determine the appropriate site levels above which all electrical plant and equipment must be located.

Secondary distribution substations tend not to have the flexibility of location and need to be installed at load centres. SSEPD either locates them on embankments above the flood level or on future networks which ensures that those at risk can be turned off from switches outside of the flood area to speed restoration and minimise supply (customer) impact.

Flash floods are generally localised and do not necessarily occur on recognised flood plains. Although extensive damage can occur this is usually restricted to secondary distribution substations. SSEPD has a strategic stock of plant and cables to cover such events.

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 incur several millions in operating expenses.

It is envisaged that an allowance for both monitoring by inspections, and replacement/upgrading could then be built into future DPCR cycles.

5.6. Substations (Risks AR9, AR10, AR11 and AR12)

5.6.1. Introduction

The relative importance of different types of substation are indicated in Table 2. Substations are key installations on the Transmission and Distribution systems and are built with considerable redundancy, as described below, however, Transmission and Distribution 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.

132kV Grid Substation showing main power conductors at high level but control circuits located in cubicles at lower level

132kV Grid Substation showing 132kV terminal tower (pylon) and start of 33kV wood pole overhead line.


Distribution Substation with equipment operating at 11kV and 400/230 volts

5.6.2. Typical equipment contained within a substation

The types of plant that typically makes up a grid substation include batteries, busbars, metering, relays, switchgear and transformers.

Transformers are also considered separately under Section 5.4.

The general policy for 132kV system design is to establish substations equipped with duplicate 132kV/lower voltage transformers at practicable and convenient locations in the proposed zones of supply, having regard to current loads and possible future load growth together with environmental aspects.

33kV or 66kV substations are normally located as far as practicable at the centre of demand in the proposed zone of supply, having due regard to present loads and possible future growth, future land use and environmental aspects. Care should be 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.

Where possible, new substations should not be sited on land which is 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 PPS 25[7] in England, TAN 15[8] in Wales and SPP 7[9] in Scotland as detailed in ETR 138. Where it is necessary to site a substation on low-lying land, the site may need to be elevated or protected.

An electricity substation protected by flood barriers in the 2007 floods in the North East of England

Distribution Licence Condition 9 required DNOs to comply with a Distribution Code which 'is designed so as to permit the development, maintenance, and operation of an efficient, co-ordinated and economical system for the distribution of electricity'. The adoption of a standard range of plant and equipment for use on the 132kV system helps to achieve this requirement by bringing economies of scale and helps to manage network risks by facilitating the interchangeability of plant under emergency situations.

Switchgear will be 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 specify 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 6.

The selection of switchgear takes into account the following factors:

- Total cost over the lifecycle of the asset,
- Risk of catastrophic failure,

[7] Planning Policy Statement 25 – Development and flood
[8] Technical Advisory Note 15
[9] Scottish Planning Policy Guidance 7 – Planning and flooding

- Substation security,
- Available space,
- Environmental pollution and
- Future availability of additional units.

Substation climate change risks

Flood Resilience

From a Flood Resilience perspective, the following guidance is given in the ETR 138:

i.) Identify all substations (within scope) that lie within a flood plain using the best available current data from the Environment Agency/SEPA;

ii.) 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;

iii.) For each substation that is deemed ‘at risk’, identify the flood impact for that particular site including societal impact;

iv.) Establish if the site is to be protected under a flood protection scheme sponsored by an appropriate public authority;

v.) Establish the most 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.

vi.) Propose an appropriate solution based on flood risk and cost/benefit assessment;

vii.) Review information from the Environment Agency/SEPA 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 1000 floods for grid supply points as appropriate to the practical limitations of the site and the outcome of the cost benefit assessment.

The floodplain 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 the Environment Agency/SEPA, it is recommended in ETR 138 that the potential flood depth is increased by the following amounts:

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

Table 11 - DEFRA Flood and Coastal Defence Appraisal Guidance, FCDPAG3 (Economic Appraisal, Supplementary note to operating authorities – Climate Change Impacts)

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 & 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 soon and it will be necessary to re-assess flood mitigation plans and expenditure in line with this data as and when it becomes available. In addition, the second generation of National Shoreline Management Plans are now available and these include projections for coastal erosion. The information from these plans will also be considered in the assessment of flood risks.

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 and be considered bearing in mind the cost benefit assessment of the design.

1 Construction of a subterranean “wall” around the perimeter of the substation site (including compound and buildings, extending above ground (e.g. concrete, sheet piling).

2 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.

3 Deployment of a temporary flood barrier around the perimeter of the substation site (or specific assets).

4 Relocation of the substation. Removes flood risk.

5 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.

Resilience 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

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 or Scottish Local Authorities.

ETR 138 states that Network Operators 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" for this type of network resilience. The cost/benefit assessments will take into account the societal aspects identified in ETR 138 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 the company determines through its cost/benefit analysis that Level 2 resilience is appropriate in any given case. 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 Ofgem, DECC and the relevant flood protection authority as a means of resolving such uncertainty.

Key substations that form part of the interconnected UK Transmission System and are essential for the maintenance of secure supplies should be considered in the same way as grid substations.

For primary substations the target level of resilience should be Level 2 unless the company determines through its cost/benefit analysis that Level 3 resilience is appropriate in any given case. 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.

Lightning resilience

Lightning storms have the potential to cause damage, latent damage, flashovers and transient interruptions to electricity transmission and distribution networks, for example damage to insulators, bushings and cables. The effects of lightning can be minimised by including both shielding measures and suppression devices into electricity networks.

Metallically enclosed ground mounted substations have inherent protection from direct lightning strikes, but they can be affected by nearby strikes. These can cause surges in connected circuits, especially overhead lines, either by a direct strike or by inducing current in these lines. To guard against these effects it is normal to install shield wires on grid circuits supported by metal structures to provide a preferential path thereby 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 also provides a degree of intrinsic electrical isolation from earth (which reduces the likelihood of a direct strike), but 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.

When flashovers caused by lightning occur, they normally result in high levels of power follow through current, which causes circuit protection to operate. In order to minimise the effects to customers, autorecloser devices are installed on the network to rapidly reconnect circuits automatically after such an event.

It is important to identify if any changes in Lightning Strike density or intensity will occur as a result of Climate Change as these parameters are necessary when designing lightning protection.

Standards for the design and resilience of the electricity networks are set out in the GB Security and Quality of Supply standard and Engineering Recommendation P2/6. This recommendation excludes common mode failure, like flooding. This is because the recommendation does not consider the performance of individual assets and explicitly excludes the loss of busbars (as might occur if a substation were flooded).

5.7 Other Impacts

SSEPD recognise that if load curves become flattened to a greater extent (for example. alternative distributed generation, storage infilling the trough) and the load utilisation factor approaches 1 (fully rated) that networks may become overloaded as these influences are in excess of the original deterministic or probabilistic designs. These effects will have a greater influence than changes in ambient temperature.

Significant work is underway in relation to this effect as part of Smart Grid trials, in particular given the enhanced load factors that Smart Grid is likely to generate on the network.

5.7. Other impacts

The above sections have identified a range of risks which impact on the network assets (premises and processes) that form the key to the UK electricity network infrastructure. There are a range of other potential impacts that have been considered and are described below –

Markets It is likely that climate change itself will bring about a greater take-up of air conditioning load with increased penetration into the domestic sector. However, against this increased demand there are opposing drivers through new building standards and other Government initiatives on thermal efficiency together with EU Energy Using Products Directives. Of greater impact are climate change mitigation actions in support of the low carbon economy, previously mentioned in the Foreword and described more fully in section 6.1 below.

Finance The sector is financed through Price Control mechanisms administered by Ofgem. It will be necessary for the industry to agree with Ofgem and DECC the approach, funding and timescales for adaptation. This is described more fully in section 8.1 below.

Logistics The industry is not reliant upon day by day supply of raw material in the same manner, for example as a coal fired power station. However, it does require supply of new equipment to install new connections for Customers, to build new network extensions or enhance existing infrastructure to meet new demand and to replace old or faulted equipment. These products are increasingly drawn from a European and global marketplace sometimes involving significant shipping distances. Network operators already consider stock holding and replenishment time risks as part of resilience planning and have been subject to review by the former DTI and BERR. Only the largest items cannot be air-freighted if the need arose and it would require simultaneous disruption of road / sea and air transport to have major effect.

The industry staff home life would be subject to the same disruption as the wider public in the event of major water or food shortages. (National Risk Register H49 H50)

People In the event of significant levels of absence due to health/heat impacts, the industry would re-deploy staff from longer term work, onto fault fixing, and then curtail planned work. The plans already prepared for pandemic flu serve as a model for this approach. In addition staff may be affected by disruption to normal travel arrangements caused by extreme events such as flooding or heat waves and there will be dependencies with the transport sector including the Highways Agency and rail and air transport companies.

National risk register elements

The national risk register includes some 50 referenced risks, some of which have a potential relationship with climate change –

H17 Storms and Gales – discussed above under the relevant asset.

H18 Low temperatures and Heavy Snow - Company emergency planning, described under 3.15 above, includes for response to faults. The difficulties in gaining access to fault locations are partly mitigated by widespread use of 4 wheel drive vehicles and the availability of a number of helicopters under direct ownership and control of network operators. It is recognised that road access by 4 wheel drive vehicles can be inhibited by other vehicles blocking roads. However, the climate change forecasts indicate a reduction rather than an increase in this risk.

HL18, 19 and 20 relate to flooding - please see section 5.6 above.

HL21 Land movement – this is referenced in the document as a potential threat to underground cables and structure due to ground drying.

H23 & H24 Pandemic and emerging diseases – please see comment above under "people"

H25 Animal disease – Climate change is likely to result in a migration of infectious animal diseases such as Blue Tongue into the UK. Such diseases may well lead to bars on access to areas of agricultural land, in the same manner as for foot and mouth disease (FMD). The industry has experience of FMD access restrictions, and established processes and protocols with DEFRA. Such restrictions result in a cessation of planned works and inhibit response times to correcting faults on the network. Consequently these have greatest impact when an FMD type access restriction coincides with a period of adverse weather such as severe wind or lightning storm.

H31 & H38 Constraint on supply of fuel – This could arise in the event of transport restriction caused by extreme weather. The industry established a range of mitigation actions, including self storage, in the light of past fuel emergencies, and are identified by Government as a priority user class

H41 & H45 – Technical failure – E3C oversees plans that are in place for major emergencies including recovery from a total failure of the grid system known as "Black Start".

H48 Heat wave – Impacts on assets are described in relevant sections above. Impacts on staff absence please see "people" H23 / H24 above. There are further impacts relating to the ability of staff to work at normal rate, but also relating to the practicality of wearing current designs of personal protective equipment (PPE), such as flame retardant overalls for cable jointing or flame retardant clothing, and insulating gauntlets for "hot- glove" working on live 11,000 volt overhead lines as indicated in the picture below. If staff were unable to work with the current PPE it would mean that fault repairs would be delayed until the heat had reduced (e.g. night time) and planned work delayed. It will be necessary to study the PPE aspect of climate change and seek, if necessary, an evolution to PPE more suited to hot environments (noting that hot glove work is already undertaken in hot climates).

5.8. Strategic risks from climate change on a likelihood/consequence matrix

The strategic risks from climate change identified above are shown on a likelihood/consequence matrix in Table 5.

5.9. Identified short and long term impacts of climate change

The identified impacts over time are shown in Appendix 8 which also quantifies the likelihood, consequences and risks for the three time periods to the end 2020, 2050 and 2080.

Companies may want to provide more detailed information concerning their own particular circumstances.

5.10. High priority climate related risks and why (level of impact to business, likelihood, costs and timescales)

High Priority Risks are not necessarily ones that score High or Very High in the risk overall assessment, but those where there is a need to take action in the short term as indicated in Appendix 8.

Present experience identifies flooding as the highest priority risk. Flooding resilience is covered in this report in Section 5.6 and has been the subject of a separate study detailed in ENA ETR 138. This issue has received particular attention due to the increased incidence of flooding affecting electricity substations, notably in 2005 and 2007. Companies have identified substations at risk and agreed with Ofgem a programme of work for the next five

6.1 Adaptation actions for the top priority risks with timescales

If ambient temperatures increase, the design operating temperature will need to increase to provide the same rating. SSEPD recognise that the majority of distribution lines do not operate near their design operating temperature and even a 5°C rise in ambient temperature will not affect statutory clearance. Even with lines which do operate at their design temperature it is only those spans which have the minimum of ground clearance which will be affected. SSEPD already install taller poles in agricultural areas due to the use of tall machinery above and beyond the existing standards.

As discussed earlier SSEPD are trialling the real time monitoring of conductor temperature to facilitate dynamic line rating and mitigate against temperature related conductor clearance issues.

This may be further mitigated through the use of demand side management and energy storage, both areas being explored as part of our current Low Carbon Networks Projects portfolio.

years with the balance of sites planned for action in the following five year programme. Companies can provide an indication of the locations affected.

Although not shown on the matrix as a major risk, vegetation management is already a cause for concern and is currently subject to a five year programme to improve network resilience under the ESQCR. Companies can also provide further information on a geographic basis.

5.11. Opportunities due to the effects of climate change which can be exploited

A European project addressing the measurement and forecasting of atmospheric icing on overhead line structures is mentioned in Sections 3.2.1 and 5.1.3. (COST 727). The outcome of this study is likely to lead to a better understanding of potential ice loadings and the ability to design more cost effective line structures. In addition, climate change is likely to result in fewer and less severe icing events which should also allow a reduction in design strengths with subsequent cost savings.

6. Actions proposed to address risks

6.1. Adaptation actions for the top priority risks with timescales

Overhead line designs

Section 5.1 above identified the extent of the impact on overhead line ratings caused by increasing ambient temperatures; the most onerous impacts being on wood pole types having design operating temperatures of 50 °C. An increase of 5 °C, for example, in the design operating temperature to 55 °C would mean that a proportion of existing spans of overhead line would sag below required statutory minimum height and would require replacement of the overhead line supports (mainly wood poles) with taller versions.

Given that the normal life of a wood pole support is of the order of 60 years, those that are being installed now, either as part of normal pole replacement or in new lines, will face the range of climate impacts identified in the period out to the 2080s. If the industry were to wait until the need arose to change individual poles because of increased operating temperatures, it would follow that the timing would be unlikely to naturally occur coincident with the need to replace the pole due to deterioration. An assessment of the age profile of the present pole stock is thus warranted and is presented below. This shows (2008 base year) that by 2020, some 53% of poles will be at or approaching 60 year nominal life and are more likely to be approaching need for replacement. The marginal cost of installing a 0.5m taller pole at time of replacement is around £20 (stout) whereas the Ofgem (DPCR5) total unit cost of replacing a single pole is some £1,800 (see 5.1 above).

ENA Member companies thus propose to engage in discussion with Ofgem and DECC with a view to agreeing revised design standards to take effect from the next price control review, starting in 2015.

6.2 Implementation of adaptation actions

SSEPD design new installations to the latest standards and specifications where this is reasonable and practicable given the overall risk.

Number of supports by age profile as at 31/03/2008								
Age	70+	60+	50+	40+	30+	20+	Unknown	Total
Asset categories								
LV Network Overhead lines								
LV Supports	54,881	77,584	369,576	408,361	224,720	187,886	387,918	1,710,926
HV Network Overhead lines								
6.6/11 kV Supports	40,079	56,919	407,397	623,604	279,878	191,082	449,925	2,048,884
20kV Supports	2,665	3,073	15,901	16,860	7,299	6,437	12,220	64,455
EHV Network Overhead lines								
33kV Pole	7,110	16,613	51,477	85,731	44,786	25,389	66,985	298,091
33kV Tower	2,888	1,168	2,639	2,417	1,631	324	504	11,571
66kV Pole	460	1,245	8,931	9,449	3,101	1,505	5,740	30,431
66kV Tower	428	94	1,105	1,172	78	26	79	2,982
132kV Network								
Overhead lines - Supports								
132kV Pole	2	68	1,015	1,647	671	587	3,749	7,739
132kV Tower	4,927	1,849	8,492	9,247	3,832	1,784	3,307	33,438

6.2. Implementation of adaptation actions

It is expected that adaptation will be incorporated in companies' long term investment programmes as indicated in section 6.4. One important aspect is to ensure that new and replacement plant is appropriately specified to take account of possible climate change effects over the lifetime of the equipment.

Accordingly it is proposed to review critical industry standards and this is covered in Section 6.3.

It is expected that flooding adaptation work for current known threats including climate change will be completed over the next ten years.

6.3. Industry specifications and guidance

It is proposed that ENA should review all Technical Standards, Reports and Guidance Documents to identify those that contain references or calculations that are dependent upon parameters that could alter under Climate Change conditions. On completion of this review, a programme could be created to amend these standards, prioritising those that require the greatest change, affect assets with long lives and where the expense of modifying the future installed population is greatest. This programme should use the most appropriate Climate Data available, where necessary commissioning research to understand potential impacts and probabilities. The programme would need to take account of developments in British, European and International standards. Depending on relationships with national and international standards, the programme should be targeted to complete before 2015, with the priority documents addressed by end of 2013 so that the implication of any changes can be considered by member Companies in their Company specific documents before the next price review.

6.4. Cost estimate for adaptation measures and benefits anticipated

INDICATIVE IMPACT COST OF DE-RATING OF ASSETS DUE TO CLIMATE CHANGE 2070-2099 High emission 90% probability							
Asset categories	**Risk Factors**			**Mitigations**		Indicative total impact to 2080 £m	Indicative annual impact - straight line model £m
	National qty	Indicative max % de-rating	Unit cost £k/unit	Assumed % length impacted	Notional life		
Overhead lines cct/km							
LV rebuild	64873	14	28.4	10	50	26	0.516
HV rebuild	168953	14	33.5	10	50	79	1.585
EHV pole	28882	14	42	100	50	170	3.397
EHV tower	3253	14	431	100	80	196	2.454
132kV pole	1773	5	79	100	50	7	0.140
132kV tower	14696	5	1162	100	80	854	10.673
Underground cables							
LV	328037	5	98.4	10	80	161	2.017
HV	153883	6.6	82.9	10	80	84	1.052
EHV	21184	6.5	256.8	100	80	354	4.420
132kV	3188	4.9	1047	100	80	164	2.044
Transformers							
HV/LV ground mount	232968	8	13.2	100	50	246	4.920
HV/LV pole mount	355962	8	2.9	100	40	83	2.065
EHV/HV	4587	5.9	386	100	50	105	2.090
132kV/HV	1946	5.9	1018	100	50	117	2.338
Total						**2645**	**40**

Note:
Quantities from aggregated Ofgem DPCR5 FBPQ Table T4 submissions (HV incl 20kV, EHV incl. 66kV)
Costs from tables 17 and 20 of Ofgem DPCR5 - Document 146a/09 issued 7 Dec 2009
O/h rebuild lengths for wood pole incl conductor and poles - taken from table 20 as above
O/h rebuild cost for steel tower - costs from Table 17 and assumed 10 supports per km
EHV transformer cost is weighted average cost 33 and 66kV on quantity addition embedded in cell D22
% length impacted is less for LV and HV due to tapering of load down length
% indicative max de-rating from draft ENA report
Notional life - estimated (could not find Ofgem ref in DR5 documents as on Health Indices)

7.1 Smart Grids

SSEPD are introducing a trial to determine the benefits and effectiveness of 'Smart Grid' applications on its network.

The effect on newly designed buildings with load management capabilities will have little impact on the network capacity in the short and intermediate term subject to suppliers adopting demand management strategies respectful of network constraints. The primary challenge is the management of existing load and properties; the retro-fitting of air conditioning, heat pumps and the like could have a more serious impact.

SSEPD are undertaking extensive trials through Innovations Funding Incentive, Low Carbon Networks Fund and Department of Energy and Climate Change (DECC) funding to explore these effects and trial a range of mitigating strategies.

Section 2 of this report made reference to the evolution to "smart" electricity networks required to facilitate the evolution to a low carbon economy. Further background is included in section 7.1 below. The consequence of such transition is that climate change adaptation will be enmeshed within other work to replace existing assets and in building new networks. The costs of adaptation then predominantly emerge as marginal costs incurred at the time of the other works, rather than an outright adaptation only cost.

An indicative scale of cost of adaptation impact has been calculated using Ofgem data on asset quantities and unit costs, and applying a "worst case" climate de-rating impact for the 2070-2099 high emission scenario 90% probability model, and using a likely pessimistic pro-rata cost / rating assumption. That indicates a total UK cost, based on the extent of the present day network and current costs, of some £2.6 billion over some 60 years. Detailed modelling would be required matching individual asset age profiles and regionality to arrive at annualised spend, but on a simplistic straight line approach it is of the order of £ 40m p.a nationally. The Companies stress that these figures are only presented to give an indication of scale; as stated above they do not represent detailed analysis, and adaptation would be interwoven with other investment and timing decisions.

6.5. Estimate of level of risk reduction and timescales

Because it is planned to incorporate adaptation measures in normal investment programmes and due to the scale of future planned investment in electricity transmission and distribution networks, it is considered that adaptation measures can effectively be built into the normal programme of work and covered by companies overall risk management processes.

7. Embedding the management of climate change risks in Transmission and Distribution Network Operators

7.1. Smart Grids

The move to a low carbon economy introduces new stresses on electricity networks arising from increased electricity demand from electric vehicles and electrification of heating and cooling with heat pumps and air conditioning loads. Work by the ENA and Imperial College has pointed to a doubling of unconstrained electricity demand well within the timescales out to 2080 covered by this climate change adaptation report.

To avoid the need to massively enhance existing electricity networks to handle this doubling of demand, it is necessary to build monitoring and intelligence into the networks to take automated actions. New and enhanced buildings will have better thermal insulation, meaning that the need for heating and cooling to be “on” for long periods will be diminished, providing the capability to share out and time shift the incidence of demand. In the case of electric vehicles there will also be a need to undertake the same measures though the degree to which time displacement is available will differ between work / shopping and home charging locations.

The ENA / Imperial work indicates that the unconstrained 100% increase in demand can be limited to some 30% through the use of smart network technology. This 70% reduction in impact through smart network technology can also assist in responding to the impact of climate change on de-rating of some network assets. Consequently the use of smart network technology provides an important related adaptation measure, though the prime rationale is facilitating the low carbon economy not adaptation.

The need for and development of smart networks will be overseen by DECC and Ofgem and as such will be captured by existing oversight, monitoring and reporting mechanisms.

8. Uncertainties and assumptions

8.1. Main uncertainties in the evidence, approach and method used in the adaptation programme and in the operation of the companies

Companies' adaptation plans are based on the evidence provided by UKCP09 and this information covers three scenarios for future climate change which are projections and may be subject to error.

Climate change thresholds that started to trigger extreme weather events such as flooding or storms could be critical for Network Operators. As indicated above, experience indicates these events are likely to cause most disruption to society, with the effects of flooding and ice storms leading to potentially very long repair and restoration times.

As indicated in Section 3, at present UKCP09 does not provide any particular guidance on the potential effects of climate change on extreme weather threats but electricity network companies will continue to maintain close contact with the Met Office and other agencies to ensure that the most up to date information is available regarding these potential threats, enabling companies to plan ahead and develop adaptation schemes if this becomes necessary.

A combination of hot periods in the summer combined with very low wind speeds could accelerate the de-rating of overhead lines. Also, very long droughts with resultant soil drying could cause an increase in soil thermal resistivities resulting in further underground cable de-rating.

Increased incidents of severe lightning or wind storms could cause additional damage to overhead lines.

The EA have indicated that information will soon become available predicting increases in flood heights due to a potential increase in river flows of 20%.

An increased likelihood of short term (severe weather) and long term climate effects may require additional maintenance and emergency management with consequent upward pressure on staffing and skill levels.

8.2. Assumptions made when devising the programme for adaptation

The base programme makes the following assumptions until 2100:

- Government regulation will continue to operate without major change.
- Appropriate financing will be in place.
- Customers will continue to have similar requirements.
- Demand for electricity will continue to grow at historic rates.
- Electricity Transmission and Distribution Systems will continue to function in a similar manner to the present day.
- Companies will be able to recruit, train and retain the required levels of staff.
- Suppliers and contractors will continue to provide services on a similar basis.

- Installation, access and maintenance in relation to network cables, overhead lines plant and equipment will remain unchanged.
- There will be no major changes to population numbers or distribution across the country.

9. Barriers to adaptation and interdependencies

9.1. Barriers to implementing companies' adaptation programmes

Electricity network companies are subject to regular Price Control Reviews of their investment programmes by Ofgem in a process described more fully in section 10.1 below. Those Reviews focus strongly on investment programmes, cost efficiency and performance.

Whilst not currently identified as a barrier, the *potential* exists for a conflict of drivers between cost reduction and early pursuit of adaptation measures, given the long lifetimes of electricity network assets, ranging from some 40 – 50 years for transformers 50 years + for wood pole overhead lines and upwards of 80 years for underground cables and steel tower ("pylon") overhead lines. From an adaptation viewpoint there might be a case for upsizing ratings or allowing more ground clearance on overhead lines to take account of future ambient temperature rises, but such measures would not pass a net present value investment test. If however, the industry, together with the Regulator, took the view that it was appropriate to agree relatively modest changes in design standards now, then the net present value issue could be overcome. This type of question is also likely to arise in other Regulated sectors.

Network Companies are regulated by Ofgem and subject to five yearly Price Control Reviews which have an extremely strong influence on capital investment programmes and operational expenditure. Companies will work with Ofgem to achieve a shared view of the potential requirements for adaptation and the associated expenditure. However, companies' plans for adaptation will be dependent on obtaining Ofgem's view of the associated financial investment plans.

Electricity networks are extensive interconnected systems that can only be modified or uprated through a systematic process that is likely to require a considerable period of time. Piecemeal upgrades are unlikely to be cost effective or successful.

9.2. Addressing the barriers identified

Network Operators will seek to resolve the above potential barriers by jointly examining with Ofgem the current assessment of impacts and adaption options, with the aim of agreeing a way forward that will be considered as part of the next round of Price Control Reviews starting in 2015. These discussions will also involve DECC and consider national priorities.

10 Monitoring and Evaluation

SSEPD recognise that the main area of concern when proposing solutions to potential climatic influences is the need to understand the performance of the current network. If, for instance, the deterministic thermal capacity of the soil in far higher then the actual cable ratings will not be affected. If only a few overhead interconnectors are fully loaded then these should be assessed for design under new ambient conditions. Others could be down rated without having any effect on the assets ability to perform its existing function.

9.3. Interdependencies including the stakeholders

A parallel challenge for electricity network companies over the coming decades concerns the change to "Smart Networks". This initiative is planned to support the requirement that Renewable Distributed Generation and Low Carbon Loads can be connected to Networks in large numbers, as part of the programme to meet the 2020/2050 Carbon Reduction targets, whilst still maintaining supplies to customers in a cost effective and reliable manner. This will mean that Networks are likely to undergo considerable change at the same time that work may need to be carried out to improve resilience to climate change impacts.

The scale of the change to "Smart Networks" is likely to be very large entailing the re-design and re-building of many circuits and substations. The resultant upgrade may be far larger than required to accommodate potential adaptation requirements and it will be necessary to understand these two requirements fully before companies submit their financial plans to Ofgem.

Therefore, although it is essential to research fully the potential effects of climate change in order to understand the possible impacts and mitigations, it is probable that the scale of any network upgrades will be dictated by the drive to Low Carbon Networks.

10. Monitoring and evaluation

Some of the issues in this chapter will be company specific, but it is expected that companies will establish their own individual monitoring processes and these will be monitored by Ofgem in future years via established processes.

10.1. Monitoring the adaptation programme

Electricity Distribution and Transmission Companies are Licenced and Regulated by Ofgem under the powers of The Electricity Act 1989 as amended by the Utilities Act 2000. The Act spans a wide range of topics, but of particular relevance are aspects that encompass Price Control, duties on Companies to comply with legislation and on Ofgem to ensure that Companies are adequately funded to discharge their duties.

Another key piece of legislation is the Electricity, Safety and Continuity Regulations 2002 (as amended) ("the "ESQCRs"), which places duties on network companies to ensure their equipment is sufficient for the purposes for and circumstances in which it is used and constructed, used and maintained so as to prevent danger, or interruption of supply so far as is reasonably practicable. Companies are thus already under an ongoing obligation to ensure the adequacy of their equipment against current "normal" conditions.

Ofgem currently undertakes 5 yearly Price Control Reviews of Transmission and Distribution Companies, looking in depth at their investment plans, performance and cost efficiency, and benchmarking network operators against each other. This process is supplemented by an annual Regulatory Reporting process designed to track progress against the 5 year plans. In exceptional circumstances, such as arising from costs imposed by newly introduced legislation within a 5 year Price Control period, Ofgem may agree a "re-opener" against those related areas of cost. The 5 year Price Control frequency is currently under review.

The industry approach to identification, risk assessment and development of mitigation plans for major substations at risk of flooding, provides an illustration of the way in which joint work on adaptation could be pursued. A working group was established under Energy Networks Association, with membership from each of the member electricity network companies together with EA, SEPA, Met Office, DECC and Ofgem. A report was prepared by the Group and submitted to the Energy Minister. That Report has formed the basis of common standard submissions to Ofgem in the recent Price Control review and will be regarded by DECC as the industry standard, if necessary by referencing it, similarly to other ENA documents, in the Guidance to the ESQCRs.

Monitoring by Ofgem of progress on adaptation can then be facilitated via a common approach through the existing 5 yearly Price Control and the annual Regulatory Reporting processes which is companies' preferred approach. This process will continue to use latest information as it becomes available.

10.2. Monitoring the thresholds above which climate change impacts will pose a risk to the company and incorporation into future risk assessments

The thresholds at which climate change will start to present a risk to companies is well understood for a number of impacts, e.g. increased temperature causing a reduction in equipment ratings. In these areas it will be necessary to monitor actual climate change effects and updated projections in order to ensure that planned adaptation activity is sufficient and timely.

In other areas of activity such as earthing systems and vegetation growth further work will be undertaken to identify the thresholds at which action needs to be taken. In addition, research into the impact of air conditioning loads, low carbon loads/generation and smart networks is already in hand and climate change impacts will be factored into this work to ensure that the thresholds are fully understood and appropriate action factored into programmes of work.

Low carbon networks and smart grids are an international issue and Network Operators will be engaged in British, European and International standards work to ensure standards are developed for the new networks and these will need to take account of the thresholds for climate change impacts on an international scale.

10.3. Monitoring the residual risks of impacts from climate change in the company

This section of the report to Defra will be provided by the ENA member company. It will focus on particular company issues and normally include reference to management through the company risk register and regular review.

10.4. Ensuring a flexible response

Working with ENA, companies will continue to review the latest information on climate change projections, including actual recorded climate change outcomes, and update action plans as necessary. This will include maintaining and developing the relationship with holders of key information including Defra, EA and the Met Office. Companies will also maintain a dialogue with DECC and Ofgem as part of annual regulatory reporting and the five yearly price control process. The general position regarding companies' resilience will be continually reviewed via the DECC, E3C bi-monthly meetings and the follow up work in the companies via ENA Work Groups.

Appendix 1

Photographs of Electricity Substations showing overhead line and underground cable connections

Photograph 4 - 400kV Grid Substation showing 400kV terminal tower (pylon)

Photograph 5 - 132kV Grid Substation showing 132kV terminal tower (pylon) and start of 33kV wood pole overhead line

Photograph 6 - Primary Substation showing equipment operating at 33kV and 11k

Photograph 7 - Distribution Substation with equipment operating at 11kV and 400/230 volts

Photograph 8 - 132kV Grid Substation showing main power conductors at high level but control circuits located in cubicles at lower level

Appendix 2

Transmission and Distribution System Information

Transmission and Distribution System Information				
System Voltage	**Overhead Lines (km)**	**Underground Cables (km)**	**Switchgear (No. of)**	**Transformers (No. of)**
Transmission				
400kV	**11,643**	**195**		**363**
275kV	**5,766**	**498**		**441**
132kV	**5,254**	**216**		**290**
DC link		**327**		
Distribution				
132kV Tower	**14,697**	**3,191**	**2,588**	**1,946**
132kV Pole	**1,774**			
33kV Tower	**2,563**	**90,991**	**39,308**	**13,262**
33kV Pole	**26,557**			
20kV	**5,094**	**1,659**	**9,496**	**8,986**
11kV and 6.6kV	**163,868**	**152,224**	**567,399**	**579,944**
LV	**64,874**	**311,237**	**1,112,000**	

Appendix 3

Met Office report published January 2008
EP2 — the impact of climate change on the UK energy industry

Executive summary

This project has engaged the Met Office – a world leading authority on climate science. In conjunction with key energy players, it has developed practical ways to respond to the challenge of climate change in the areas of Renewable, Conventional & Nuclear Generation, Transmission & Distribution network planning, and Energy Trading & Forecasting.

The regulator, Ofgem and the Department for Business, Enterprise & Regulatory Reform (BERR) have been kept informed and advised of the challenges that may need to be addressed. It is hoped their involvement in this project will maximise the chances of influencing future price review decisions.

This has been a year-long project, directed by experts within the industry and supported by the Met Office, which has been delivered on time, to budget and to specification.

Background

This was an industry-funded project involving 11 UK energy companies focussing on the priorities identified by an earlier scoping study. It has been a groundbreaking initiative that has brought climate science closer to business applications; this is the first project sponsored by an entire sector to review the specific impacts of climate change on their industry. Supported by climate scientists, experts from the industry worked together to understand their precise requirements and developed practical applications and business strategies for a changing world.

The project has:

- Developed innovative new techniques that apply climate models to energy applications so that the industry is better placed to adapt to climate change.
- Investigated future wind resource, enabling the industry to understand the continued uncertainty of future wind power. This will assist risk management and investment decisions.
- Modelled future soil conditions and their impact on cables so that Companies can understand the cost and benefits of installing cables for a more resilient future network.
- Built a tool to enable UK coastal and marine sites of interest to be screened to assess if sea level rise should be considered in more detail.
- Investigated how the urban heat island effect may change in the future so that Networks can develop plans for their infrastructure in cities.
- Produced guidance to help make best use of public domain information on climate change such as the United Kingdom Climate Impacts Programme new scenarios of climate change (UKCIP08).
- UKCIP08 will enhance regional detail and will be available in November 2008.
- Delivered new site-specific climatologies of temperature, wind speed and solar radiation that account for climate change so that decisions can be based on realistic climate expectations.
- Examined the relationship between historic weather patterns and network fault performance with a view to developing a tool to predict future network resilience.

The project has found that because of climate change:

- With a few exceptions, such as the thermal ratings of equipment and apparatus, there is currently no evidence to support adjusting network design standards. For example existing design standards for overhead line conductors do not require change.
- The risk profile for transformers will be affected. Design thresholds of temperature will be exceeded more often and there will be more hot nights in cities.
- Soil conditions will change; higher temperatures and seasonal differences in soil moisture are expected. Future conditions could be included in cable rating studies by increasing average summer soil temperatures in the models by approximately 0.5°C per decade.
- The output of thermal power stations (and in particular Combined Cycle Gas Turbines) could be suppressed with higher air temperature meaning lower air density and, in turn, lower mass flow. Conditions at each location should be considered, especially during re-design or new build and, if appropriate, adaptation planned.
- Historical climatologies are no longer valid because climate is not stationary. The new climatologies that take account of climate change are already being adopted and will improve demand forecasting and planning out to 10 years ahead.
- Wind resource is uncertain and understanding future resource represents a significant challenge. Although we don't yet have the answers, this project has highlighted possible strategies for improving our knowledge.

Next steps

To retain momentum an energy and climate change industry group will be set up. This group would be facilitated by the Met Office and would meet as necessary to discuss latest innovations and developments in climate science with leading experts. The group would share thoughts and ideas on areas of common interest as Companies work to adapt to climate change.

Appendix 4

IFI Projects with Climate Change Considerations		
Project Title	**Project Manager**	**Project Participants**
Vegetation Management	ADAS	NG, UKPN, SP, ENW, CN
Pluvial Flood Risk Modelling	ADAS	CN
Future Network Resilience (ENA)	Met Office	All
Dynamic Ratings Project	Met Office	CN
Impact of Climate Change on the UK Energy Industry	Met Office	All
Urban Heat Island Study	Birmingham University	CN
Earthing Information Systems	BGS and NSA	UKPN, CN
Flooding Risk Reduction	Mott McDonald	NG
Investigation to Network Resilience to Weather Events	EA, Met Office	NG, ENA
Flooding Risk Analysis Pluvial Flooding Risks	Total Flood Solutions	NG
Flooding Risk and Severe Weather Mitigation Demountable Flood Barrier Facilitating Work (Phase 1 and 2)		NG

NOTE: NG = National Grid, UKPN = UK Power Networks, ENW = Electricity North West, CN = Central Networks

Appendix 5

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 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 ranging to 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.

Standard etc.	Date	Title	Comment on climate content
BS116	1923	Oil immersed switches and circuit breakers for a.c. circuits	Ambient air temperature up to 40°C
Electricity Supply Acts 1882 to 1936	1931	Electricity Commissioners 1931 design requirements	
BS 171	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
BS 116	1937	Oil circuit breakers oil switches etc for a.c. circuits	Ambient peak up to 40°C with average over any 24 hour period not greater than 35°C
BS 137	1941	Insulators of ceramic material or glass for overhead lines with nominal voltages greater than 1000 V	Lightning withstand, pollution performance and temperature cycling
BS 1320	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

Standard etc.	Date	Title	Comment on climate content
Electricity Supply Act ELC 53	1947	Overhead Line Regulations (differs from 1931 ELC 53 in ref to BS 1320)	Lines to withstand simultaneous 50mph wind and (57 lb / cu ft) ice load with factor of safety. Max conductor temperature 122 F
BS 116	1952	Oil circuit breakers for a.c. systems	Ambient peak up to 40°C with average over any 24 hour period not greater than 35°C
BS 171	1970	Power transformers	Not greater than 30°C average air temperature in any one day or average greater than 20°C in one year Lightning withstand
Statutory Instrument 1355	1970	The Electricity (Overhead Line) regulations 1970	Design for 760 N/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
BS 137	1973	Insulators of ceramic material or glass for overhead lines with nominal voltages greater than 1000 V	Lightning withstand, pollution performance and temperature cycling
BS 171	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
BS 7354	1990	Design of HV open terminal substations	Wind speed, ice thickness, pollution and lightning withstand
PD IEC TR 61774	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

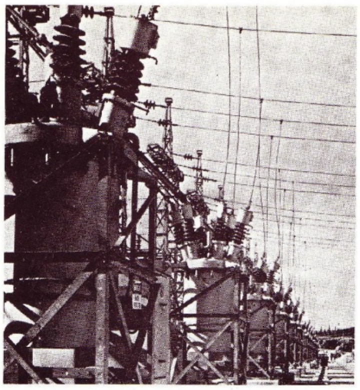
Standard etc.	Date	Title	Comment on climate content
IEC 60265-1	1998	HV switches for rated voltages 1kV to less than 52kV	
IEC 60076-1	2000	Power Transformers	Ambient temperature max 40°C minimum -25°C Lightning withstand
IEC 60694	2002	Common specification for switchgear and control gear (superseded by BS EN 62271-1)	Sets ambient temperatures, pollution etc. E.g. outdoor equipment for -minus 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 24 h, 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 a.c. systems	Ambient not greater than 40°C or less than – 30°C
BSEN 62271 -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 24 h, does not exceed 35°C. Minimum minus 5°C indoor minus 25°C outdoor
IEC 60076-7	2005	Loading guide for oil immersed power transformers	Normal service conditions
BSEN 62271-200	2005	A.C. metal-enclosed switchgear and controlgear 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 24 h, does not exceed 35°C. Minimum minus 5°C indoor minus 25°C outdoor.

Standard etc.	Date	Title	Comment on climate content
BSEN 50423	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
IEC 60947	2007	Low Voltage switchgear and Control Gear	Ambient not greater than 40°C and its average value, measured over a period of 24 h, does not exceed 35°C
IEC 61462	2007	Composite insulators – hollow insulators for use in outdoor and indoor electrical equipment	
BSEN 62271-102	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 minus 5°C indoor minus 25°C outdoor.
IEC 60137	2008	Insulated bushings fro alternating voltages above 1000 V	Standard for bushings (the external connections into transformers, circuit breakers etc) - covers ambient temperature, ice accretion
IEC 60815	2008	Guide for selection of insulation in respect of polluted conditions	
IEC 60529	2009	Degrees of protection provided by enclosures (IP guide)	Ability to withstand driven rain / immersion etc.
BSEN 62271-100	2009	High voltage circuit breakers	links to 60694 ambient conditions 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 minus 5°C indoor minus 25°C outdoor
BS EN 61936-1		Draft standard on substation design	
ENA TS 43-40		High voltage single circuit lines on wood poles	Design includes ref to maps showing combined wind / ice severity by altitude across UK

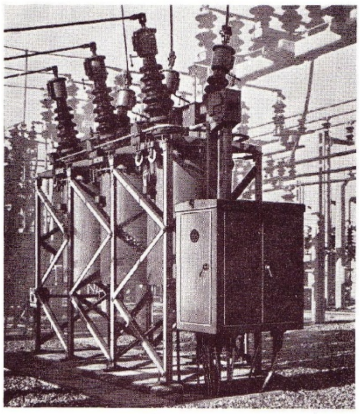
Appendix 5.1
UK Equipment to old design standards in service around the world

AEI SWITCHGEAR - TYPE BL BUSHINGS

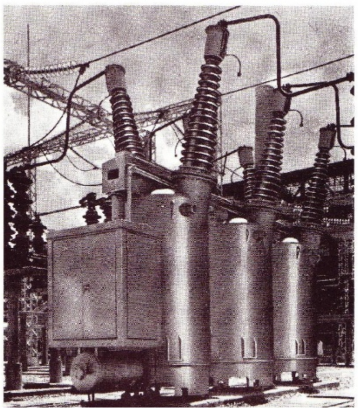
Bushings in Service—



33-kV on Type JB 427 circuit-breakers at Baie Comeau, Canada.



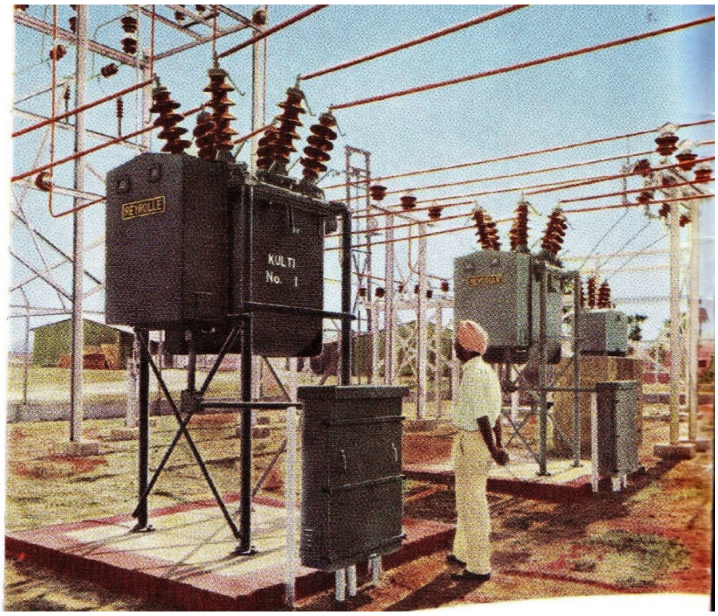
66-kV on Type OW 407 circuit-breakers at Iver, Buckinghamshire.

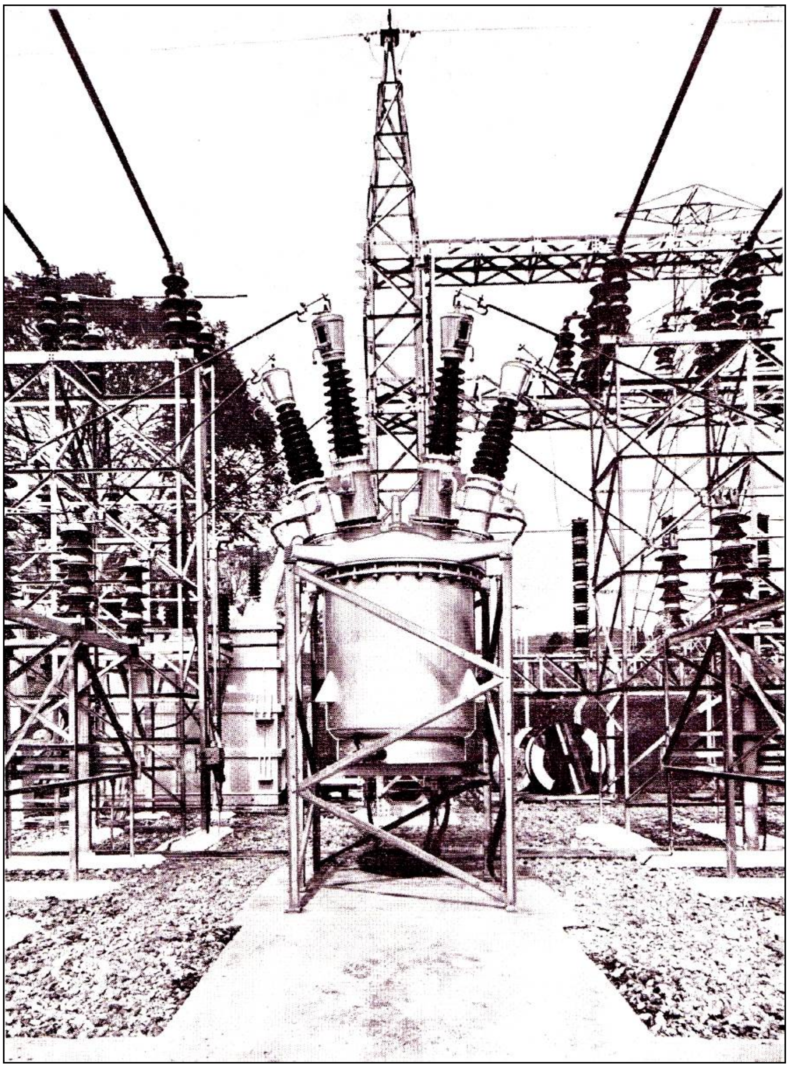


132-kV on Type OW409 circuit-breakers at Taaibos, South Africa.

Temporary leaflet . Issued by AEI SWITCHGEAR DIVISION
Trafford Park, Manchester 17. Code No. 2B

An installation of spring-operated type-ORT2 switchgear in India





Photograph 9 - Rated at 750MVA this Type JB429 oil circuit-breaker is in service on the 66kV system of the Central Electricity Board, Malaya

Appendix 6

Appendix 1

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 controlgear:

- 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 controlgear:

- 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

APPENDIX 7
EXTRACT FROM ENA ENGINEERING TECHNICAL REPORT (ETR) 138
Resilience to Flooding of Grid and Primary Substations

Resilience 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 1or Level 2 above) including provision of limited alternative supplies.	Level 3

As described in Section 7 above electricity supplies may be made resilient through defending key sites against inundation, contributing to a publicly funded area protection scheme or providing network interconnection so that supplies could be maintained even if key sites are disabled due to flooding.

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 or Scottish Local Authorities.

Network Operators 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" for this type of network resilience. The cost /benefit assessments will take into account the societal aspects identified in this ETR and other reviews into the recent floods, in particular 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 the company determines through its cost/benefit analysis that Level 2 resilience is appropriate in any given case. 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 reasonably practicable in the circumstances. If a company is uncertain about the level of resilience, it may consider consulting with Ofgem, DECC and the relevant flood protection authority as a means of resolving such uncertainty.

Key substations that form part of the interconnected UK Transmission System and are essential for the maintenance of secure supplies should be considered in the same way as grid substations.

For primary substations the target level of resilience should be Level 2 unless the company determines through its cost/benefit analysis that Level 3 resilience is appropriate in any given case. 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.

Each company should assess their infrastructure, document a programme of work and factor that programme into their investment plans as appropriate. These will be risk based programmes founded on the guidance established in this ERep and will be dependent on the availability of necessary funding.

Joint Transmission/Distribution sites will be treated as indicated in Appendix 6.

Careful consideration will need to be given to the implementation timescales. The overall timescale will be proposed by Network Operators when flood depth data is available to measure risk and mitigation for the individual substations. Network Operators will need to consider the availability of contractor resources and equipment, the ongoing workload of the Network Operators in other areas and the inflationary implications of overwhelming the contractor market. Appropriate prioritisation and project planning will be required.

As a general principle Network Operators will target the completion of agreed protection to grid and primary substations as follows:-

- Transmission Sites
  By the end of the TPCR finishing in 2022.
- Distribution Sites (Grid and Primary)
  By the end of the DPCR finishing in 2020.

However, these timescales may be extended if additional substations are identified to be at risk due, for example, due to increased climate change allowances and/or visibility of risks associated with surface or ground water flooding.

Network Operators will prioritise their investment programmes to ensure that risk is appropriately managed during the implementation period consistent with available funding for these programmes. If it is likely to take more than one year to implement permanent mitigation then Network Operators should attempt to mitigate risk by establishing site specific actions in their Emergency Plans that will include:-

- Considering the use of temporary barriers and minimising the damage likely to be inflicted by flooding e.g. by ensuring main Transmission Circuits can remain energised whilst the substation is out of action. These short term actions will also be applied if a substation requires relocation, which is likely to be a lengthy process.
- Working with partner agencies under The Civil Contingencies Act to maximise the use of mutual aid and cooperation in order to minimise the impact of any electricity outage. (For any sites identified as being particularly vulnerable Network Operators may want to consider submitting them for inclusion in multi-agency flood plans.)
- Identifying the plant and equipment at risk for a range of flood levels.
- Use of temporary protection for the complete site or most vulnerable plant where reasonably practical and identifying suitable trigger levels, such as Environment Agency Flood Warnings
- Identifying emergency switching or other arrangements to minimise the affects of a substation outage.
- Identifying appropriate response staff and training them in flood resilience response.

APPENDIX 8
RISK MATRIX OVER NEXT CENTURY

Headline climate projection	Illustrative UKCIP data				Projected direct or indirect impacts	Risks and opportunities	Consequences	Stakeholder impacts	2020s		Short term risk	2050s		Medium term risk	2080s		Long term risk	Actions already in place/planned	Potential actions	Timescale for action
		2020s	2050s	2080s					Likelihood	Impact		Likelihood	Impact		Likelihood	Impact				
Warmer drier summers	Temperature increase Deg C maximum predicted rise	2.7	5.2	8.1																
					Warmer summer daytime temperatures	Reduced rating of overhead lines	Some circuits will need earlier upgrading	Some capital works programmes brought forward	-2	-1	-2	-3	-2	-6	-3	-3	-9		Factor rating reduction into forwrad CAPEX programme	
						Reduced rating of underground cables	Some circuits will need earlier upgrading	Some capital works programmes brought forward	-2	-1	-2	-3	-2	-6	-3	-3	-9		Factor rating reduction into forwrad CAPEX programme	
						Reduced rating of transformers	Some transformers will need earlier upgrading	Some capital works programmes brought forward	-2	-1	-2	-3	-2	-6	-3	-2	-6		Factor rating reduction into forwrad CAPEX programme	
						Reduced rating of switchgear	Some switchgear will need earlier upgrading	Some capital works programmes brought forward	-2	-1	-2	-3	-2	-6	-3	-2	-6		Factor rating reduction into forwrad CAPEX programme	
					Heatwaves	Reduced rating of transformers in urban heat islands e.g. London	Some transformers will need earlier upgrading	Some capital works programmes brought forward	-2	-1	-2	-3	-2	-6	3	3	-9		Factor rating reduction into forwrad CAPEX programme	
					Ground drying	Possible damage to earthing systems	Earthing system maintenance increased	Some capital works programmes brought forward	-2	-1	-2	-3	-3	-9	-3	-4	-12		Factor incidence of earthing system upgrades into forward CAPEX programme	
					Ground movement	Possible damage to foundations and underground cables	Increased incidence of network faults	Increased incidence of customer interruptions	-2	-1	-2	-3	-2	-6	-2	-2	-4		Factor incidence of earthing system upgrades into forward CAPEX programme	
						Possible damage to foundations of overheda line structures	Increased incidence of network faults	Increased incidence of customer interruptions	-2	-1	-2	-3	-2	-6	-2	-2	-4			
Warmer wetter winters	Percentage Increased rainfall	20%	41%	73%																
					River flooding	Flooding to most vulnerable substations	Substation equipment seriously damaged and suppies interrupted	Supplies interrupted to customers including emergency services and other utilities. Lengthy and expensive repairs.	-4	-4	-16	-4	-4	-16	-4	-4	-16	In accordance with ENA ETR 138, all substations surveyed and appropriate protection schemes developed for sites at risk		10 years
					Pluvial Flooding	Flooding to most vulnerable substations	Substation equipment seriously damaged and suppies interrupted	Supplies interrupted to customers including emergency services and other utilities. Lengthy and expensive repairs.	-3	-4	-12	-3	-4	-12	-3	-4	-12		In accordance with ENA ETR 138, all substations will be surveyed and appropriate protection schemes developed once EA/SEPA fluvial flood risk data becomes available from late 2010	10 years
Sea level rise	Increase in coastal sea levels	12 cm	26cm	43cm																
					Sea flooding	Flooding to most vulnerable substations	Substation equipment seriously damaged and suppies interrupted	Supplies interrupted to customers including emergency services and other utilities. Very lengthy and expensive repairs.	-3	-5	-15	-3	-5	-15	-3	-5	-15	In accordance with ENA ETR 138, all substations surveyed and appropriate protection schemes developed for sites at risk		10 years
Warmer drier summers and warmer wetter winters	Temperature increase Percentage Increased rainfall	2.7 20%	5.2 41%	8.1 73%	Changes to vegetation growth including increased tree growth	Trees and other vegetation interfering with overhead lines	Increased incidence of network faults	Increased incidence of customer interruptions	-3	-1	-3	-3	-1	-3	-5	-2	-10			

Note regarding UKCIP data
This is illustrative data showing maximum predictions for high emissions and 90% probability. Sea level rises show central estimates for each period of relative sea level change (cm) with respect to 1990 levels. Locations with maximum increases for each period have been slected.

Note regarding Confidence Levels and Thresholds Plesae refer to the comments in Section 5 of the Report.

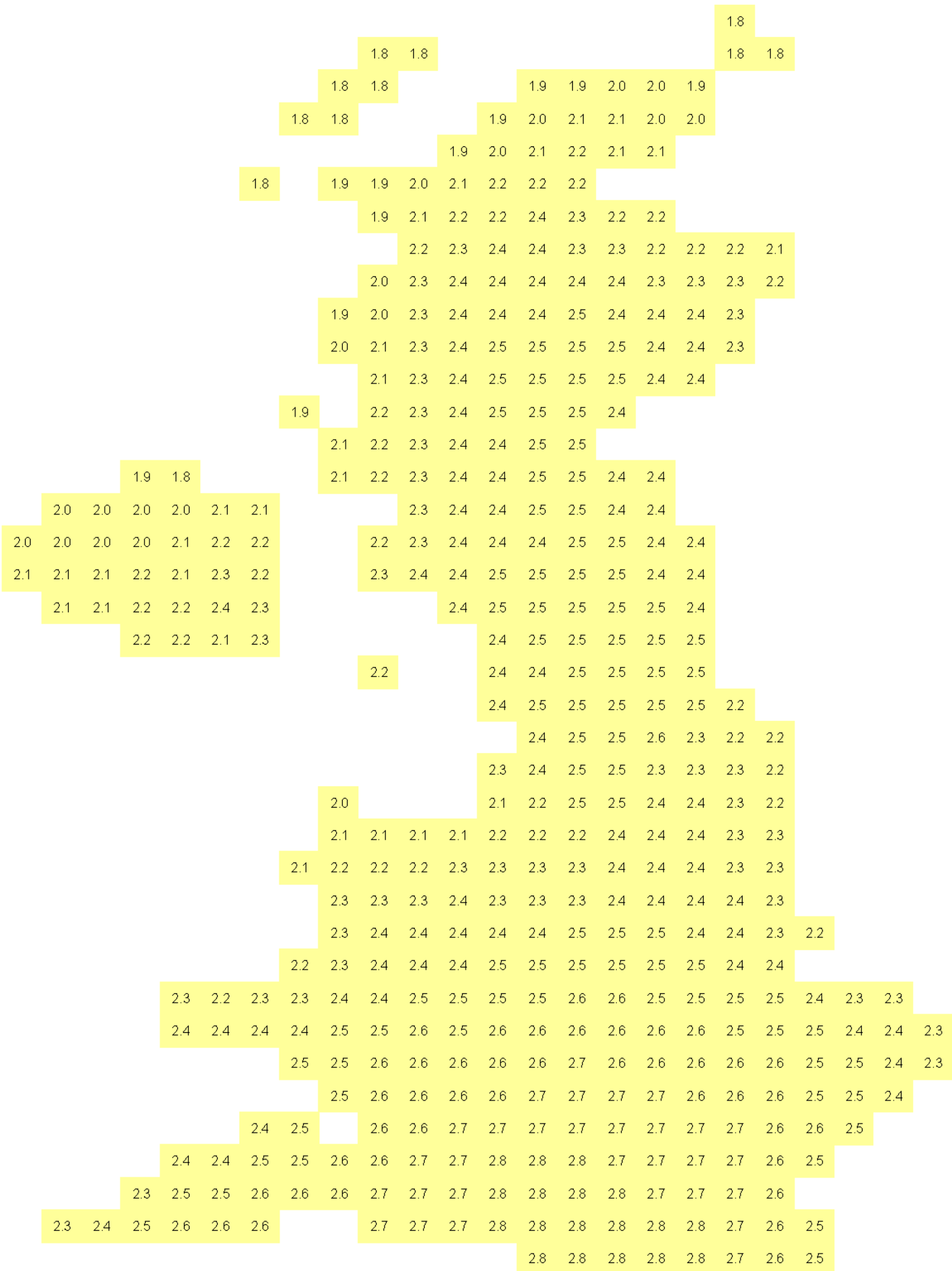
	Likelihood	
Likelihood	1	Rare
	2	Unlikely
	3	Possible
	4	Likely
	5	Almost certain

	Impact	
Risk	-5	Very high
	-4	High
	-3	Moderate
	-2	Low
	-1	Negligible
	0	No change
Opportunity	1	Slight
	2	minor
	3	Moderate
	4	Major
	5	Significant

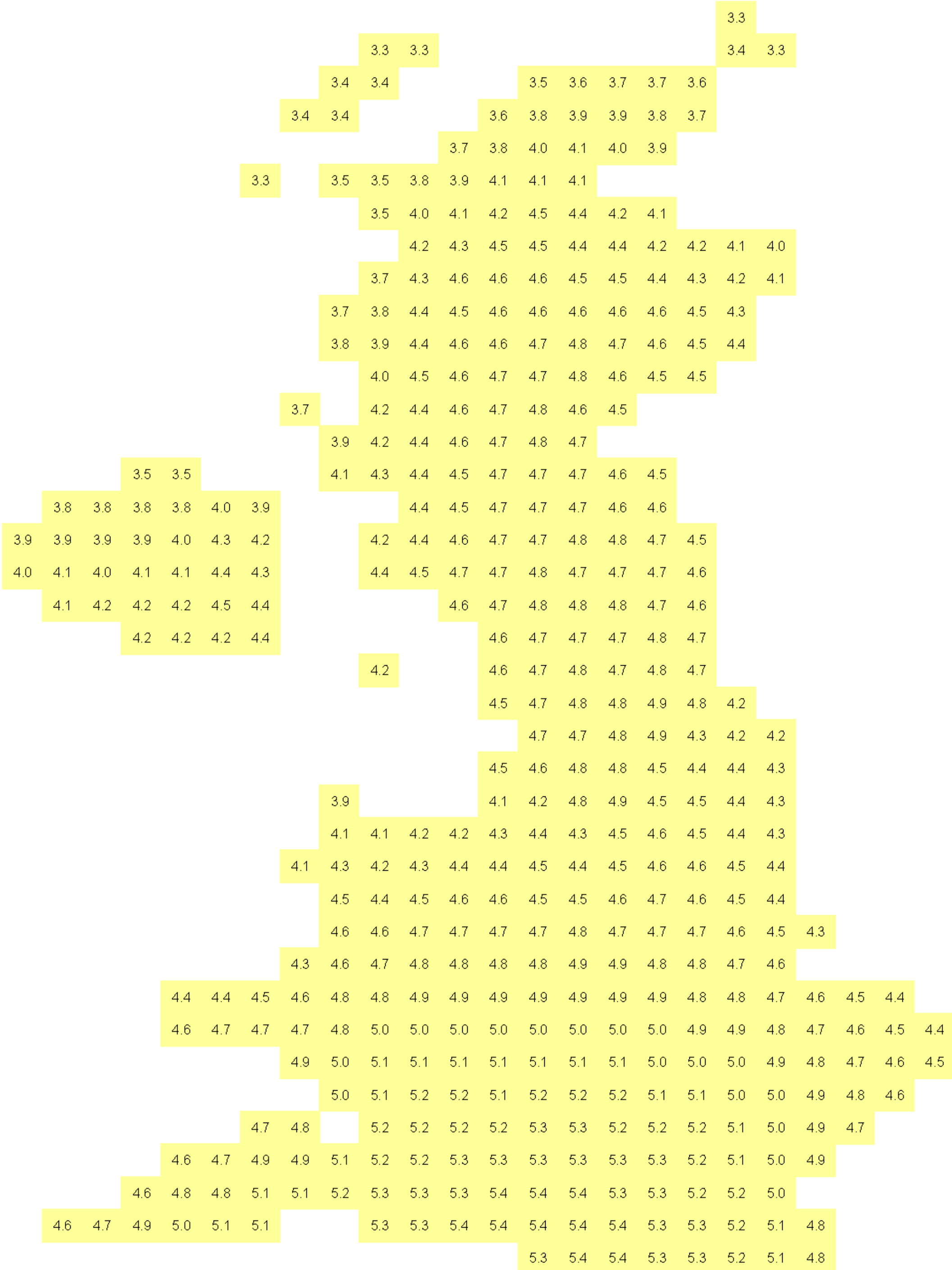
Risk/opportunity matrix							
Risk	-5	Very high	-5	-10	-15	-20	-25
	-4	High	-4	-8	-12	-16	-20
	-3	Moderate	-3	-6	-9	-12	-15
	-2	Low	-2	-4	-6	-8	-10
	-1	Negligible	-1	-2	-3	-4	-5
	0	No change	0	0	0	0	0
Opportunity	1	Slight	1	2	3	4	5
	2	minor	2	4	6	8	10
	3	Moderate	3	6	9	12	15
	4	Major	4	8	12	16	20
	5	Significant	5	10	15	20	25
			Rare	Unlikely	Possible	Likely	Almost certain

APPENDIX 9
UK TEMPERATURE CHARTS
NOTE: Charts for all other emission scenario and seasonal arrangements are available.

PLOT TITLE:	SUMMER MEAN TEMPERATURE CHANGES		
VARIABLE:	Mean Daily Temperature	TIME PERIOD:	2010-2039
MEANING PERIOD:	Summer	EMISSIONS SCENARIO:	High
PROBABILITY:	90th Percentile	MAX: 2.8	MIN: 1.8



PLOT TITLE:	SUMMER MEAN TEMPERATURE CHANGES		
VARIABLE:	Mean Daily Temperature	TIME PERIOD:	2040-2069
MEANING PERIOD:	Summer	EMISSIONS SCENARIO:	High
PROBABILITY:	90th Percentile	MAX: 5.4	MIN: 3.3



PLOT TITLE:	SUMMER MEAN TEMPERATURE CHANGES		
VARIABLE:	Mean Daily Temperature	TIME PERIOD:	2070-2099
MEANING PERIOD:	Summer	EMISSIONS SCENARIO:	High
PROBABILITY:	90th Percentile	MAX: 8.4	MIN: 5.0