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Climate Resilient Infrastructure: Preparing for a Changing Climate

Synthesis of the independent studies commissioned by the Government's Infrastructure & Adaptation Project

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defra
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Context

On 9th May 2011 the Government published *Climate Resilient Infrastructure: Preparing for a Changing Climate*[1] which sets out the Government's view on adapting infrastructure in the energy, ICT, transport and water sectors to the impacts of climate change.

It makes the case for action, identifies who needs to act, the challenges to acting and the opportunities available. Recognising that infrastructure is largely private sector funded and operated, it sets out how Government can assist others in realising an infrastructure network able to adapt to the impacts of climate change.

The Government's vision is for:

> ***An infrastructure network that is resilient to today's natural hazards and prepared for the future changing climate*.**

This synthesis document is designed to summarise the findings from the four independent studies that the Government's Infrastructure & Adaptation project commissioned and published between 2010 and 2011.

As climate change adaptation and some aspects of infrastructure policy (for example water and transport) are devolved issues this document covers UK Government policy in England and in the UK for reserved matters. It does not cover the work of the national authorities in Wales, Scotland or Northern Ireland in regard to their devolved functions.

Introduction

The Infrastructure & Adaptation project was set up by the Government's Adapting to Climate Change Programme[2] in 2009 as infrastructure vulnerability to the impacts of climate change was recognised as a priority issue that needed to be addressed. The project was established to examine how to improve the climate resilience of infrastructure.

The project focused on four sectors - energy, ICT, transport and water - reflecting the project's focus on national economic infrastructure. Although these are only part of the national infrastructure system they are all vital in their own right and form a set of interconnected networks on which other infrastructure sectors and parts of the

[1] Available at http://www.defra.gov.uk/environment/climate/sectors/infrastructure-companies/

[2] The Adapting to Climate Change Programme is based in Defra and leads on domestic adaptation policy. More information about this programme is available at this link to the Defra website: http://www.defra.gov.uk/environment/climate/adapting/

economy and society rely on to function. They are central in the drive to support the transition to a low carbon, climate resilient economy.

The Infrastructure & Adaptation Project was a priority project under Defra's Adapting to Climate Change Programme. It was chaired by a director at the Department for Transport and brought together senior officials from across the following departments.

- The Department for Environment, Food and Rural Affairs
- The Department for Transport
- The Department for Business, Innovation and Skills
- The Department for Energy and Climate Change
- The Department for Communities and Local Government
- The Cabinet Office
- The Environment Agency
- The Highways Agency

The project's studies engaged extensively with infrastructure experts and organisations including engineers, infrastructure operators and investors. These are listed in Annex A.

Studies Commissioned by the Infrastructure & Adaptation Project

To achieve the aims of the project, four independent studies were commissioned and published. Each study can be accessed online through the Defra website[3].

This document summarises the main findings from each study:

1: *Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change* – URS Corporation Limited
2: *Adapting the ICT Sector to the Impacts of Climate Change* – AEA Technology
3: *Adapting to climate change in the infrastructure sectors* – PwC
4: *Infrastructure, Engineering and Climate Change Adaptation; ensuring services in an uncertain future* – Engineering the Future

All four reports were independent and their findings, conclusions and recommendations were not endorsed by Government but were considered by the Infrastructure & Adaptation project as part of its two-year programme of work to identify and examine strategic solutions to improve the long-term resilience of new and existing infrastructure in the energy, transport, ICT and water sectors to future climate change impacts.

[3] http://www.defra.gov.uk/environment/climate/sectors/infrastructure-companies/

Contents

1. Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change – URS

1.1 Introduction

This study, undertaken by URS Corporation Limited[4], was commissioned to increase understanding of the long-term risks from climate change to energy, transport and water infrastructure.

The scope of the report includes climate change risks to infrastructure as well as the interdependencies across the three infrastructure sectors and how these could be exacerbated by long-term climate change. In the report URS review the adaptation options available, consider the barriers to action and set out a number of recommendations to improve the climate resilience of infrastructure in the three sectors.

Key findings

- Current business and economic planning models tend to focus on the next 10 to 15 years, whereas the design life of infrastructure ranges from 10 to 120 years and parts of the UK's existing infrastructure is older than this. Unless this is addressed it will lead to investment decisions on replacing and upgrading the UK's infrastructure that fail to take into account the impacts of climate change expected beyond the timeframes in the planning models but within the time the infrastructure remains in use.
- Awareness and understanding of the need to adapt to climate change is increasing within each of the sectors, but this is yet to lead to serious adaptation action.
- The focus within each sector remains on responding to climate change's effects as they occur through short-term contingency planning, rather than adapting in advance or addressing the impacts of incremental changes in climatic conditions.
- Perceived uncertainty associated with the impacts of climate change, as well as the financial risks involved, can result in reluctance to plan for the long-term impacts of climate change.
- Uncertainty, potentially long payback times and lack of consideration of the long-term impacts of climate change in the relevant regulatory frameworks means that some businesses find it difficult to justify financial investment in adaptation.

[4] http://www.urscorp.eu/

The study's main findings are set out in this document including:

- the main climate risks identified to energy, transport and water infrastructure;
- the adaptation options available;
- the barriers to action;
- the interdependencies identified; and
- the recommendations made to the Infrastructure & Adaptation project.

1.2 Methodology and approach

The report is based on a literature review as well as stakeholder engagement. A range of stakeholders were consulted, including owners and operators of infrastructure assets, contractors, research institutions, policy makers and regulators.

This included holding a workshop which assessed the vulnerability of infrastructure to projected climate impacts in the 2030s, 2050s and 2080s, evaluating the nature and significance of technical risks and operational implications.

Infrastructure examined in the report

Sector	Infrastructure components	Key elements
Energy	Electricity	Generation, transmission, distribution and supply
	Gas	Production and processing, transmission and distribution, storage, shipping and supply
	Oil	Exploration, production, refining, distribution and supply
	Renewable energy (offshore and onshore wind and hydro-generation)	Production and transmission
	Nuclear	Production, construction and decommissioning of plants
Transport	Road	Motorways, truck roads and local roads
	Rail	Tracks, signalling systems, bridges, tunnels, level crossings, viaducts and key stations
	Ports	Commercial ports
	Aviation	Commercial airports, the Civil Aviation Authority and NATS
Water	Water supply - abstraction, treatment and delivery	Pumping stations, reservoirs, treatment works and pipeline networks
	Waste water collection, treatment and disposal	Sewers, surface water drainage, pumping stations and treatment plants

1.3 Climate change risks to energy infrastructure

The climate impacts that present specific risks to energy infrastructure are:

- increases in precipitation;
- possible changes in wind;
- increased frequency of storms; and
- higher temperatures.

These are all likely to become significant to the sector by the 2050s.

Implications of the risks to energy infrastructure

Infrastructure component	**Key risks**
Fuel processing facilities, storage / transportation of fuel	Increased storminess and sea level rise / sea surges threaten to flood infrastructure
Power generation	Flooding of power plants due to increased precipitation and sea level rise
	Loss of efficiency of fossil fuel power plants due to increased temperatures
	Loss of efficiency of, and storm damage to, renewable energy sources due to increases storminess
Energy distribution systems	Increased risk of damage to distribution systems due to increased precipitation and storminess
	Reduced capacity of networks to distribute electricity due to increased temperatures

Adaptation options and opportunities identified include:

- Upgrade flood defences near vulnerable facilities.
- Increase fuel storage capacity to mitigate for supply disruption, establish contingency plans to enable electricity supplies to be re-routed in the event of disruption.
- Consider focusing investment for new build thermal generation in locations where temperatures are likely to be cooler.
- Make use of smart grid technology to balance the electricity supply network by providing better information on inputs from renewable and other energy sources as climatic conditions vary.
- Increase public understanding and encourage widespread action by the population to manage their energy demands more effectively.
- Energy infrastructure has a significant degree of resilience to climate change. Energy infrastructure around the world operates in a variety of climates including those that are expected to be experienced in the UK as a result of climate change; this experience can be readily transferred to the UK if and when it is needed.

- Due to the shift to low carbon, there is an opportunity to design adaptation measures into new energy infrastructure. It is important to incorporate adaptation in the design and build of this infrastructure as the typical design life of these projects is over 30 years (and up to 100 years for nuclear energy).

1.4 Climate change risks to transport infrastructure

The climate impacts that present specific risks to transport infrastructure are:

- increases in frequency and intensity of storms and extreme weather events; and
- increased flood risk.

Transport operators identified extreme weather events as their biggest threat, referring to recent incidents such as the floods in summer 2007 and gales in January 2007 which caused significant disruption to services.

Implications of the risks to transport infrastructure

Infrastructure component	Key risks
Roads	Flooding from increased precipitation and storminess
	Damage to bridges due to increased river flow resulting from precipitation and storminess
	Damage to road embankments in south-east England due to wetter winters and drier summers
Rail	Flooding from increased precipitation and storminess
	Damage to bridges due to increased river flow resulting from precipitation and storminess
	Damage to road embankments in south-east England due to wetter winters and drier summers
	Overheating of underground trains due to increased temperatures
Ports	High tides / storm surges causing increased sea level at ports
	High winds at ports due to increased storminess
Airports	High winds at airports due to increased storminess

Adaptation options and opportunities identified include:

- For road and rail networks, conduct more frequent and improved inspections of the locations (especially bridges) likely to be affected by flooding.
- Improved inspection and assessment regimes for clay embankments vulnerable to moisture fluctuations.
- Implement an emergency planning regime to be better prepared to cope with passenger health problems in the event of underground trains overheating.
- Improve forecasting of imminent storms to reduce the risks to ports and airports by allowing ships to be safely moored and planes to be safely grounded or diverted to facilities where effects are likely to be less severe.

- Incorporate considerations of potentially changing wind direction and strength into design of new airports and airport expansions.
- Experience in other countries with different climatic conditions shows that there are many adaptation solutions available. Work investigating these opportunities seems to be more advanced in the road and rail industry than for ports and aviation.

1.5 Climate change risks to water infrastructure

The climate impacts that present specific risks to water infrastructure are:

- changing precipitation patterns; and
- increasing likelihood of extreme events.

These changes will be both gradual and sudden, as the projections show long-term trends towards changing patterns as well as increasing likelihood of extreme events.

Implications of the risks to water infrastructure

Infrastructure component	Key risks
Water supply, treatment and infrastructure	Reduced security of water supply due to changing precipitation patterns and periods of drought
	Increased river flooding due to increased precipitation and storm surges
Wastewater collection, treatment and disposal	Increased river and sewer flooding due to increased precipitation and storm surges
	Increased pollution incidents due to changing precipitation patterns and periods of drought

Adaptation options and opportunities identified include:

- Increase capacity and structural stability of water storage to increase the security of supply. This could be achieved though dredging reservoirs, reinforcing dams, creating new reservoirs and underground storage.
- Flooding risks could be reduced by using sustainable drainage systems by making drainage more effective and robust to climate change.
- The water sector is already taking long-term adaptation actions as well as short-term resilience planning. This is partly because the water utilities are regulated to prepare Water Resource Management Plans with a 25 year forecast considering population change, climate change and investment projections.

1.6 Climate risk to infrastructure interdependencies

The UK's infrastructure is highly interconnected; energy, transport, water and Information and Communications Technology (ICT) rely on parts of each other's systems to function properly. Parts of the UK's infrastructure such as gas are also dependent on infrastructure in other countries, and so the impacts of climate change

outside the UK could have knock-on effects on the UK's infrastructure[5]. This is identified as a major area for research and one that needs increased awareness and attention within the UK's infrastructure sectors to ensure interdependencies are understood and effectively considered in business planning.

Sector	Interdependency
Energy	Gas used to generate electricity
	Access to facilities and supply of materials and fuel depends on the transport system
	Water supply critical to cooling at power plants
	ICT important for real-time monitoring of localised energy generation supply to grid
Transport	Energy supply essential for electrified rail lines as well as signals and lighting across the transport system
	Failure in one part of the transport system can shift traffic onto other parts
	Water drainage effects risk of flooding transport infrastructure
	ICT critical for all transport systems (such as signalling and air traffic control) as well as emergency services
Water	Water infrastructure requires energy for operation
	Wastewater sludge often requires transport for off-site disposal
	Water and wastewater systems are highly integrated
	ICT is increasingly important due to increasing demand on remote operation of assets
ICT	Completely dependent on energy supply to function

Two specific types of interdependency are identified in the report. These are 'cascade failures' and 'regional convergences'.

Cascade failures and regional convergences
A **cascade failure** is when the failure of one piece of infrastructure triggers failures in other, interconnected parts. A **regional convergence** refers to a concentration of important infrastructure in an area; as many important systems link though such areas there would be knock-on consequences for the country if these locations were affected by an extreme weather event.

The report advises that a cross-sector group be established to increase information sharing of technical and operational risks as well as appropriate adaptation measures.

[5] This issue will be examined by a forthcoming Foresight project, *The International Dimension of Climate Change*.

Regional convergence case study – Humberside
The Humberside area is an example of a regional convergence. Humberside is supported by a vast network of energy, water and transport infrastructure. The region is densely populated and is vulnerable to flooding due to its low elevation and coastal flood plain location. Floods occurred in 2000 and 2007, the 2000 floods causing over £150million worth of damage. The incident of extreme weather events in the future could impact key infrastructure with more severe consequences if it occurs where different elements of infrastructure converge, such as: • Road and transport infrastructure: the M62 and M180 combined with smaller A-roads link the major centres. Flooding of these could result in significant transport delays. • Gas pipelines: the gas landing station near Hull is supported by a large network of pipelines with significant onward supply to adjacent regions. Coastal flooding and erosion could disrupt supplies. • Power stations: the region includes three major coal fired power stations as well as renewable and combined heat and power capacity. In total these comprise 17% of the UK's energy generation capacity. Loss of generation capacity or damage to transmission systems from flooding would result in loss of power affecting the region and as over 10% of the power is exported, impacts would be felt across the country. • Sea storms also have the potential to disrupt the landing of imports, which could present risks to gas and biomass energy supplies.

1.7 Barriers to adapting infrastructure to the impacts of climate change

URS identify a number of barriers to adaptation across the energy, transport and water sectors. Overcoming these will require national, cross-sector action to provide the policy, regulatory, investment and operational framework that will enable improvements in the long-term resilience of national infrastructure.

Barrier	Action needed
Difficulties in attracting investment to adaptation	Need to ensure that investment in adaptation is incorporated into new infrastructure and refurbishment of existing infrastructure
Policy, standards and design	Need to ensure that policy, standards and design for new and existing infrastructure ensure that the long term impacts of climate change are considered
Business operations	Work needed to incorporate the issue of resilience to climate change into operational business decisions
Interdependencies	Need to identify key interdependencies and vulnerabilities within and between the three infrastructure sectors so that cross sector solutions can be developed
Knowledge and awareness	Need to ensure that the climate change projections, science and impacts are better understood by those in planning, investment and asset management

Societal expectations	Manage the expectations and demands of society to enable greater appreciation of the strains that climate change may put on infrastructure and key services

1.8 Recommendations to the Infrastructure & Adaptation project

The report makes a number of recommendations for Government, industry, regulators and society.

Technical and operational
• Infrastructure providers should identify the likely affects of long-term climate change impacts on new infrastructure and examine and design-in possible acceptable minimum levels of resilience. • New legislation and/or regulation is needed to ensure this happens and that the interdependencies are properly identified and addressed for the design life of the infrastructure. • Funding should be made available to continue the development of the evidence base including knowledge of infrastructure operational thresholds and possible trigger points. • Businesses need to be supported in increasing their understanding of how to use climate projections, such as UKCP09. • New infrastructure should be designed and built so that it can be readily adapted. • Information sharing should be promoted, and a cross-sector forum should be set up to facilitate and promote this. • Industry should review the technical and operational risks from climate change on a regular (3-5 year) basis taking account of developments in climate science to ensure that infrastructure is resilient to long-term climate change.
Ensure maximum available investment
• A case needs to be made for investment in resilience and adaption now. • New financial mechanisms should be developed to ensure that funds for adapting to climate change are available for the duration of the infrastructure's lifetime. • The timescales for 'payback' of investments in new or replacement infrastructure must allow for the potential impacts of future climate change to be considered and accounted for.
Develop policy, standards and design
• Provide a suite of solutions in a single and accessible document that clearly defines appropriate climate change adaptation provisions for infrastructure. • Climate change consideration needs to be incorporated into planning systems as well as standards for upgrading and maintaining existing stock.
Change operational practices
• Integrate long-term operational planning into existing business processes to overcome the shorter term focus of existing business planning. • Embed climate change adaptation into business planning processes.

Inter- and intra- sector solution planning
• Address interdependencies across the three sectors. Interconnections need to be considered between sectors as well as at a variety of scales (national, regional and local).
Improve knowledge and awareness
• Improve understanding of UKCP09 and the tipping points and interrelations between sectors within the planning and engineering profession.
Societal expectations
• Societal behaviour change can form part of the adaptation response, for instance reducing demand for certain services, such as energy. • Industry and Government should work together to develop a communication programme to raise awareness of the need to invest in adaptation measures.

2. Adapting the ICT Sector to the Impacts of Climate Change – AEA Technology

2.1 Introduction

This study, undertaken by AEA Technology plc[6] was commissioned to increase understanding of the long-term risks from climate change to Information and Communications Technology (ICT) infrastructure.

The report examines the technical and operational impacts of climate change on the ICT sector, what this means for other infrastructure sectors and the international aspects of the UK's ICT infrastructure. It also examines how the sector needs to adapt to climate change and how well the structure of the sector facilitates climate change adaptation. Based on this, the report makes recommendations for the changes required to increase resilience and the barriers that need to be overcome.

Key findings
• ICT is to a large extent inherently adaptable and resilient to shocks and changes. It is in a strong position to adapt to climate change. ICT is improving and developing quickly with new technologies being constantly introduced so the system should be able to adapt and evolve as new challenges arise. • The frequency and severity of the kinds of weather events that already cause disruption to the system are increasing at the same time as demand for reliable services is increasing rapidly, so it is important to address the risks that this workstream has identified.

The study's main findings are set out in this document including:

- the main climate risks identified to ICT infrastructure;
- the interdependencies identified;
- the adaptation options available;
- the barriers to action; and
- the recommendations made to the Infrastructure & Adaptation project.

2.2 Methodology and approach

The report is based on an evidence review and workshops. The evidence review provides a clear and robust synthesis of current knowledge and the workshop gathered the views from organisations across academia, policy and government, the regulator, networks and services as well as practitioners in related sectors.

[6] http://www.aeat.co.uk/cms/

The report focuses on resilience to climate impacts, and although it recognises that climate resilience is just one aspect of overall resilience needed within the ICT sector, other elements are not considered in the report. 'Adaptation' is defined as "the actions which can be taken to enhance resilience to climate impacts".

2.3 Climate change risks to ICT

There is a low baseline of awareness of the risks of climate change among ICT providers. The report found little evidence that these organisations are putting in place appropriate climate risk management or adaptation strategies. The report identifies a large number of ways in which climate change may impact on ICT infrastructure and service provision.

Climate variable	Risk to ICT
Increasing temperatures (particularly heat waves)	Increasing risk of overheating in data centres, exchanges and base stations which is likely to increase the air conditioning requirements and costs
Changing temperature, precipitation and humidity patterns	Potential to change the optimal location and density of wireless masts since wireless transmission is dependent upon temperature. Higher temperatures reduce the distance wireless signals can transmit and changes to precipitation and humidity can affect the ability of wireless devices to pick up signals
More extreme rainfall events and rising water tables	Flooding of underground ICT infrastructure and increased subsidence
Increasing frequency and severity of extreme weather events	Damage to above-ground infrastructure
Extreme weather events (such as heavy snowfall)	Potential to prevent engineers reaching sites to restore or repair failed components delaying recovery from the other impacts of these events. This is likely to correspond to a high level of demand on ICT systems as large numbers of people work from home to avoid travelling in the snow

Adaptation options and opportunities identified include:

- ICT is to some extent already resilient and adaptable to future climate risks. This is because there are multiple networks available (meaning that if one fails, there are usually other options to enable communication), the high speed at which technology is developing and the short anticipated lifetimes of ICT infrastructure.
- In some cases it may be worthwhile developing devices and components with higher temperature operating ranges.
- Virtualisation provides opportunities for enhancing resilience by allowing computational load to be transferred from site to site around the globe and so avoiding areas of increased weather risk.

- Technology is developing rapidly and the modular nature of the ICT infrastructure will allow newly developed components to be added when they are needed in response to changing climatic conditions.

2.4 Climate risk to infrastructure interdependencies

All infrastructure is to some extent dependent on the other components of the system, and the ICT sector is wholly dependent on the provision of energy. At the same time every other infrastructure sector is dependent on ICT for its continued daily operation.

ICT services are highly globalised, and this creates complex interdependences.

International interdependencies
The ICT system is interdependent internationally to an extent that is probably unique for the UK's infrastructure, as it covers not just the supply of materials but also the hosting, storage and transmission of the data itself, which can be stored in different countries, and even different continents, from where it is used. This is possible because data is transmitted at extremely high speeds through the fibre optic network. The data centres and service centres used by the UK in other countries could be vulnerable to climate change risks completely different, and potentially more extreme, than those in the UK. This international interdependency puts parts of the UK's ICT system at risk from the impacts of climate change across the globe. The UK's physical ICT infrastructure relies on imported materials including rare metals and pine telegraph poles. Climate change could affect the availability of these materials as well as their shipment if it results in severe weather events that disrupt transport by air and sea.

2.5 Barriers to adapting ICT to the impacts of climate change

Barrier	**Implications**
Relatively low level of climate change risk awareness among ICT providers and users	Little adaptive action taken so far
Short term business model	Does not consider the longer-term and uncertain risks that arise from climate change
Limited evidence base	Makes forward planning harder
Increasing trend towards sharing elements of infrastructure by several providers	Increased challenge for any one organisation to ensure the resilience of its whole ICT system.
Increasingly virtual nature of ICT services, including parts that may be physically located outside the UK	Increased challenge for any one organisation to ensure the resilience of its whole ICT system.

2.6 Recommendations to the Infrastructure & Adaptation project

Enhance the climate resilience of the network

- Maintain the system's inherent resilience at sufficient levels to deal with local events that may rapidly put pressure on networks at a time of crisis.
- Rural areas may not have the same level of resilience as urban areas due to more limited access to networks, and where possible this should be addressed.
- A set of minimum national standards for ICT infrastructure resilience should be used to identify potential areas of weakness and to stimulate adaptation actions.

Take advantage of rapidly developing technology

- Raise the level of climate change awareness within the research and development parts of the ICT sector. Government can support this with funding and the provision of more detailed data sets.
- Explore the potential of using cloud computing to enhance climate resilience by enabling data to be transferred from site to site around the globe, avoiding areas of increased weather risk.

Improve planning and business processes

- Planning for the location of infrastructure and key buildings such as data centres should take into account the predicted future trends of climate change as well as traditional commercial drivers. Government can facilitate this though mapping and providing access to the relevant data.
- Major procurers of ICT services, such as large companies, should use procurement and contractual processes to require an improved level of climate resilience, emphasising continuity of service rather than compensation for disruption.

Improve response to weather events

- Improve contingency planning making wider use of early warning systems and developing better collaboration between providers and operators, as well as the Met Office, the Environment Agency and Local Authorities (to assist preparation and recovery).
- Address adaptation from a local planning perspective, ensuring that critical elements of the ICT infrastructure are not developed in locations likely to be vulnerable to extreme weather events and if they are, that they adopt design standards and performance tolerances capable of dealing with the predicted events.

Research and development

- Develop the evidence base for the likely impact of climate change on ICT services.
- Research the potential roles of government, regulators and existing market structures in addressing these risks.

Raise awareness within the ICT sector
• Raise awareness within the ICT sector of the potential impacts of climate change. The Government can contribute to this, but it is also recommended that the major telecommunications providers organise collaborative efforts to build the business case for companies themselves to address climate risks. • Government, ICT providers and users should work together to review models for ownership, roles and responsibilities in the context of climate resilience, and to conduct a horizon-scanning exercise to scope out the long-term trends in the ICT sector and compare them with climate change.
Climate risk management in the ICT sector
• Government should consider how to draw the IT industry into the Critical Infrastructure Resilience Programme in future, alongside telecommunications infrastructure. • ICT providers and customers should develop corporate climate risk management programmes in the context of their wider risk management strategies and make greater use of weather forecasting for early warning, including linking into the Environment Agency flood warnings.

3. Adapting to climate change in the infrastructure sectors – PwC

3.1 Introduction

This study, undertaken by PwC[7], was commissioned to explore the implications of climate change impacts for both existing and future investment in the energy, water, transport and ICT sectors as well as to examine the role of Government and regulators in encouraging action on adaptation to climate change to maintain robust and resilient infrastructure systems.

The report examines whether the different market, policy and regulatory models in the infrastructure sectors, together with Government policy and legislation more generally, provide adequate incentives for infrastructure providers to consider climate resilience across their existing economic infrastructure and future investment. It considers infrastructure in the energy, water, transport and ICT sectors.

Key findings
• The UK faces less severe climate impacts than many other countries, and appears to be amongst the leaders in considering infrastructure adaptation. • The UK should build on this relatively strong position as early action and preparation could give the country a competitive advantage in terms of increased resilience to climate change, as well as producing technologies and skills for export. • There is a rising level of awareness of the need to adapt to climate change due to improved scientific and technical knowledge, media interest, Government action and the work of market leaders. Some investment decisions are already taking potential adaptation measures into account. • Adaptation cannot eliminate the impacts of climate change completely, and in some cases it can be efficient to accept some residual risks. • Successful adaptation includes identifying the risks from climate change, incentivising decision making to address these risks and developing systems that are robust over the long-term as clearer information about climate change emerges. • Successful adaptation needs to consider interdependencies, and address them though a systems approach. • Private sector led adaptation should be promoted and encouraged by levering existing market forces; these are likely to become stronger drivers as markets become more familiar with climate risks and adaptation solutions.

The study's main findings are set out in this document including:

- the role of Government, regulators in adaptation the UKs infrastructure to the effects of climate change;

[7] http://www.pwc.co.uk/

- the barriers to action; and
- the recommendations made to the Infrastructure & Adaptation Project.

3.2 Methodology and approach

PwC conducted a literature review which they used to identify the key market developments in the infrastructure sector. They also used this review to inform their assessment of the appropriateness of different adaptation decisions. This was followed by an analysis of the investment decision making process of investors, owners and operators of new and existing infrastructure. This was informed though engagement with relevant stakeholders, including the owners and operators where relevant, as well as the use of case studies (Drax Heron biomass plant and United Utilities East-West mains link). PwC used the risks identified by the URS study to inform this study.

3.3 The roles of different stakeholders in infrastructure adaptation

The report outlines the roles of key stakeholders to implement adaptation action in infrastructure.

Stakeholder	Roles
Government	• Raise awareness and encourage action in infrastructure adaptation though information provision and use of the Climate Change Adaptation Reporting Power • Foster partnership working across sectors and between different stakeholders • Maintain and update existing information provision initiatives (such as UKCP09 and the Climate Change Risk Assessment) • Facilitate cooperation across companies and sectors on developing greater or more in-depth understanding of risks
Regulators	• Although climate change is not explicitly prescribed as a statutory duty for many regulators it is embodied within their wider mandates (such as protecting short- and long-term consumer interest as well as security of supply) • Therefore they should use the levers they have to incentivise adaptation, balancing the needs for adaptation against concerns for efficiency and value for money
Investors and insurers	• Greater disclosure of climate change risks and adaptation actions should help to increase their understanding and catalyse action

Infrastructure operators	• Need to increase their consideration of adaptation in their projects. This can include physical design and location, operational procedures and building or retrofitting additional resilience features, to emergency and contingency planning • By addressing climate risks, operators should see long-term benefits in more resilient infrastructure, enhanced security of supply and reduced costs • Owners and operators of infrastructure need to embed adaptation thinking throughout their organisations and work with other infrastructure companies, regulators and Government to address cross-sectoral risks and interdependencies
Local authorities and local enterprise partnerships	• Encourage and coordinate action at the sub-regional level, bringing together infrastructure operators and other stakeholders to address climate risks at the local level • Catalyse funding for cross-sectoral initiatives and encourage more targeted solutions • Co-ordination and facilitation across these local groups should also encourage action nationally

3.4 Barriers to adapting infrastructure to the impacts of climate change

PwC identified a number of challenges which will need to be overcome for the UK to successfully adapt.

Barrier	Implication
Information gaps, and existing information not sufficiently tailored for some stakeholders	• Awareness tends to be driven by recent events, or emphasis within existing policy or regulation • There is low or little appreciation for the need to consider interdependent risks across sectors or networks
Uncertainties with long-term adaptation needs	• Uncertainty weakens the business case for adaptation, making it harder to secure resources for adaptation projects
Adaptation must be balanced against other priorities	• Even when climate change risks are considered, building in climate resilience still needs to be balanced against other objectives, and tends to be a low priority
The short-term focus of some regulators, many of which do not have climate change adaptation as an explicitly prescribed statutory duty (although it is embodied within wider mandates)	• The emphasis on short-term value for money within some regulators, against a backdrop of a recovering economy, means adaptation measures are not being addressed on a systematic basis by regulators

Competition with other priorities for attention at the Board level or from shareholders in the private sector	• Except for very large, long-life assets, or where the risk is particularly significant, adaptation may not always receive sufficient attention at Board level or from shareholders
Poor understanding of interdependencies within and between infrastructure sectors	• This has resulted in interdependencies being given a lower priority for adaptation, despite their importance

Case Study: United Utilities West-East Link Pipeline[8]

United Utilities are building a 55km water pipeline to link Prescot reservoir in Merseyside to Woodgate Hill reservoir in Bury, Greater Manchester at a cost of £125million. The pipeline will have a capacity of 100million litres a day and is expected to be completed in 2011.

The West-East Link Pipeline is an example of an infrastructure project building in adaptation to the impacts of future climate change. The pipeline is needed to increase the region's water supply in the face of three main drivers:

- EU environmental legislation, which is likely to reduce the future water resources available;
- the likely future impacts of climate change; and
- risks to security of supply.

United Utilities used UKCIP02 scenarios to forecast river and reservoir flows which were used to incorporate the impacts of climate change in the cost benefit analysis. The pipeline is expected to remain fit for purpose for the duration of its 100 year life.

3.5 Recommendations to the Infrastructure & Adaptation Project

Communicate a Government vision for infrastructure adaptation

- Government should communicate a coherent vision of how and when the nation's economic infrastructure should adapt to climate change, the role of the different stakeholders in adaptation and the benefits of timely action. This would give the owners and operators of economic infrastructure in the UK a clearer vision of how to respond to climate change. This needs to be clearly communicated to all stakeholders.

Promote cross-sectoral consideration of adaptation and climate resilience

- Cross-sectoral consideration of adaptation and climate resilience should be promoted. Stakeholders should engage in increased information sharing and cross-sector cooperation. There could be opportunities for co-funding adaptive action which should be explored.

[8] http://welm.unitedutilities.com/

Align short-term resilience with longer-term climate change adaptation
• Short-term priorities should be better aligned with longer-term adaptation to climate change. This includes the Government's general short-term priorities, such as value for money and efficiency, as well as the Cabinet Office work on short-term resilience. This alignment should be clarified in the Government's long-term vision for adaption.
Use existing regulatory levers to address adaptation
• Existing regulatory levers should be used to drive adaption. Regulators should ensure that appropriate consideration is given to climate adaptation challenges in the investment planning process. Regulatory and planning time-horizons may need to be reassessed to balance climate risks with efficiency and value for money concerns.
Bridge information gaps
• Government and regulators have an important role in encouraging collaboration within and between sectors and at local levels to address information gaps in a cost-efficient manner, and the sharing of climate change information for the wider benefit of businesses and the economy.
Promote disclosure of climate risks
• Government should continue to use the Adaptation Reporting Power to promote disclosure of climate risks. This transparency will enable stakeholders and the public to scrutinise and assess the resilience of their infrastructure. • Investors and insurers should seek to build on this momentum and encourage the sharing of knowledge and best practice in the infrastructure sectors and more widely.
Promote good practice though procurement and financing
• Government should promote good practice though public procurement and Government owned financial institutions though their investment approval processes. The Green Investment Bank may provide an opportunity to raise the profile of adaptation actions.
Encourage innovative approach to financing cross-sectoral adaptation
• Pooling funding from different parties, or using financial instruments that help share the costs and risks, could help catalyse adaptation projects that address cross-sector climate change risks. • There is scope for innovative approaches to the financing of adaptation and the Green Investment Bank may be able to play a role in catalysing this.

4. Infrastructure, Engineering and Climate Change Adaptation; ensuring services in an uncertain future – Engineering the Future

4.1 Introduction

This study, undertaken by the Engineering the Future Partnership[9] was commissioned to explore how innovation and new engineering approaches can boost the climate resilience of the country's infrastructure.

The report discusses how the challenges posed by climate change can be tackled alongside addressing other issues, such as delivering climate change mitigation measures, serving a growing and changing population and contributing to economic growth.

Key findings

- Adaptation responses have to address climate change in two ways:
    - The long-term trends such as rising sea levels and changing temperatures; and
    - Acute and extreme weather events such as flash flooding.
- The UK will need more engineers with the skills to deal with complex infrastructure systems. These skills will help the UK adapt to climate change as well as creating marketable skills and solutions that can be exported to other countries.
- Experiences and skills should be exchanged internationally as the conditions climate change is expected to cause in the UK are already dealt with in other countries.
- Fully adapting to climate change while maintaining current levels of services is not cost effective and is unlikely to be affordable. In some cases it is more cost effective to accept the risks and pay to recover from the impacts of climate change than to invest in adaptation measures.
- Carbon reduction targets will have a significant impact on infrastructure and these should be modelled alongside the effects of climate change.
- Focusing on economic efficiency can lead to reduced redundancy and diversity, which reduces resilience.
- Climate resilience comes at a cost and there are likely to be unavoidable failures beyond the limits of what the Government and the public are willing to pay to adapt to climate change.

[9] http://www.raeng.org.uk/societygov/thefuture/default.htm

The study's main findings are set out in this document including:

- the risks posed to infrastructure by climate change;
- the interdependencies within and across the infrastructure system, both nationally and internationally;
- the potential innovative engineering approaches to adaptation;
- the potential opportunities climate change might create; and
- recommendations on how to meet these challenges.

4.2 Methodology and approach

To inform this report the *Engineering the Future* partnership held four workshops on the needs and opportunities for adaptation in the four infrastructure sectors (energy, water, transport and ICT). There was also an additional workshop focusing on interdependencies. Represented at these workshops were the engineering industry, academia, regulators and Government.

4.3 Climate change risks identified to infrastructure

Sector	Risks
Energy (electricity, gas and oil infrastructure)	• Flooding of power stations close to rivers and the coast due to increased heavy rainfall, sea level rises and greater probability of storm surges • Flooding could also affect fuel supply infrastructure • Drought could threaten the supply of cooling water to power stations • Discharge water flowing into rivers suffering reduced flow due to drought can cause ecological problems and could lead to power stations being shutdown • Summer heat or storms could affect the power distribution infrastructure by high temperatures reducing efficiency of transmission or storms causing power lines to touch and short circuit • Sea level rises could affect electricity substations in coastal regions • Soil shrinkage due to drought could affect oil and gas pipelines • Wind and wave power systems may suffer in extreme, stormy conditions
Transport (road, rail, airports, seaports, inland waterways, pedestrian routes, cycle paths)	• Flooding and snow poses increased risks to sections of all transport routes • Increases in electrical storms and extreme wind could cause increased disruption to airports • Sea level rises, combined with increases in storm surges and fog pose threats to seaport facilities

	• Both drought and prolonged rainfall could disrupt the use of inland waterways • Electrical storms can interfere with the use of GPS systems
ICT	• Increased frequency of high winds can affect telephone poles • Change in rain density may cause attenuation of mobile phone signals • Ground heave could affect buried cables • Changes in wind speed or direction could have implications for the launching and stability of high altitude communications platforms
Water	• Changes in rainfall patterns leading to reduced supplies from reservoirs and river flows as well as changing the quality of raw water • Increases in rainfall density may lead to increased water pollution incidents • Increases in the intensity of severe rain events could lead to an increase in the frequency and severity of flooding. It will also increase pressure on drainage systems • Increased temperatures could lead to increased demand from consumers • Increased sea levels may lead to failure of, or damage to, flood defences in coastal and estuary areas. This increases the potential for saline intrusion into coastal aquifers and sewers • Dry periods in combination with floods could change erosion and deposition patterns on river and canal banks, impacting on navigable waterways • Higher mean water temperatures could affect biological treatment processes and drinking water quality in distribution networks

4.4 Interdependencies

A modern, efficient, networked infrastructure necessarily creates interdependencies between and within infrastructure sectors. These interdependencies are both within the UK and increasingly with systems in other countries.

Sector	Dependency on infrastructure	Dependency on overseas systems
Energy	Water for cooling power stations and fuel refining; ICT for electricity and gas control and management systems; Transport for fuel and workforce	Dependent on interconnectors with France, the Netherlands and Ireland
Transport	Energy infrastructure for fuel and increasingly electricity; ICT for management of services and networks; Drainage systems to prevent flooding; Internally across transport systems	Dependent on European air-traffic and maritime control
ICT	Energy supplies are essential for all services; Transport for maintenance workers	ICT system functions as a global system so is highly dependent internationally
Water	Energy for pumping and processing; ICT for control systems; Transport for workforce and supply of chemicals for processing	None identified

4.5 Innovative engineering approaches to climate change adaptation

Innovative solutions are needed to address these risks and interdependencies. These must include more flexible and responsive infrastructure systems, such as smart grids which allow for better management of supply and demand as well an element of self-healing (where systems can switch automatically to different demand and power flows). This is essential for increasing system resilience as well as making the best use of renewable power generation.

Human built infrastructure interfaces with the natural environment, and the dependencies between natural and artificial systems must be properly managed. For example, rivers allow natural drainage and these natural systems should be considered alongside built infrastructure.

To engineer a resilient infrastructure in a cost-effective way it will be essential to develop systems that perform diverse functions with adaptation measures delivered alongside the primary functions of infrastructure. Already some railway embankments function as flood defences and more opportunities for dual purpose

infrastructure should be actively sought. These will need to be planned, designed and implemented with care, and must be used to add capacity and redundancy, not to simply replace single use systems (as this can increase interdependencies and risk).

Dual use infrastructure case study: the SMART tunnel[10]

The Storm-water Management and Road Tunnel (SMART) is an example of a dual use infrastructure approach to Kuala Lumpur's long-term traffic and storm-water management process.

The 9.7km long tunnel was initially conceived as a flood relief tunnel to divert a 1 in 100 year flood away from the city centre, and it was decided that it could be used in periods of low rainfall as a highway tunnel to alleviate the congested highway infrastructure. A 3km twin deck road has been built into the central part of the tunnel with complex water control gates at each end to protect motorists.

Innovative solutions were found to design-out the complex conflicts between operation as a water tunnel and a modern highway. The tunnel was opened to traffic in May 2007 and the flood relief function has already been utilised on a number of occasions.

4.6 Opportunities

While recognising the risks and dangers posed by climate change the report also considered some of the opportunities that could arise from climate change.

Job opportunities: Adapting to climate change will create new, quality jobs for skilled engineers and technicians, who will be needed to design, install, upgrade and maintain new resilient infrastructure.

International competition: Climate change could make the UK a lower risk location for business compared to other, more vulnerable countries. This will depend on the UK having stable and long-term policies in place for both mitigation and adaptation and will require the country to build resilient, robust and efficient supply chains internationally.

4.7 Recommendations to the Infrastructure & Adaptation Project

Government

Government's role is to shape policy and regulation promoting investment in infrastructure and encouraging collaboration across sectors. Specifically, Government should:

- Publish a National Infrastructure Adaptation Plan: This should be based on long-term planning within Government on policy and regulation to provide a higher degree of certainty for investors.
- Develop a method to prioritise vulnerabilities, identifying which ones should be tolerated and which need to be addressed.

[10] http://www.smarttunnel.com.my/

Individuals, organisations and businesses
Individuals, organisations and businesses should take a realistic view of the future reliability of infrastructure based services, specifically: • Recognise that some infrastructure failures are unavoidable. Organisations need to limit the consequences of failure and improve their own restoration capabilities, both though engineering solutions and by managing consumer expectations. • Communities must build their resilience to climate change and involve businesses and individuals in the response to extreme weather events.
Regulators
More flexible regulations and design standards would facilitate adaptation: • Regulations must reflect uncertain future climatic conditions; regulators should set probabilistic standards rather than absolute requirements. • Regulations should be reformed to allow more information sharing and collaboration across the supply chain, this should enable all relevant groups to view infrastructure holistically. • The focus of regulation on efficiency needs to be reconsidered as this reduces redundancy within the system so can undermine its resilience. • Standards should be changed to allow a partial service to be resumed after an emergency when a full service is still unavailable.
Engineers
The engineering profession needs to plan, design and maintain infrastructure at a national and local scale to drive cost effective resilience: • Engineers need to design innovative infrastructure with multiple purposes, an example given in the report is of reservoirs that also function as flood defences. • More training in the use of probabilistic methods is needed to enable engineers to deal with complex risk scenarios. • Adapting national infrastructure requires a systems approach, based on collaboration, planning and sharing of information between sectors.
Researchers and research funders
Researchers and research funders need to continue to develop and improve the understanding of these issues: • Conduct research to improve understanding of the future demand on infrastructure. • Provide regional maps of severe weather impacts mapped against critical infrastructure elements. • Create a catalogue for the key standards and processes of coordination between sectors. • More research is needed into the behavioural changes that may result from climate change to ensure that appropriate advice is given to the public.

Annex: Organisations Engaged throughout the *Infrastructure & Adaptation* Project

Throughout the two-year *Infrastructure & Adaptation* project, a large number of organisations and individuals inputted into the project's workstreams and their findings. This engagement benefitted not only the individual workstreams but also the Government document *Climate Resilient Infrastructure: Preparing for a Changing Climate*.

Organisations who participated in the project include:

Abellio

Adaptation Sub Committee, Committee on Climate Change

Anglian Water plc

Associated British Ports

Association of British Insurers (ABI)

Association of Electricity Producers

Association of Train Operating Companies (ATOC)

Automobile Association

Aviva plc

Birmingham International Airport

Bournemouth & West Hampshire Water plc

British Airports Authority

British Dam Society

British Energy

British Ports Association

BP

BT Group

Carbon Disclosure Project (CDP)

Centrica

Chartered Institute of Water & Environmental Management (CIWEM)

Civil Aviation Authority

Consumer Council for Water

Council for Science & Technology

Dorset County Council

Dover Harbour Board

Drax Group plc

East Coast Mainline Co.

E.ON

EDF Energy

Eiser Infrastructure Capital Equity Fund

Electricity North West Ltd

Energy Networks Association

Environment Agency

Forth Ports

Geode Networks Europe

Health and Safety Executive (HSE)

Highways Agency

HS1 Ltd

Hutchinson Ports

IBM

Institution of Chemical Engineers (and their members)

Institutions of Civil Engineers (and their members)

Institution of Engineering & Technology (and their members)

Institution of Highways & Transportation

Institution of Mechanical Engineers (and their members)

Intellect

International Power

Leeds University Climate Change Centre

Macqaurie Group

Manchester Airport

National Grid

Network Rail

Northumbrian Water Ltd

Ofcom

Office of Rail Regulation (ORR)

Office of the Gas & Electricity Markets (Ofgem)
Ontario Teachers' Pension Plan Board
Powerfuel
QinetiQ
RAC Foundation
RAILPEN Investment
Renewable Energy Association
Road Haulage Association
Royal Academy of Engineering (and their members)
RSA Group
RWE npower
Scottish Power
Skanska
Southern Energy
Sellafield Ltd
Severn Trent plc
Society for Motor Manufacturers & Traders
Stagecoach
Surrey County Council
Thames Water Utilities Ltd
Transport for London
UKCIP
UK Energy Research Partnership
UK Major Ports Group
United Utilities plc
Universities Superannuation Scheme (USS)
Veolia
Water Service Regulation Authority (Ofwat)
Water UK
Waterwise
Warwickshire County Council
Western Power Distribution plc
Yorkshire Water Services

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