LWEC Technical Papers for Infrastructure Report Card – No. 7 ICT

No. 7 ICT: Service structures and networks

Revised Report for NERC and Environment Agency

Ricardo-AEA/R/ED59691
Issue Number 1
Date 30/10/2014

Suggested citation: Horrocks, L., Walmsley, N. and Winne, S. (2014) LWEC Technical Papers for Infrastructure Report Card: No. 7 ICT Service structures and networks. Report for NERC and the Environment Agency.

Acknowledgements: The authors acknowledge the prior work undertaken under contract RMP5604 to Defra dated 2 March 2010, which formed the basis for this paper. We also gratefully acknowledge the helpful review comments from John Beckford on the first draft.

Customer:

NERC and Environment Agency

Customer reference:

4060091157

Confidentiality, copyright & reproduction:

Contact:

Lisa Horrocks
Ricardo-AEA Ltd
Gemini Building, Harwell, Didcot, OX11 0QR
t: 01235 75 3651
e: lisa.horrocks@ricardo-aea.com
Ricardo-AEA is certificated to ISO9001 and ISO14001

Author:

Lisa Horrocks, Neil Walmsley and Sarah Winne

Approved By:

Sarah Winne

Date:

30 October 2014

Ricardo-AEA reference:

Ref: ED59691- Issue Number 1

Highlights and key messages

Impacts of climate change on ICT

ICT structures and networks are potentially vulnerable to a number of current and future climate risks in the UK and internationally. Rather than changes in average climate, it is extreme weather that poses the highest risk. The evidence base is limited and quantified studies are almost non-existent, but based on expert elicitation, the highest confidence risks arise from the impacts of flooding on structures and facilities located in vulnerable areas likely to become more susceptible to extreme weather in future.

However, while the direct impacts of climate change on components of ICT infrastructure are expected to be minor, some critical aspects warrant further investigation, not only to confirm the scale of potential impacts, but also to explore the potential for adaptations which can bring wider system benefits and enhanced resilience to extreme weather events.

Interdependencies

Any weather-related impacts on ICT can have considerable cross-sectoral implications for other infrastructure sectors and business generally, due to complete dependence on ICT. Disruptions to connectivity and ICT service provision will become increasingly unacceptable from both work and social perspectives, which may challenge current reactive approaches in the sector to dealing with extreme weather events. Conversely, the complete dependence of ICT on electricity supply means that ICT is particularly vulnerable to knock-on consequences of climate impacts on energy.

Trends and drivers

Given the pace of development and change in ICT, new risks or solutions can emerge relatively quickly. For example, increasing use of remotely-held data and applications offers simultaneously greater resilience (from the local disruption of single device failure), and greater potential risk (if network connectivity were to fail).

The implications of growth in cloud and distributed computing, and consequent increased reliance upon remote data centres (which can be located anywhere around the world) and continuous connectivity should be priorities for further study. These trends bring both challenges and opportunities for managing and planning resilience in ICT. Control over physical resilience is shifting further away from the end-user.

Management of climate risks

To some extent, as a result of network structure and commercial determinants, the ICT infrastructure is inherently resilient and adaptable to climate impacts, although this is probably rarely the case at the level of an individual end-user.

Adaptation options for the ICT sector will enhance the resilience of the infrastructure, take advantage of new technologies and improve business processes. The deregulated nature of ICT coupled with commercial drive for continuous connectivity may promote autonomous improvements in resilience.

Research gaps

The evidence and research base on climate change impacts on ICT structures and networks, and the ICT sector more widely, is currently limited. There are therefore many opportunities for further research as well as policy-oriented studies to substantiate the largely qualitative findings established in this paper.

Table of contents

Appendices

1 Introduction

1.1 UK ICT

Information and communications technology (ICT) is a relatively new and rapidly developing infrastructure sector. For the purposes of this paper, ICT is understood as the networks, systems and assets which enable the transmission, receipt, storage and manipulation of voice and data traffic on and across electronic devices (following Horrocks et al, 2010). It covers a wide range of interrelated systems and individual components, including: copper and fibre-optic cables, exchanges, masts, aerials and antennae; system devices (e.g. network switches, routers, wireless access points); end-user devices (e.g., computers, telephones, PDAs/tablets and other hand-held devices, SCADA control devices, GPS devices); and the structures and services integral to the provision of ICT (e.g., cloud infrastructure and data centres, call centres, electronic data interchange, on-line commerce). ICT can also be considered to include satellite technologies, applications, big data and information management, though these are outside the scope of this paper.

ICT components and systems are inter-connected and interdependent. ICT is the only sector of national infrastructure that directly connects one user to any other user via multiple pathways simultaneously and with the capability of dynamic re-routing in real time. The national infrastructure asset is therefore the network itself, rather than individual service structures or components: the operation of the network relies on the whole infrastructure to enable the generation of value.

ICT is central to the "business as usual‟ operation of every industry and sector, and the contemporary world is highly reliant on ICT for social and leisure purposes, as well as work. Growing demand for more, or new, or different ICT assumes that the ICT is always available. There is a distinction between public ICT, such as cable infrastructure, and privately-owned ICT, such as dedicated data centres. The responsibility for addressing climate impacts will in some cases fall to the customer or end-user, rather than the public infrastructure provider.

Wireless connectivity, especially via mobile devices, continues to grow as an applied technology offering advantages in speed and cost of deployment. The commercial imperative that drives the ICT sector, coupled with continuing development of applications and usage, is leading to the commoditisation of a number of aspects of ICT, and the result is growth in the number of data centres, outsourced services, call-centres and, cloud computing, in which both data and applications are run across the internet, remote from the user. Such developments mean that the operation of the system relies absolutely on the availability of power and continuous data connectivity.

While the other sectors of national infrastructure in the UK are completely dependent upon ICT, the ICT infrastructure has a very low dependency on other sectors, aside from energy, upon which it is completely dependent (AEA, 2009). The UK's National Adaptation Programme (Defra, 2013) recognises a priority[1] to develop a better understanding of climate risks to ICT service delivery and thereby their interdependencies with other sectors. Velykiene and Jones (2011) provide a brief overview of the current/future status of ICT infrastructure, in the context of future development of the physical infrastructure sectors.

---

[1] NAP Objective 10, "To develop understanding and promote expertise in managing interconnected and interdependent services, to minimise the risks of cascade failures which could be exacerbated by climate change and identify how systems thinking can support this objective."

1.2 The changing climate of the UK

Weather already has the potential to interrupt or reduce the quality of ICT services through a wide range of direct and indirect impacts, including international impacts on supply chains. Extreme weather leading to floods or heatwaves is a particular concern. The changing climate is expected to bring increases in both the frequency and severity of this kind of weather.

Jenkins et al (2009) presented studies of recent trends in UK climate. Average temperature across all regions of the UK has risen since the mid-20th century, as have average sea level and sea surface temperature around the UK coast. Over the same time period, changes in precipitation and storminess have been harder to characterise, with only a slight trend for increased rainfall in winter and decreased rainfall in summer detected over the last 250 years. All regions of the UK have experienced an increase in the amount of winter rain that falls in heavy downpours.

The UK Climate Projections (UKCP09) provide probabilistic information about climate change in the UK over the 21st century (Murphy, et al., 2009). During the course of this century, average temperatures across all areas of the UK are expected to rise, more so in summer than in winter, and more so in southern England than in the Scottish Islands. The largest increases in precipitation are in winter on the western side of the UK. The greatest reductions in precipitation are in summer in the far south of England. The wettest days in winter become wetter in England. Southern England sees the largest decline in summer wettest day rainfall. Relative humidity and cloudiness during the summer decrease in parts of southern England with minimal changes in winter and everywhere else. The Met Office Hadley Centre regional climate model projects reductions in winter mean snowfall of typically 65 to 80% over mountain areas and 80 to 95 % elsewhere, by the 2080s, relative to the 1961-1990 baseline (quoted in Horrocks et al, 2010).

For sea level rise, Murphy et al (2009) developed a high++ (H++) scenario to test vulnerability beyond the standard range of uncertainty included in UKCP09. This indicated that time-mean sea-level rise around the UK could be 93 cm to approximately 190 cm in 2095 (relative to the present day mean of 1980–1999).

The impacts of climate change will also be felt around the world, with different risks likely to be significant in different regions in the very near term, according to the Intergovernmental Panel on Climate Change (IPCC, 2014). In a review of climate risks to UK ICT infrastructure, global changes in climate and their associated impacts are also relevant because networks and services depend increasingly upon international partners, suppliers, materials, and to some extent, skills and expertise.

2 Potential impacts of climate change on ICT

Horrocks et al (2010) provided an overview of the potential climate impacts, risks and opportunities to the ICT sector, based largely upon expert elicitation through workshop discussion and case studies. Experts engaged in that study were unaware of any other research or modelling of climate change impacts on ICT. Future outputs from the Infrastructure Transitions Research Consortium (ITRC) may provide more detailed analysis to support some of the general findings summarised below.

ICT is already vulnerable to weather-related impacts, and may therefore face increasing or new risks from climate change, including potential for interrupted or reduced quality ICT services. Impacts are both direct (on structures and networks in the UK) and indirect (such as through disruption to supply chains and networks overseas, or via other sectors or stakeholders). Climate impacts on ICT can also result in significant knock-ons to other sectors.

2.1 Current and future direct impacts and risks to structures and networks

Industry standards for the individual components which make up the ICT infrastructure require specific tolerances to power supply, temperature and humidity (among other things). The majority of the components and devices typically used in the UK are also used in other parts of the world which already experience environmental conditions beyond the range of UKCP09. Provided such components are appropriately installed and maintained they should accommodate the climate conditions anticipated in the UK this century. RAE (2011) suggests that increases in temperature are likely to have a minimal impact upon the UK ICT network. Velykiene and Jones (2011) agreed that the impacts of climate change on the ICT sector are likely to be, at most, minor ones. While specific incidents (e.g. floods, winds) may impact certain components, those authors found no substantial empirical data or evidence to indicate more significant effects. The climate challenge for ICT is not primarily associated with the performance of individual components and devices, but with extreme changes in the local environments which surround them.

Elements of the network located below ground (such as cabling) are potentially vulnerable to flooding, rising water tables, water ingress (particularly during times of snow melt or flooding), subsidence caused by drought or flooding, and consequential risks arising from damage to other structures (such as bridges) which support ICT. Above ground, structures (such as masts, antennae, switch boxes, aerials, overhead wires and cables) are at risk from precipitation (water ingress), wind, snow (weight), unstable ground conditions (flooding, subsidence) and changes in humidity. High humidity can lead to condensation and risk of water ingress and short-circuiting of equipment. The serviceable lifespan of some components may be affected by increased environmental stress (high winds, temperatures).

The majority of impacts may cause disruption to individual organisations or local areas as a result of parts of the telecommunications network being affected by local weather events. However, there is potential for wider knock-on effects from localised disruption to ICT services on interdependent infrastructure and business sectors. Table 1 summarises the main potential climate impacts on ICT identified by Horrocks et al (2010).

Table 1 Potential climate impacts on ICT and their consequences and level of impact. *(Red crosses indicate a potential negative effect, green ticks a potential positive effect, and black bi-directional arrows where the direction of the effect is uncertain.) Source: Horrocks et al (2010).*

Climate impacts on ICT		**Potential Consequences**						**Level of impact**		
Climate factor	Potential impact	Degradation of	Availability of services	Quality of services	Repair and recovery	Business costs	Health and safety	National	Local	Individual (organisation)
Increase in daily maximum temperatures (and higher frequency of "very hot" days and heatwaves in summer)	Increased risk of overheating in data centres, exchanges, base stations, etc (increased air-conditioning requirements and costs, failure of free-air cooling)		✗			✗	✗		●	●
	Increased heat-related health and safety risks to exposed workers (e.g., maintenance engineers, drivers, staff in exchanges)				✗		✗			●
Increase in average temperatures	Location / density of wireless masts may become sub-optimal since wireless transmission is dependent upon temperature (refractive index)		✗	✗		✗			●	●
	Impact on quality of radio-frequency propagation if vegetation type changes in response to climate			✗					●	
Increase in minimum temperatures (fewer frost days and less snowfall)	Reduced costs of space heating in assets (data centres, exchanges, etc) in winter					✓				●
	Reduced impacts of snowfall on masts, antennae, etc, requiring less maintenance	✓	✓			✓	✓	●		

Climate impacts on ICT		Potential Consequences						Level of impact		
Climate factor	Potential impact	Degradation of	Availability of services	Quality of services	Repair and recovery	Business costs	Health and safety	National	Local	Individual (organisation)
	Less frequent requirement to cope with snow-melt water surge (flood) problems	✓	✓		✓	✓	✓		●	●
Increase in extreme daily precipitation in winter (and higher frequency of "very wet days")	Increased risk of flooding of low-lying infrastructure, access-holes and underground facilities	✘	✘			✘	✘		●	
	Increased erosion or flood damage to transport structures which may expose cables / trunk routes	✘	✘			✘			●	●
	Reduced quality of wireless service with higher rainfall rates			✘				●		
	Increased flood risk to assets located in flood plains or urban environments (increase in flash floods), e.g. data centres, exchanges		✘		✘	✘			●	●
	Increasing difficulty to repair faults and restore service with increasing volume of adverse weather-related problems		✘	✘	✘	✘	✘		●	●
Decrease in daily precipitation in summer (and greater likelihood of drought)	Increased risk of subsidence, reduced stability of foundations and tower structures	✘				✘			●	

Climate impacts on ICT		**Potential Consequences**						**Level of impact**		
Climate factor	Potential impact	Degradation of	Availability of services	Quality of services	Repair and recovery	Business costs	Health and safety	National	Local	Individual (organisation)
Changes in storminess and wind	Changes in storm / wind-loading damage to all above ground transmission infrastructure	⇔	⇔		⇔	⇔			●	●
	Lightning strike damage to transmitters	⇔	⇔	⇔		⇔			●	●
Rising sea levels (particularly in south-east and eastern England) and increase in storm surges	Increased saline corrosion of coastal infrastructure (broadcasting towers, etc	✘				✘			●	
	Increased risk of coastal erosion and coastal flooding of infrastructure (e.g. exchanges) in vulnerable areas	✘	✘		✘	✘	✘		●	●
	Potential change in reference datum for some telecommunication / satellite transmission calculations			✘					●	
Changes in (absolute) humidity	Changes in corrosion rates	⇔				⇔		●		
	Changes in requirements for dehumidification to maintain internal environments within tolerance ranges of system devices					✓				●

Many of the components that make up ICT infrastructure have short lifetimes relative to climate change. Unlike other national infrastructure, some components may be renewed and replaced many times before the major effects of climate change are felt. Thus, the gradual changes in mean climate are unlikely to affect ICT directly, because there is scope for new technologies to adapt with every renewal cycle. The longer-lived assets (buildings used for various purposes, mast structures, and copper (or fibre-optic) cabling) may be susceptible to changes in means but it is more frequent or more severe extreme weather events which present greatest direct impacts on ICT.

Increases in extreme daily precipitation, including very wet days, may have several negative effects upon ICT infrastructure, including increasing the risk of flooding to low-lying infrastructure and underground facilities. It may result in increased erosion and flood damage to transport structures which could expose cables. Precipitation changes (rate of rainfall, size of rain events, distribution of raindrop sizes and whether precipitation falls as rain, snow or in mixed phase) can affect the quality of wireless services through impacts on wave propagation.

Flooding poses possibly the most significant threat to the ICT sector, affecting not only the infrastructure and assets directly but also staff, stakeholders and interdependent sectors. Many parts of the ICT infrastructure are located in flood prone areas as a result of increasing urbanisation of flood plains and are therefore vulnerable to damage and disruption. Infrastructure along the coast may be vulnerable to storm surges and erosion.

Heatwaves increase the risk of overheating in older buildings (such as Victorian exchanges) and lead to increased demand for cooling in data centres. Extreme temperatures bring potential health and safety issues for outdoor or exposed workers. Increases in temperature can limit the range of wireless signals, particularly at extremely high temperatures.

Severe windstorms around the UK have become more frequent in the past few decades (though not above that seen in the 1920s). High winds and storms have the potential to knock down masts and damage above-ground assets, including the power lines supplying energy to the sector. Lightning strikes also pose a threat to transmitters.

With growth in cloud computing, critical vulnerabilities within ICT networks are emerging associated with the physical location of data centres. These have similar climate vulnerabilities to any other built assets, but have additional requirements to consider. Data centres have high power consumption both for operating the technology and for cooling it. Horrocks et al (2010) developed a case study exploring the impacts of future temperature and humidity changes on the cooling requirements for data centres and identified significant concerns for facilities reliant on free-air cooling.

Spatial patterns

The exposure of ICT structures to weather-related damage and disruption depends upon their location. ICT infrastructure is spread across the UK and overseas, though it is often concentrated in urban areas due to the high demand for services. Infrastructure such as above ground cables and transmitters located in the south of the UK will be more exposed to higher temperatures than in the north, for example. Data centres and underground systems will be more exposed to moisture and flooding if located on a flood plain or low-lying ground. Infrastructure located along the coast, including submarine fibre optic cables connecting the UK to overseas networks, is potentially vulnerable to damage caused by erosion, sea level rises and storm surges

Whilst individual structures may be locally exposed to increasing risks from precipitation, flooding, heatwaves and storms, the wide spatial distribution and inherent interconnectivity of ICT help to ensure that the network at a national level is robust. Very few impacts are expected to affect the entire national ICT network, and those that might do are related to potentially minor changes in quality of signal resulting from temperature effects on radio-frequency transmission.

At a local level, however, the impact of extreme weather is more significant, particularly in rural areas, locations at the end of a network line, or areas served by only one or two networks. In fact, mast sharing in remote and rural areas may increase vulnerability due to the dependence of all networks on only one structure. From the perspective of individual businesses, therefore, climate change may pose some additional challenge to the continuation of "business as usual". Such risks for small businesses and remote workers are relatively sensitive to climate change and extreme events such as flooding (CCRA, 2012).

2.2 Indirect climate impacts and risks for UK ICT

Indirect impacts on ICT can arise from climate-related disruption to provision of critical materials and resources within the UK. The occurrence of extreme weather events can prevent staff reaching either their normal place of work or attending sites to repair or restore failed components of the infrastructure (such as base stations, antennae, exchanges). Extreme weather events can also generate increased use (transmission volumes) of the ICT infrastructure as greater numbers work from home or otherwise at a distance from their normal place of work. This increases demand for reliable and resilient ICT networks.

The ICT sector has a relatively low dependency on other sectors for its continuing operation, but is completely dependent upon energy. Any climate-related disruption to critical energy supplies has the potential to cause multiple and wide-ranging impacts on ICT networks. For example, high temperatures during summer could increase demand for energy for cooling of buildings, including data centres, whilst also affecting energy availability such as through de-rating of power lines (operation at less than maximum power in order to safeguard the lines). Increased humidity may also lead to increased degradation of energy equipment and infrastructure (McColl et al, 2012). With increased co-dependence of power and data on the same lines, this is a further risk for ICT.

Particularly in urban areas, many parts of the ICT and interdependent infrastructure are co-located: underground communications cables may run alongside power, gas and water lines and routed through buildings, roads and bridges. In these cases, the failure of one part of the infrastructure can rapidly lead to damage in others (RAE, 2011).

The effects of climate change around the world provide a further source of indirect impacts on ICT. This international interdependence extends not only to the global supply chains supporting provision of materials and devices, but also to the hosting, storage and transmission of data.

Many online and telephone services critical to business and leisure in the UK are hosted at data or call centres physically located overseas. Rising sea levels and extreme weather events may affect the operation of data centres and service centres in low-lying areas such as the Netherlands and vulnerable areas of the sub-continent of India. Raw materials (such as pine for telegraph poles, and rare or precious metals) and components are sourced from or manufactured in different countries, and may face increasing climate impacts on their production and transport. Supporting architectures and infrastructure, such as fibre-optic networks, are routed across the world, and potentially vulnerable to a wider range of climate impacts.

The full range of international climate risks associated with the 'off-shoring' of data and applications, including with growth in cloud computing, still needs research and evaluation. However, as the impacts of climate change are felt more severely around the world, the UK may become an increasingly attractive place to locate ICT infrastructure and components, compared to more exposed and vulnerable regions (RAE, 2011).

2.3 Knock-on effects from climate impacts on ICT

The UK's national infrastructure and wider economy are heavily reliant on ICT networks and services, though there is also a co-dependency. Any disruption to ICT service provision can have knock-on effects and in extreme cases has the potential to result in multi-sector 'cascade failures' (CCRA, 2012).

Across business sub-sectors, ICT forms a fundamental part of organisations' systems and transactions. With the high value of transaction rates per minute, unplanned ICT downtime represents a significant financial risk to business (CCRA, 2012). From a business continuity perspective, it is likely that these risks are understood and planned for by larger companies, though some significant vulnerabilities may remain (e.g., if multinational organisations rely on single-instance business systems[2] operating globally). However, small to medium-sized companies (SMEs) and individual workers may not have systems in place to cope with unplanned disruption to their ICT systems (Baglee et al, 2012).

Because of the increasingly distributed nature of the ICT system, the impacts of a significant failure of ICT in one place are unlikely to be geographically constrained. It is possible for local incidents to have widespread consequences for business and end-users. For example, the failure of a data centre in Sheffield, due to over-heating or flooding, could affect every user whose data travels through or is held in that centre, regardless of where in the world that user is located (Horrocks et al, 2010).

---

[2] Single-instance business systems involve running one instance of a software application on a server, serving multiple users at the same time, potentially at multiple locations around the world.

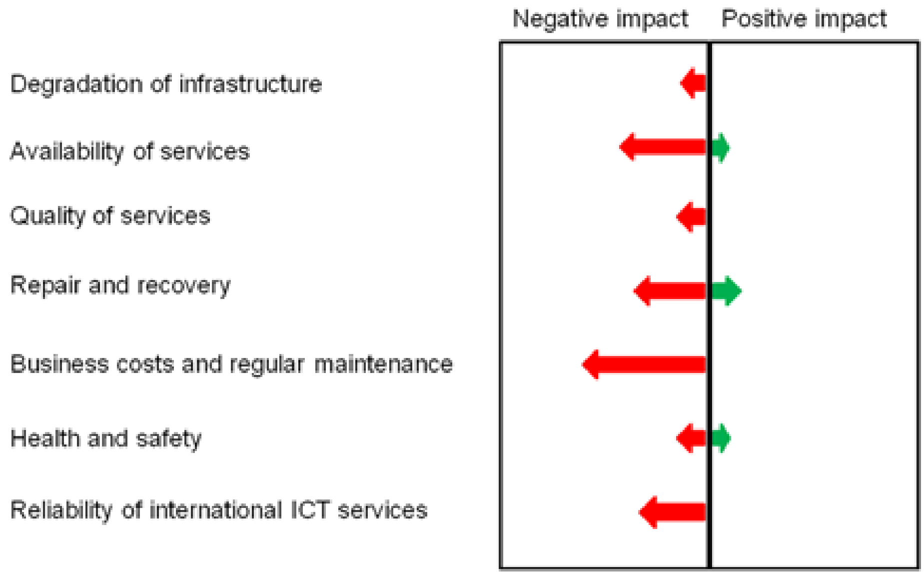
3 Assessment and management of climate change risks

3.1 Assessment

With recent studies from government (e.g. Horrocks et al, 2010, CCRA 2012) and industry (e.g. RAE 2011), there is an increasing awareness of the potential climate change impacts on ICT structures and networks. However, the evidence is predominantly at a qualitative level, with very limited research that has started to assess the magnitude and potential costs of climate change risks. This gap in knowledge has been identified as a priority for further research by the National Adaptation Programme and a number of research projects are under way to address this, including the Infrastructure UK programme 'Interdependencies Planning and Management Framework' programme (Defra, 2013).

Horrocks et al (2010) presented a qualitative assessment of the relative magnitude of the potential consequences of climate impacts on ICT, reproduced in Figure 1.

Figure 1 Relative consequences arising from climate change impacts on the ICT sector.
Source: Horrocks et al (2010)



From the perspective of the national network, ICT is already to some extent both resilient and adaptable for future climate risks. There are two main reasons for this:

- Multiple alternative networks for communication are available. If one fails, there are usually a number of other options to enable communication.
- The technology is developing rapidly, and much of the infrastructure therefore has short anticipated lifetimes. It is therefore inherently flexible and adaptable, with the possibility for "next generation" devices to be increasingly suited to the climates in which they will be operated. Rugged devices for use in harsh climates and for military applications also exist, showing that the technology is already available to address conditions more extreme than those predicted for the UK.

However, from the perspective of an individual end-user, whether a single home-worker, a provider of another national infrastructure service, or a large multinational corporate business, the fact that, at a national level, the telecommunications infrastructure is resilient, may be less important than the realities of whether the ICT services on which they rely locally are available and of sufficient quality for their business purposes.

Horrocks et al (2010) also uncovered the potential for equity issues related to the impacts of climate change in the ICT sector. Rural single-sited SMEs are potentially more vulnerable to localised weather-related disruption of their ICT than larger multinational companies. Larger companies also have a greater capacity to transfer their ICT requirements between sites around the world to mitigate weather risks.

3.2 Management: adaptation opportunities

In ICT, as elsewhere, adaptation actions to address climate risks will rarely be undertaken as a response to climate change alone. Given the backdrop of resilience and flexibility within the ICT sector as a whole, it is those options which provide clear additional benefits (such as cost savings, improved efficiency or resource efficiency) that will be most likely to be adopted. Generic adaptations, focusing on the enabling role of technology improvements and greater co-ordination and information-sharing between stakeholders, apply in the ICT sector. Specific adaptations include awareness-raising, research and development, planning, contingency planning, and adapted procedures.

Management of climate impacts on ICT relies more on the private sector taking action than in other infrastructure sectors. Some providers are considering the issues in the context of contingency planning, and some are beginning to develop adaptation strategies. However, greater awareness of climate risks across key ICT stakeholders is needed. Building on the review of adaptation options by Horrocks et al (2010), we characterise four main areas for adaptation.

3.2.1 Enhancing climate resilience of physical structures and networks

While there is inherent resilience available from the multiple networks which make up ICT, there is potential for resilience to be enhanced to cope with localised extreme weather hazards. The diversity of systems and their interoperability must be maintained or improved to ensure a level of redundancy sufficient to deal with local events that may rapidly put pressure on, for example, mobile networks, at times of crisis.

While urban areas are well-served by a wide range of alternative network coverage, more rural and potentially more vulnerable locations do not receive the same level of service. It may be that further strategic or dynamic nodes could be introduced for specific locations where interconnectivity needs to be maintained under disaster conditions, balanced against cost benefit analysis.

The most exposed and/or sensitive ICT structures can be addressed through improvements in spatial planning and environmentally-appropriate design, just as in any other sector. Planning for the location of key buildings, such as data centres, should place a greater emphasis on long term environmental and climate change considerations alongside traditional commercial drivers. In order to facilitate this kind of planning, there may be a need for mapping and access to relevant data.

Specific adaptation actions appropriate in each circumstance require detailed analysis of local infrastructure, service requirements, and customer relationships. Actions will likely involve customers, ICT infrastructure providers, government, and other stakeholders at national and local levels.

End-user and system devices are not particularly vulnerable to climate impacts. However, in some instances there may be a commercial interest in developing devices and components with higher temperature operating ranges, in combination with advances in, say, energy and water efficiency for data centres.

3.2.2 Technological development

The modular approach to infrastructure design, coupled with a rapid refresh cycle, facilitates incremental adaptation in ICT, allowing progressively more climate-resilient components to be integrated. With respect to devices, there would be only limited benefit from revising technical standards or product specifications as a precautionary response to climate change. In most cases the product life is short relative to climate change. Product designs (and accompanying standards) can be expected to 'evolve' in new generations of devices, in response to a range of drivers, including experience of weather events. The pace of technological change in the ICT sector enables this flexibility, but to maximise the potential for adaptation, greater climate awareness in the research and development parts of the sector may be required.

Whole trends in the sector may be tuned for climate adaptation benefits. Advances in cloud computing provide unique opportunities for enhancing resilience, by, for example, enabling computational load to be transferred from site to site around the globe, to avoid areas of increased local weather risk, but this will depend on good early-warnings and even higher maintenance of connectivity with end users.

3.2.3 Adaptation to address interdependencies

Defra (2013) identified a need for better understanding of the interdependencies between the ICT sector and critical infrastructure to help in planning for the risk of cascade failures. Defra (2013) also recognises the importance of links between the National Adaptation Programme and wider resilience planning in the infrastructure sectors to foster proportionate levels of investment.

Resilience in other sectors dependent on ICT would be improved through increased awareness of the potential risks to ICT structures and networks and increased collaboration and engagement around specific issues. Conversely, ICT companies are generally well-practised at managing risk in their own sector, but may be less effective at considering the implications of risks in related sectors (e.g., failures in the energy sector that affect the ICT sector, extreme weather impacts on road that affect maintenance and repair of telecommunications infrastructure). There is a role for a knowledgeable ICT sector to enable the analysis and management of climate risk throughout service supply chains and to educate customers about the potential risks and opportunities that a changing climate might present.

It may be possible to tune other business processes to drive a market for increased climate resilience of ICT. Procurement procedures could be used to demand an improved level of climate resilience, which emphasises continuity of service rather than compensation for disruption. Organisational protocols for system back-up and information security (such as business continuity standards) already exist, and can provide resilience for both providers and consumers of ICT against disruption from climate events.

3.2.4 Contingency planning and responding to extreme weather events

The telecommunications providers are already well-equipped to deal with weather disruption. However, the approach seems to be to accept that the risk will occur and then respond to its consequences, rather than to be proactive and to reduce or avoid the risk occurring. With increasingly severe and frequent extreme weather, this may become expensive and unsatisfactory.

More comprehensive contingency planning for a range of climate hazards and responses could be supported by wider use of weather event early warning systems, linking infrastructure providers and operators directly with the Met Office and the Environment Agency (for flood, storm and heat warnings). Better collaboration with local authorities may help to ensure a more efficient and effective recovery phase following weather disruption.

Good practice in business continuity should ensure that organisations can develop suitable contingency arrangements for weather-related extreme events (alongside plans for other natural disasters and terrorism incidents). Arrangements may include access to emergency power and backup data centres. Baglee et al (2012) noted that the ability for individual companies to plan for certain events and disruptions may be limited in practice due to the scale of the events, the nature of the organisation and the resources available to them, with larger organisations better able to adapt than smaller ones.

3.2.5 Barriers to adaptation

Horrocks et al (2010) identified a number of challenges and barriers to adaptation in ICT. These included:

- Low awareness of climate change risk and limited efforts to adapt in the wider private sector
- The additional cost of adaptation measures, particularly if dependent on end-users funding the measures, undermining competitiveness.
- The lack of a strong business case for action on climate risk at the level of individual projects
- Ownership and sharing of ICT infrastructure by a large number of organisations can make it hard to assign responsibility for managing risks.
- The increasingly virtual nature of ICT is not well served by existing (geographically-based) approaches to resilience and managing the consequences of hazards
- Uncertainty surrounding the likelihood and consequences of different climate impacts, and limited evidence base on experiences of recent weather events
- The difficulty of designing efficiently for a wider range of futures
- The short timescales of investment cycles and strategic planning relative to the long term planning needed for climate change.

4 Drivers and interactions

Socio-economic and technological drivers are significant in shaping the future development of the ICT sector, and interacting with the impacts of climate change and potential for adaptation.

1. Nature and pace of technological development

The ICT sector continues to grow and evolve rapidly. Massive increases in consumer demand for ICT for leisure as well as business purposes combine with new technological developments and changes in the way individuals and organisations use ICT services. Technological developments such as the growth and widespread use of smart phones, tablets, online software and cloud computing as well as a greater use of remote working has increased the flexibility of working practices, and social connectivity has driven a blurring of ICT use for leisure and work. Demand for ICT services (and the necessary power to operate it) will continue to grow (McColl et al, 2012).

Such developments are increasing the diversification and number of ICT systems, providing multiple routes for information flows and improving the overall resilience of the system. Users of ICT are less dependent upon single routes which may be subject to interruption, though in remote areas where ICT coverage is poorer this may still be the case. (CCRA, 2012)

2. Increasing dependency on ICT systems

ICT is completely embedded in core business processes. Other national infrastructure and the wider economy have been dependent upon effective and continuous operation of ICT for a number of years. Generation and transmission of electricity is dependent on real-time communications for both market and networks operations. At the same time, ICT is increasingly dependent on grid-sourced electricity to operate (Frontier Economics, 2013b).

Interdependencies are increasing, with almost all electronic appliances with a business function having some connection to the wider ICT network. As the UK moves towards a low carbon economy with greater diversification of power sources and more sophisticated municipal systems, smart grids are increasingly needed to effectively and efficiently manage the inherent complexities. While this increase in the role of ICT provides many benefits and allows for more sophisticated approaches to addressing the needs of society, it is naturally increasing the exposure and sensitivity of the UK's infrastructure and economy to failures of the ICT system (CCRA, 2012). Underlying trends towards a highly-digitised and interconnected world will need systems thinking to manage climate, and other, risks effectively.

3. Increasing access of UK population to ICT

Over the past decade, the proportion of the UK's population with access to ICT networks and systems has grown, including lower income groups, older people, and communities in remote locations, increasing access to opportunities. Workers are now more able to work flexibly, from home or when travelling, using broadband and other technology, changing working and commuting patterns (Thornes et al., 2012). Different parts of the economy, such as the farming sector, are also undergoing a shift as younger generations are increasingly using and introducing new technologies into working practices (Frontier

Economics, 2013a). These trends exacerbate the increasing dependence on reliable network connectivity. Cultural shifts in the use of different social networks mean that any disruption to the availability or quality of ICT services is becoming unacceptable.

Despite this increase in access, there are still issues of equal access and continuity of service. ICT systems and infrastructure for people working in remote areas may not be as resilient as those in urban areas (CCRA, 2012). Lower income communities and groups are often more vulnerable to the impacts of climate change due to a range of factors (Banks et al, 2014), and may additionally be those with limited access to ICT.

4. New skills and training

Alongside the new skills and innovations required for technological development in ICT, additional skills and capabilities may be needed in order to enhance climate resilience of networks and structures, and develop adaptation strategies. Many of these skills may already exist within the ICT sector, but it is likely the demand for them will increase and there may be insufficient capacity to address the needs of the sector. Greater collaboration between infrastructure sectors, and with government and universities, may be required to share skills, resources and prioritise actions (RAE, 2011).

5 Confidence in the science

The climate factors that are relevant to ICT are generally well-understood, despite some gaps (such as in relation to microwave radio communications (Paulson, 2011)). However, there is only a limited amount of evidence about the specific impacts that climate will have on ICT. For example, Kovats et al (2014) noted that in Europe, extreme weather events currently have significant impacts in multiple economic sectors (*high confidence*). However, we are less confident about the exact impact of those extreme weather events upon ICT structures and networks in the UK. The rapidly-changing nature of ICT also makes it difficult to assess the degree of confidence in the expected impacts of climate change on ICT infrastructure.

Table 2 provides an estimate of the level of confidence in the different impacts of climate on ICT. In general there is a high or medium level of agreement on the impacts, but this is based on the judgement of the small number of experts and industry stakeholders. Therefore the evidence is generally fairly limited.

Table 2 Assessment of confidence in identified climate impacts on ICT

Climate Factor	Potential impact	Degree of confidence
Increase in daily maximum temperatures (and higher frequency of “very hot” days and heatwaves in summer)	Increased risk of overheating in data centres, exchanges, base stations, etc. (increased air-conditioning requirements and costs, failure of free-air cooling)	High agreement, limited evidence
	Increased heat-related health and safety risks to exposed workers (e.g., maintenance engineers, drivers, staff in exchanges)	High agreement, limited evidence
Increase in average temperatures	Location / density of wireless masts may become sub-optimal since wireless transmission is dependent upon temperature (refractive index)	Medium agreement, medium evidence
	Impact on quality of radio-frequency propagation if vegetation type changes in response to climate	Medium agreement, medium evidence
Increase in minimum temperatures (fewer frost days and less snowfall)	Reduced costs of space heating in assets (data centres, exchanges, etc.) in winter	High agreement, limited evidence
	Reduced impacts of snowfall on masts, antennae, etc, requiring less maintenance	Medium agreement, limited evidence
	Less frequent requirement to cope with snow-melt water surge (flood) problems	High agreement, limited evidence

Increase in extreme daily precipitation in winter (and higher frequency of "very wet days")	Increased risk of flooding of low-lying infrastructure, access-holes and underground facilities	High agreement, medium evidence
	Increased erosion or flood damage to transport structures which may expose cables / trunk routes	Medium agreement, limited evidence
	Reduced quality of wireless service with higher rainfall rates	Medium agreement, medium evidence
	Increased flood risk to assets located in flood plains or urban environments (increase in flash floods), e.g. data centres, exchanges	High agreement, medium evidence
	Increasing difficulty to repair faults and restore service with increasing volume of adverse weather-related problems	High agreement, medium evidence
Decrease in daily precipitation in summer (and greater likelihood of drought)	Increased risk of subsidence, reduced stability of foundations and tower structures	Medium agreement, limited evidence
Changes in storminess and wind	Changes in storm / wind-loading damage to all above ground transmission infrastructure	High agreement, limited evidence
	Lightning strike damage to transmitters	High agreement, limited evidence
Rising sea levels (particularly in south-east and eastern England) and increase in storm surges	Increased saline corrosion of coastal infrastructure (broadcasting towers, etc)	Medium agreement, limited evidence
	Increased risk of coastal erosion and coastal flooding of infrastructure (e.g. exchanges) in vulnerable areas	High agreement, limited evidence
	Potential change in reference datum for some telecommunication / satellite transmission calculations	Medium agreement, limited evidence
Changes in (absolute) humidity	Changes in corrosion rates	Medium agreement, limited evidence
	Changes in requirements for dehumidification to maintain internal environments within tolerance ranges of system devices	Medium agreement, limited evidence

6 Research gaps and priorities

The research base is extremely thin, especially in relation to quantified evidence of impacts. A number of key areas for research exist, including:

- Data and case study analysis of recent weather events on ICT infrastructure, and networks, and collection of related data on the costs of climate-related ICT disruption in the wider economy. This would start to strengthen the business case for action on adaptation, and could lay the groundwork for improved near-real time monitoring of impacts.
- Detailed assessment and quantification of direct climate change impacts on long-lived infrastructure and networks (as presented in Table 1). Evidence is currently predominantly at a qualitative level, with very limited research that has started to assess the magnitude and potential costs of climate change risks. This gap in knowledge has been identified as a priority for further research by the National Adaptation Programme and some research is under way to address this, including the Infrastructure UK 'Interdependencies Planning and Management Framework' programme.
- Specific consideration of data centres, and their design and operation for resilience to climate change impacts, both changes in means and extreme weather events, and for facilities located in UK and globally.
- Specific research related to the performance of individual technologies under climate change (including projections of absolute humidity and examination of potential changes in wireless transmission based on temperature and rain rates in UKCP09)
- Spatial analysis of ICT climate vulnerabilities across the UK, focusing on the identification of critical nodes vulnerable to flood damage
- Distributional analysis of potential climate impacts to ICT (who suffers most, and who pays for greater resilience)
- Vulnerability of overseas ICT networks and supply chains: the full range of international climate risks associated with the 'off-shoring' of data and applications needs research and evaluation.
- Systems-based research, in conjunction with other national infrastructure sectors, to understand the acknowledged interdependencies (including the extent of the ICT connectivity of their assets and the degree to which they rely on ICT for continued operation), and how best to manage weather risks that can lead to cascade failures.

Alongside this, further policy-oriented research would be welcome. There is a wide range of policy options that could be considered to incentivise adaptation in ICT (including support for innovation in research, funding for demonstration projects, public sector co-investment in adaptation measures, measures to embed climate risk in the current market, regulatory incentives, etc). Scoping and appraisal of these options is needed. A policy study to review the potential role of government, the regulator, and existing market structures in addressing climate risks in the ICT sector may be helpful.

7 References

AEA (2009) An Overview of Systemic Interdependencies of the UK National Infrastructure. Report to the Chief Scientific Advisor of DfT and BIS.

Baglee, A., Haworth, A. and Anastasi, S. (2012) Climate Change Risk Assessment for the Business, Industry and Services Sector, UK 2012 Climate Change Risk Assessment Defra contract number GA0204.

Banks, N., Preston, I., Hargreaves, K., Kazmierczak, A., Lucas, K., Mayne, R., Downing, C., Street, R. (2014) Climate Change and Social Justice: An Evidence Review, Joseph Rowntree Foundation. (Available at http://www.jrf.org.uk/sites/files/jrf/climate-change-social-justice-full.pdf [Accessed 23 April 2014]).

Defra (2013) The National Adaptation Programme: Making the country resilient to a changing climate. Defra, London.

CCRA (2012) The CCRA Evidence Report, UK 2012 Climate Change Risk Assessment, Defra, Report No: D.4.2.1 by HR Wallingford ltd, AMEC Environment & Infrastructure UK, the Met Office, Collingwood Environment Planning, Alexander Ballard Ltd, Paul Watkiss Associates, Metroeconomica.

Frontier Economics (2013a) The Economics of Climate Resilience - Agriculture and Forestry Theme: Agriculture Report for Defra contract number CA0401, Frontier Economics Ltd, Irbaris LLP.

Frontier Economics (2013b) The Economics of Climate Resilience - Buildings and Infrastructure Theme: UK Power Generation and Transmission. Report for Defra contract number CA0401, Frontier Economics Ltd, Irbaris LLP, Ecofys.

Horrocks, L, Beckford, J, Hodgson, N, Downing, C, Davey, R and O'Sullivan, A. (2010). Adapting the ICT Sector to the Impacts of Climate Change – Final Report, Defra contract number RMP 5604. AEA group, published by Defra.

IPCC, 2014: Summary for Policy Makers. In: Climate Change 2014: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available from http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf

Jenkins, G.J., Perry, M.C., and Prior, M.J. (2009) The climate of the United Kingdom and recent trends. Revised edition. Met Office Hadley Centre, Exeter, UK.

Kovats, S., Valentini, R., Laurens M. Bouwer L.M., Elena Georgopoulou, E., Jacob, D., Martin, E.,Rounsevell, M., Soussana, J.F., 2014: Chapter 23. Europe.. In: Climate Change 2014: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available from http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap23_FGDall.pdf

McColl, L., Agelina, T. and Betts, R. (2012) Climate Change Risk Assessment for the Energy Sector, UK 2012 Climate Change Risk Assessment, Defra contract number GA0204.

Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A. (2009), UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter, UK.

Paulson, K.S. (2011), The effects of climate change on microwave telecommunication. Presentation at 11th International Conference on Telecommunication, ConTel, Graz, Austria, 2011.

RAE (2011), Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future. Published by The Royal Academy of Engineering on behalf of *Engineering the Future*, London, UK.

Thornes, K. Rennie, M., Marsden, H. and Chapman, L. (2012) Climate Change Risk Assessment for the Transport Sector, UK 2012 Climate Change Risk Assessment, Defra contract number GA0204.

Velykiene, R., and Jones, C.B. (2011) A fast track analysis of ICT constraints on evolving physical infrastructure, ITRC Working paper series No. CS-TR-1282 (available at http://www.itrc.org.uk/wordpress/wp-content/PDFs/Fast-Track-Analysis-ICT-evolving.pdf)

Appendices

Appendix 1 – Headlines from UKCP09

The UK Climate Projections (UKCP09) provide probabilistic information about climate change in the UK over the 21st century (Murphy, et al., 2009). Expected changes[3] under a medium emissions scenario by the 2080s (relative to the 1961-1990 baseline) include:

- Average temperature increases in all areas of the UK, more so in summer than in winter. Changes in summer mean temperatures are greatest in parts of southern England (up to 4.2ºC (2.2 to 6.8ºC)) and least in the Scottish islands (just over 2.5ºC (1.2 to 4.1ºC)).
- Mean daily maximum temperatures increase everywhere. Increases in the summer average are up to 5.4ºC (2.2 to 9.5ºC) in parts of southern England.
- Total annual precipitation amounts show very little change.
- The biggest changes in precipitation in winter are increases of up to +33% (+9 to +70%), seen along the western side of the UK.
- The biggest changes in precipitation in summer are decreases of about –40% (–65 to –6%), seen in parts of the far south of England.
- Relative humidity decreases by around –9% (–20 to 0%) in summer in parts of southern England, but by less elsewhere. Summer mean cloud amount may also decrease in parts of southern England.
- Relative sea level rise, with respect to 1990 levels, shows an increase of 36.3cm for London, 36.2cm for Cardiff, 24.4cm for Edinburgh and 25.3cm for Belfast under the central estimate.

---

[3] The figures provided are the central estimates of change (those at the 50% probability level) followed, in brackets, by changes which are very likely to be exceeded, and very likely not to be exceeded (10% and 90% probability levels, respectively).

Appendix 2 – Interdependencies on ICT

The table indicates some critical interdependencies on ICT (from Horrocks et al, 2010).

The nature of critical dependencies upon ICT	
Category	**Dependence upon ICT**
Business as usual	Customer transactions (including electronic banking) Staff to staff communication (email, phone call, video-conferencing) Financial management E-commerce Ticketing and billing systems Customer/passenger information systems Healthcare provision ATMs
Control Systems	Traffic Signalling Traffic Management Navigation (water borne, satellite and land-based) Vehicles – road and rail Aircraft and Marine Vessels Rail Signalling Air Traffic Management Supply-chain Management Logistics (goods despatch and delivery) Real-time delivery management and reporting SCADA Remote management of pumps and switches in network Water distribution Energy generation and distribution (especially nuclear and 'smart grid') ICT network management (much of the infrastructure is managed through the infrastructure!)
Incident Management	Policing, Fire & Rescue, Ambulance (esp Airwave) Transport delay rectification Natural emergencies (e.g. Cockermouth) Man-made emergencies (e.g. Buncefield)

RICARDO-AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 01235 75 3000
Web: www.ricardo-aea.com