International Dimensions of Climate Change

Report 6.2: Impacts of Climate Change on Overseas Infrastructure (excluding sea-level rise)

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July 2010

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Executive Summary

Life in the developed world in particular has come to be underpinned by the need for a constant supply of goods and services and disruption of any kind is becoming increasingly damaging. Similar patterns of activity are emerging throughout the developing world. Growth there over the next 50 years will drive the demand for huge amounts of new infrastructure adding to a ubiquitous, international web of infrastructure which is deeply inter-dependent and inter-connected.

The world is witnessing the consolidation of resources, particularly energy, around a smaller number of consolidated sources necessitating longer, more vulnerable supply chains. The search for global value chains will continue to drive international transport activity and development is opening vast swathes of the world's population to motorisation. Improving telecommunications promise to accelerate the move to vast new off-shore digital work forces on which the UK will increasingly depend.

The UK has a number of obvious and acute dependencies on overseas infrastructure with dependence on energy and energy infrastructure being the most pronounced. However, the UK's extensive integration into the world economy, its levels of consumption of imported goods and the nature of global risk mean that its dependencies on infrastructure also extend to less obvious places. The other dependencies can be characterised as chronic and virtual dependencies and may be much harder to guard against in the face of climate change.

Infrastructure will be subject to the full range of international manifestations of climate change. Both the gradual increase in mean temperatures and the more frequent occurrence of extreme weather events pose significant challenges. Often taking the form of fixed capital assets designed to last for decades, infrastructure can suffer from inherently weak adaptive capacity.

There remains a lack of analysis around the impacts of climate change on international infrastructure. Connective infrastructure between states is neglected as is infrastructure in the developing world.

In the medium term climate change will open up some new opportunities including new shipping routes and energy exploration opportunities. In the longer term it will be overwhelmingly problematic imposing costs and disruption on most infrastructure networks.

Climate change will also impact infrastructure in a variety of indirect ways. Mitigation efforts will inevitably penalise infrastructures which support intensively carbon- based activities. Uncertainly surrounding climate change and the global response to it are likely to exacerbate what has been characterised as an international infrastructure investment crisis. In a number of regions climate change will also undermine the stable high quality governance which is necessary for the effective management of complex, long term infrastructure projects.

1 Introduction

The importance of infrastructure around the world has grown quickly over the last 50 years and with the latest wave of globalisation and leaps in telecommunications, dependence on modern infrastructures has intensified exponentially over the last two decades in particular. In the UK, as across the developed world, lives of private citizens have come to be based around a continuous supply of goods, services and energy (Instanes, 2006). Globalisation, the creation of global supply chains and the opening of worldwide markets, has been made possible by global transport infrastructures and international telecommunications infrastructure. In the absence of sufficient indigenous supplies of energy, life in the UK is increasingly fuelled by resources extracted and delivered from around the world.

While this has facilitated significantly improved standards of living for many, the extent to which infrastructures are embedded into daily routines mean that their periodic disruption is now increasingly damaging (Gheorghe, 2007). The impact of disruption is being further compounded by the complex interdependencies which have developed between infrastructure networks. Power and communications in particular are critical to all modern infrastructures. Failures of either can quickly cascade across infrastructure networks to impact other, ostensibly unconnected, areas of activity (Venables, 2009).

Climate change is already occurring and even with effective mitigation strategies and the reduction of emissions over coming years the world’s climate will continue to warm (DECC, 2009). Climate change will manifest itself differently in different regions of the world and with its growing national and international ubiquity; infrastructure will be exposed to the full range of impacts. The intrinsic adaptive capacity of infrastructure to meet these challenges is constrained in a variety of ways (Paskal, 2009). Infrastructure often takes the form of fixed, capital stock which is expensive to construct and built to last for decades. In 1960 the Channel Tunnel Study Group first proposed a twin bore railway tunnel to link the UK to mainland Europe. Designs for the final incarnation of the project were prepared in the early 1980's and its final cost was over £4.65 billion by completion in 1994. Expected to be in service until at least 2086, the Tunnel is typical of infrastructure designed to last into the second half of this century but planned with limited understanding of how climatic conditions might change (Rothengatter, 2003).

Even infrastructure being planned today suffers from the uncertainties which surround climate projections and the risk that climate change might be even more severe than currently expected. Most international infrastructure is now privately owned and as global enterprises seek out new markets and economies of scale, infrastructure interconnections and inter-dependencies now regularly span across international boundaries. Communications and information infrastructures can increasingly operate on a trans-national basis with almost no reference to traditional geographic boundaries. Against this backdrop, the UK's ability to ensure the resilience of the international infrastructure it depends on, even on a multi-lateral basis, is being diminished (Gheorghe, 2007).

This paper forms part of the International Dimensions of Climate Change (IDCC) project being run by the Foresight team within the Government Office for Science (GO-Science). The project aims to improve the UK's understanding of how climate change in other parts of the world could impact it to 2100. The IDCC project will feed in to the UK's first Climate Change Risk Assessment (CCRA) required by the Climate Change Act (Crown, 2008).

2 Methodology and Scope

2.1 Methodology

The methodology for the preparation of this report consisted of a review of the literature relating to trends and technical developments across infrastructure generally and in the fields of energy, communications and transport particularly. A limited amount of literature focused specifically on infrastructure adaptation is available and was also drawn upon. Scenarios drawn from IPCC AR4 WGII were used as a basis for projections about the long-term impacts of climate change on overseas infrastructure. The World Bank in its World Development 2009 Report categorised three types of infrastructure:

- **Spatially universal infrastructure**, which includes housing, water, sanitation and basic social services (such as Health)
- **Economically productive infrastructure**, such as energy, ICT, irrigation, ports and transport, which can complement the work force in manufacturing and services and facilitate employment growth.
- **Spatially connective infrastructure**, which can include transport modes that connect regions within a country or facilitate international trade.

(The World Bank, 2009)

This report will draw upon these definitions of infrastructure and compliment them with the distinction between 'infrastructure' and 'critical infrastructure' which is increasingly common in infrastructure policy discussion. In the UK, 'critical infrastructure' comprises infrastructure, the loss or disruption of which would have a major impact on the availability or integrity of essential services leading to severe economic or social consequences or to loss of life. (Cabinet Office, 2008). While covering issues of relevance to all the infrastructures defined above, this report will address itself primarily to the energy, telecommunications and transport sectors in line with GO-Science guidance for the project.

2.2 Scope

The most comprehensive listing of national adaptation efforts, including those relating to infrastructure, lies with the UN and is compiled and updated through the national reporting mechanisms agreed as part of the Framework Convention on Climate Change (UNFCCC). As acknowledged by the UNFCCC Secretariat, the analysis and preparation required for a thorough impact assessment are substantial undertakings so much so that they are beyond the capacity of many developing states (UNFCCC, 2009). Currently, no analysis exists of the implications of climate change for the web of internationally connective infrastructure. The collation and analysis effort necessary to tease out the requisite data from a wide and disparate range of sources was considered beyond the means of this report. Rather, the report has been designed to offer an initial analysis of the ways the UK's dependency on international infrastructure might change and how climate change, in combination with other important drivers and trends, might disrupt the flow of goods and services to the UK.

- Section one provides the context in which future infrastructure development will take place by offering an overview of likely future trends in each of the infrastructure sectors;
- Section two attempts to develop a typology of dependencies in which further analysis of the UK's dependencies might be grounded;
- Section three draws on national impact assessments to offer an overview of the types of disruptions international infrastructure might face as a direct result of climate change;

- Section four looks to how climate change will act with other key drivers of development to indirectly impact on international infrastructure over the course of this century.

3 Analysis

3.1 Infrastructure Trends

3.1.1Energy Infrastructure

The picture in the energy sector is broadly that of OECD countries curbing growth in their appetite for energy in the coming years while developing nations' demand increases considerably in order to fuel the dramatic growth of their economies (OECD, 2006). Renewables have the potential to make a significant impact in the long term but there are substantial challenges to their wide deployment in the short or medium term (DECC, 2009). Renewables will account for at least 25 per cent of global energy by 2030, but under any of the International Energy Agency's (IEA) Outlook scenarios it will be fossil fuels that will remain most important to the global energy mix and thus remain at the centre of global competition for resources (IEA, 2008).[1]

Of the current OECD economies, the UK and the EU as a whole face some particularly difficult trends. While their demand for energy will generally level out, their indigenous reserves of oil and gas are quickly dwindling with the result that the already high dependency on imported energy is set to grow even further in the years ahead. The UK and Europe could import 65 per cent of their energy by 2030 (IEA, 2008). Existing European energy infrastructure largely reflects the era of cheap and plentiful energy in which it was built. It features sub-regional infrastructures based around large centralised production and developed in isolation from each other. The legacy for the EU is poor connectivity, inefficiency and susceptibility to disruption (Muzi, 2008). In response the next 50 years will be marked by the reorientation of European energy infrastructure toward energy grids (European Commission, 2008). These energy grids will improve the linkages between member states and draw on smart technology to facilitate better demand management. The grids will be based on the more widely distributed points of energy generation

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[1] This section draws on the IEA's Energy Outlook scenarios. In particular, it draws upon the Reference Scenario which takes account of recent policy interventions and assumes the world continuing broadly on its present course.

lending themselves to the growing use of renewable technology (Muzi, 2008). In terms of electricity, the UK currently has very limited connectivity with mainland Europe via the IFA interconnector which runs between the UK and France. The most ambitious energy grids plans, based around the renewable potential of the North Sea, envisage the number of interconnectors and the volume of electricity traded with mainland Europe increased 20-fold by 2050 (Ofgem, 2010)

While the IEA's scenarios presume a continuation of current policy and demand trajectories, significant debate surrounds the actual shape that energy use and the energy mix will take out to 2050. In the UK, the regulatory body Ofgem has produced a variety of scenarios for the UK energy market over the next fifteen years which indicate that the speed of economic recovery and the degree of commitment to environmental policies in coming years could have a significant impact on the UK's overseas energy dependency (Ofgem, 2009). The feasibility of renewable sources constituting a significant part of the energy mix in the medium to long term is also contentious. Serous recent studies have variously ranged from extremely sceptical projections to suggestions that 100 percent renewable power generation across Europe is a realistic goal for 2050 (MacKay, 2009; PriceWaterhouseCooper, 2009). The conclusions eventually reached on the basis of these various debates will have profound implications for the shape of the UK's energy infrastructure and its overseas infrastructure dependencies. Meanwhile, Ofgem notes that further protraction of the debate will itself delay investment decisions undermine investor confidence and expose the UK to new infrastructure-related vulnerabilities (Ofgem, 2009).

In emerging economies and the developing world much of the appetite for energy will also be satisfied by imports. Largely on the basis of demand from China, India and the Middle East, emerging countries will import as much energy as the developed world in 2030, although 1.4 billion people will still exist without access to electricity. As a consequence of this widespread, growing dependency over 50 per cent of the world's energy will be traded across borders by 2030 and a growing web of international infrastructure will underpin this additional activity (Umbach, 2010).

Projections point toward seismic shifts for energy infrastructure through the first half of this century in particular. Much of the developed world’s existing infrastructure is becoming obsolete and will have to be replaced while massive new demand will drive the creation of new infrastructure in the developing world (Umbach, 2010). Infrastructure for the transport of energy is becoming more important at the same time as patterns of supply and demand are making it more vulnerable. As smaller and more easily exploited energy reserves, such as those in the North Sea, deplete, the sources of this energy are being consolidated around a much smaller number of large reserves (BP, 2009). By 2030 the OPEC countries of the Middle-East will be the majority producers of oil followed by Africa and Russia. Africa will outstrip Russia to become the world’s second largest exporter of oil (IEA, 2008). For the UK, this consolidation of resources and infrastructure presents new energy risks around geopolitics, resource nationalism and physical disruptions to supply chains (Wicks, 2009).

3.1.2 Transport Infrastructure

Transport is critical to economic development international transport in particular has grown rapidly over the last 20years driven by growing international investments and the free movement of people and goods globally (IPCC, 2007). Forecasts suggest an even more dramatic expansion in the demand for global transport activities through the first half of this century (OECD, 2010). Continued economic growth and the emergence of various developing countries as world powers will be key drivers as the energy expended on transport activity by 2030 is an estimated 80 per cent higher than today. If China, India and parts of Latin America are able to fulfil their development potential, the growth in transport activity is likely to be even more rapid (Skeie, 2009). Despite the huge boom in transport activity over the last 50 years much of the world still lives without access to transport. For instance, 33 per cent of China’s population still do not have access to personal motorised transport or public transport of any kind. Development is bringing with it the prospect of motorised transport for vast swathes of populations which in turn will demand huge new domestic road and rail infrastructures throughout much of the world (IPCC, 2007).

Internationally, transport activity consists largely of passenger transport and freight transport. Stimulated by migration, trade and growing prosperity, air travel has been the fastest growing mode of international travel over the last decade at about 4 per cent per annum globally (Skeie, 2009). In the developed regions of Europe and North America growth in air travel will slow but this will be more than matched by the appetite of regions such Asia/Pacific where the most intensive centres of demand could witness growth of up to 12 per cent per annum. Globally, passenger numbers will double within 15 years (Boeing, 2009).

Freight traffic will grow even more quickly than passenger transport in the decades ahead. Industrialisation and the trend towards specialization in manufacturing and engineering have necessitated large shipments of goods and materials over substantial distances (IPCC, 2007). Around 90 per cent of global freight is transported by sea. However, modern just-in-time working methods and the demand for responsive supply chains has driven the demand for more flexible modes of freight delivery, namely trucking and air freight, which are both growing even more quickly than the sector overall (OECD, 2010).

Aside from growth, technology will be the major determinant of transport modes and the requisite infrastructure going forward. Substantial gains in the efficiency of aircraft engines and improved aerodynamics will complement the use of lightweight materials in commercial aviation over the next 5-20 years (Kivits, 2010). There has been some consideration of using hydrogen as a commercial aircraft fuel but this is unlikely to occur before the latter half of the century. On land, the profile of recent hybrid technologies has not been matched by the relatively small degree of progress they actually represent. In the near term, the increased global use of light duty diesel represents an opportunity for progress before battery powered vehicles and hydrogen fuel cell technology potentially achieve fuller market penetration over the medium term (WBCSD, 2004)

3.1.3 Telecommunications

The high rate of change in the telecommunications sector means few long-term projections exist and assessments of future trends rarely extend confidently beyond the coming 5-10 years (de Bijl, 2008). In the developing world the spread of telecommunications technology and access to the internet will be greatly enhanced by the falling costs of mobile technologies which will be cheaper to deploy than classic fixed line and fibre infrastructures. Mobile technology alone could potentially add 300 million users to telecommunications networks in the coming years (Whyte, 2008). Mobile technology and the use of ‘internet relief kits’ will make the internet the most accessible and reliable form of communication and see it quickly rolled out to affected areas in the wake of disasters. Access to telecommunications has the potential to drive health improvements through remote access to expert advice and diagnosis, and educational improvements through access to broad range of low cost learning resources. (CSOC, 2010)

Populations in much of the developing world will be transformed into large, cheap, digitally connected workforces driving much greater outsourcing of digital labour and vastly increase the linkages between the developed and developing worlds (Scott, 2003). However, much of this roll-out to the developed world will be dependent on the requisite satellite technology and predominantly Chinese infrastructure ownership will give it significant influence over the pace and nature of changes.

In the developed world high-speed internet access will soon become near-universal. Internet literacy will become as central as traditional literacy skills and access will come to be considered a public good; largely free to access, always on and essential to the maintenance of daily routines. Public services will increasingly be delivered online entailing huge savings but also building in considerable dependency on telecommunications infrastructure (BIS, 2009). The widespread adoption of VoIP, greater data processing capabilities, miniaturisation and improved battery life are likely to be central to technological innovation in the coming decades. Radio frequency identification (RFID) has been singled out as a technology which, while requiring significant new supporting infrastructure, has the potential to provide huge benefits across a number of sectors (OECD, 2006). The technology depends on miniscule microchips, half the size of a grain of sand, which transmit a unique ID code. They require no battery and will eventually be manufactured for less than £0.01 each. As the infrastructure for reading and transmitting information from tags becomes more widespread it is predicted that they will form the basis of an 'internet of things' to compliment the internet of data (Miodrag, 2010)

In the UK, reliance on communications infrastructures already significantly contributes to social and economic life. 'Digital Britain' directly accounts for an estimated ten percent of GDP and telecommunications vitally underpin the vast majority of the nation's other economic activity (BIS, 2009). The National Health Service now depends on the largest data and communications system in Europe. The proportion of government services available online had risen from 30 percent at the beginning of the decade to over 75 percent by 2005. While online services are currently often replicated in analogue at present, government has described a transition from 'being on the web' to being 'of the web' whereby it provides services, wherever possible, solely via the internet (ibid). This transition will take place over the coming decade and will increase the criticality of communications infrastructure still further. In the private sector, the UK's comparative advantage over rival trading nations has been identified as lying in the 'knowledge economy' as a source of innovation and services to global markets (BERR, 2009). Exploiting this advantage and delivering services internationally is likely to leave the UK particularly dependent on international communications infrastructure (BIS, 2009).

3.2 Infrastructure Dependency, Global Risk and Adaptive Capacity

While the modern wave of globalisation has been particularly intensive over the last two decades, aspects of it have been apparent in international trends of at least the last 50 years (Nayyar, 2006). Throughout this period creeping and then intensive globalisation has been underpinned by a massive expansion of internationally connective infrastructure in a variety of sectors of which energy, transport and telecommunications have been the most prominent. For instance, dramatically expanded transport and communications infrastructure has revolutionised the manufacturing of goods opening up global value chains which create choice, improve efficiency and ultimately generate wealth (OECD, 2007).

3.2.1 Global Risk

However, the prosperity which globalisation and international connective infrastructure has generated has also been accompanied by the exposure to new global risks. In the last decade the variety and potency of these new global risks has been demonstrated repeatedly. Al Qaeda’s attack on the United States in 2001, the food and fuel price spikes of summer 2008 and an international financial crisis have all demonstrated the propensity for global risks to be realised, to manifest in unexpected ways and to spread rapidly with little regard for borders (Evans, 2009).

Thinking on these emerging global risks has barely kept pace with the rush towards the benefits of globalisation and global integration. However, the realisation of successive global risks in quick order over recent years has quickly driven the subject up the policy agenda. to the extent that global interdependence and the risks springing from it were at the heart of the UK’s first national security strategy in 2008, ‘Security in an interdependent world’ (Cabinet Office, 2008). While infrastructure has been cited as an example of international dependency across various documents, including the National Security Strategy, it has so far only been in the context of infrastructure on which the UK depends most obviously and acutely for the delivery of goods and services. The impact of a disruption or destruction of this infrastructure would be that of a sudden shock and potentially dire social and economic consequences (Gheorghe, 2007).

However, literature on emergent global risk is careful to emphasise the increasingly systemic nature of the problem:

> “…while sudden shocks can have a huge impact, be they serious geopolitical incidents, terrorist attacks or natural catastrophes, the biggest risks facing the world today may be from slow failures or creeping risks.”
>
> (WEF, 2006, p. 1)

The gradual emergence of these risks over a long period can mean they go unobserved and their potentially huge long-term implications underestimated. They will stem from big structural shifts and potentially roll out over years and decades (ibid). Demographic transition and growing consumption are typical of these huge but gradual shifts occurring over coming decades. Through this lens, climate change may be an unusual phenomena in that it represents the emergence of a ‘creeping risk’ but will also be punctuated by increasingly frequent shocks in the form of severe weather events.

This mantra of potentially deeply embedded systemic risk translates well onto modern infrastructure. So far almost all analysis of infrastructure and dependencies on it has focused on areas where they are most acute, such as the delivery of energy. These acute dependencies are an obvious source of risk but our experience of risk in global systems suggests that these obvious challenges may not be the only, or even most dangerous, sources of risk. Highly interconnected networks of infrastructure are almost ubiquitous at all levels of social activity in all of the world’s developed populations and are emerging rapidly through the developing world (Hall, 2006). Regional and international infrastructures, on which patterns of human activity depend, will be a source and a conduit for pockets of unforeseen risk generated by a variety of stresses, not least climate change.

To this extent, the remainder of this section will examine the impact of climate change, and the potential implications for the UK, based around three types of infrastructure dependency; acute infrastructure dependency, chronic infrastructure dependency and virtual infrastructure dependency. The categorisations are not watertight, nor completely satisfactory. However, they do provide the basis for a fuller discussion of the UK's infrastructure dependencies, global risk and the implications of climate change for both.

3.2.2 Acute Infrastructure Dependencies

Acute infrastructure dependencies develop around infrastructure which delivers critical goods and services. Without these goods and services the UK would rapidly begin to experience severe financial and economic consequences. The UK's acute dependencies on overseas infrastructure span across several sectors of the activity including water, communications, transport, finance and health. However, it is the dependency on overseas energy infrastructure which has been most pronounced in recent times (Wicks, 2009).

Declining domestic production of fossil fuels mean that, even accounting for their declining share of the national energy mix, the UK will continue to be very dependent on gas and oil throughout this century (Ofgem, 2009). Projections show that, even if the UK were to meet the target of an 80 per cent emissions reduction by 2050, fossil fuels would still account for 70 per cent of the UK's energy mix and it would all be imported. If the UK managed a 60 per cent reduction in emissions, imported fossil fuels could account for some 85 per cent of the UK's energy use (IEA, 2008). Under these circumstances the UK's dependence on the infrastructure which delivers primary energy are extremely acute. The supply of natural gas in particular has traditionally been determined largely by the availability of pipeline infrastructure which is expensive to construct and must be planned well in advance. In 2008 72 per cent of the UK's gross gas imports were by pipeline from Norway (Wicks, 2009).

Natural gas is essential to processes in UK industry, electricity generation and heating. It has been estimated that, in addition to the social impacts and the risk to vulnerable members of the community, a physical disruption in the supply of gas could cost the UK economy £600 million in terms of lost output (Oxera, 2007). It is this dependence on a continuous supply of a good or service, the potential for severe social and economic costs to flow quickly from failure, which characterise acute infrastructure dependencies across all sectors.

However, while their disruption is potentially most catastrophic in the short term, acute infrastructure dependencies often inherently lend themselves to the building of adaptive capacity. Technological limitations aside, political will is one of the most crucial determinants of adaptive capacity (Kelly, 2005). The prospect of the failure in the supply of a critical good or service and the immediate suffering of a domestic population as a result lends tremendous political urgency to the protection of critical infrastructure assets both domestically and abroad (Gheorghe, 2007). Adaptive capacity and adaptation can be derived as an unwitting consequence of the intensive maintenance and scrutiny to which essential human systems are often subject (Wandel, 2006). The UK's acute dependencies on oversees infrastructure across various sectors come under the remit of a number of Government agencies including the Centre for the Protection of National Infrastructure (CPNI) , the Foreign and Common wealth Office (FCO), Ministry of Defence (MOD), Department for Energy and Climate Change (DECC) and the Department for Business, Industry and Skills (BIS). Critical infrastructure also benefits from various bi and multi-lateral arrangements such as the European Protocol for Critical Infrastructure Protection (EPCIP). Adaptive capacity is rarely created in response to the prospect of climate change alone (Kelly, 2005). While these arrangements are driven by the risk of extreme weather incidents and malicious threats much more than gradual climate change, the resilience energies expended on them inevitable feed the UK's adaptive capacity in respect of both.

3.2.3 Chronic Infrastructure Dependencies

In contrast to the rapidity associated with acute dependencies, failures from chronic infrastructure dependencies are likely to manifest themselves more slowly. Chronic infrastructure dependencies could be defined as the aggregated result of low levels of dependency on a group of different infrastructures which are all are all facing common or separate stressors. The UK's chronic infrastructure dependencies are based on patterns of activity which are important to its national interest and which depend upon a variety of different infrastructure sectors.

A topical example of chronic infrastructure dependency for the UK lies in agriculture and food security. DEFRA has defined food security as 'consumers having access at all times to sufficient, safe and nutritious food for an active and healthy life at affordable prices' (DEFRA, 2008). By most measures, and certainly when compared to the majority of the world's population, the UK enjoys good levels of food security. Unlike the energy sector, the sources of the UK's imported food are well distributed with no single country accounting for more than 13 per cent. The UK's food mix consists of approximately 40 per cent imports. While this low in historical terms, the trend is toward falling self- sufficiency, growing exposure to international markets and a growing chronic dependency on international infrastructure (Cabinet Office, 2009). The volatility of global food markets has been demonstrated in recent years as the price of rice and wheat has risen to 20 and 30 year highs respectively.

Infrastructure is integral to every stage of the agricultural supply chain. Irrigation, harvest, transport and distribution are all dependent on a variety of regional and international infrastructure. For the UK, the plural nature of its food supply chains means that the prospect of failure in any single infrastructure node is of low concern. However, in combination, shifting demand, growing populations, diminishing resources and climate change will act as stressors on a variety of infrastructure, impeding the supply of food and exposing the UK to a variety of risks associated with global food insecurity (Cabinet Office, 2009).

3.2.4 Virtual Infrastructure Dependencies

The concept of virtual dependencies was introduced in the early-1990s (Allan, 1993). It has largely been used in the context of water and was defined as the volume of water required to produce a commodity or service. When there is an international transfer of products or services from one place to another, there is little direct physical transfer of water. There is however a significant transfer of virtual water. The concept of virtual water represents the recognition of water as a global commodity and an attempt to better understand a specific country’s dependence on it even when dependent processes are played out remotely.

The UK has a notably high virtual water dependency per capita (RAE, 2010). Its high degree of integration into the global economy and the level of consumption of imported goods mean that domestic freshwater supplies may only account for one third of the UK’s actual dependency on freshwater (RAE, 2010). Two-thirds of the water we are dependent upon is used in transactions often far removed from the UK with the food and energy sectors owning a significant portion of its international water footprint. This virtual water dependency extends necessarily to a virtual water and waste management infrastructure dependency. The consequences of failures in specific regional water and waste management infrastructures could quickly manifest themselves in product shortages and rapidly increasing prices for UK government or industry (Barnett, 2004).

Virtual infrastructure dependencies do not apply only to the infrastructure around scarce resources. The concept can easily be extended to infrastructure in other sectors. The quality of health care infrastructure in developing countries is a crucial determinant to their ability to identify and contain the spread of pandemics (Fair, 2007). Where pockets of particular pandemic risk exist, in areas of South East Asia for example, even the most benign hospital, road and local telecommunications infrastructure has the potential to emerge as a virtual infrastructure dependency for the UK.

Virtual dependencies are not linear in their nature and to some extent they can all be unique. Some will be essentially chronic while others will be acute. Often second and third order considerations some will be temporary while others will endure. Many do and will exist unnoticed until changing circumstances and changing patterns of activity reveal or relieve the dependency.

In many cases vulnerabilities will not be identified or responded to in the context of ‘UK dependency’. Activity may be driven by international development needs or a commercial imperative. Nevertheless, in contrast to acute dependencies and for a variety of reasons, the UK’s adaptive capacity in relation to virtual infrastructure dependencies is much more limited. The ability to predict and plan for virtual dependencies is growing but remains under-developed and represents a fundamental barrier to adaptive capacity. Geographically, virtual dependencies are likely to emerge in parts of the world where the impacts of climate change are most pronounced and have the most disruptive effect on human systems. Further, they are likely to emerge in response to deficits of local adaptive capacity which are indicative of the developing world (Kelly, 2005). Under these circumstances the advantages of wealth and technological progress, which the UK and its neighbours enjoy in relation to their critical infrastructure, cannot be so easily brought to bear.

3.3 The Direct Impacts of Climate Change on Overseas Infrastructure

In its latest assessment the IPCC has projected that warming in the 21st century will be greatest over land and at the most high northern latitudes. Snow cover will be reduced and the retreat of permafrost already apparent will hasten. Climate change is very likely to cause more frequent and more extreme heat waves. Storms will be stronger and, along with heavy precipitation events, will occur much more often in global terms (IPCC, 2007).

Through a survey of national climate risk assessments for infrastructure the limited NGO and academic work on the subject, this study has collated overviews of the challenges the energy, transport and telecommunications sectors might face as a result of global warming into the next century. Existing work on the impacts of climate change on infrastructure is constrained by uncertainties over climate change at the relatively fine-grained level which would make it relevant to regions or sectors (Transportation Research Board , 2008). Further, its ability to project future impacts over the medium and longer term is limited by the number of other socio-economic factors which will be central to the development of infrastructure through this next century. Aggregating the uncertainties among all these factors has been beyond the scope of all work on the subject to date. Indeed, it may not be possible at all. Rather, infrastructure and risk assessments have generally proceeded, consciously or not, from of baseline scenario which assumes little or no change in the many other technical, demographic and financial sources influence. Reflecting these limitations on forward projections, the overviews are intended as indicative of impact of climate change, the scale of the adaptation challenge and the propensity for global disruption throughout the 21st century.

3.3.1 Energy Infrastructure

Internationally, the changing climate will have implications for infrastructure across the breadth of energy extraction, refining, generation and distribution activities (Acclimatise, 2009). As distributed regional sources primary energy begin to deplete, the international supply of fossil based energy is becoming consolidated around a smaller number of proven large resources (IEA, 2008). The growing global reliance of these reserves is leading to longer more complex supply chains which are inherently more vulnerable to disruption (Wicks, 2009). Ambitious new pipeline projects have become integral to various regional energy strategies and are typical of the need to transport primary energy sources over ever greater distances (Instanes, 2006). The climate driven challenges to such projects will continue to grow throughout the century. Ground settlement, measured in meters in some locations, poses a particular problem for pipelines. In the US, the Joint Pipeline office has estimated that, as a result of thawing permafrost and soil subsidence, 22,000 of the trans-Alaska oils pipelines 80,000 vertical support members could experience problems. Underwater pipelines will also be at growing risk of being dislodged by the force of extreme weather events (US ARC, 2003).

Offshore oil and gas installations are particularly vulnerable to storm surges and high winds which can disconnect oil and gas platforms from their moorings and damage platform decks. In the summer of 2005 Hurricanes Katrina and Rita destroyed 113 platforms and damaged 457 pipelines in the Gulf of Mexico. The result was 30 per cent reduction in the US's refining capacity causing a global spike in energy prices (US Congress, 2006).

In addition to the acute disruptions resulting from more extreme weather, climate change will entail a number of chronic challenges to existing processes in the oil and gas sector. In particular, the oil and gas sector have historically taken ready access to a plentiful supply of freshwater for granted (Robinson, 2010). Decreasing water availability and the increasing propensity for drought in mid and semi low latitudes will likely constrain the activities of oil and gas industries in these regions. At some high latitudes, such as northern Canada, increases in ambient temperature and shorter winters will reduce sea ice cover and may open up new oil and gas exploration opportunities in the medium term (Larsen, 2008). However, continued warming into the second half of the century may subsequently restrict access and other challenging reserves, whose future exploitation is thought profitable on the basis of projected high oil prices, may be reassessed as economically unfeasible in the light of emergent risks to infrastructure and operations from climate change (Acclimatise, 2009).

Of more direct interest to the UK could be the consequences of climate change for the permafrost and arctic regions of northern Russia, from which the majority of the country's oil and gas resources are extracted. According to most estimates the UK's reliance on energy from these regions is set to grow even further out to 2020 (Helm, 2007). However, fears about underinvestment and Russia's ability to meet the growing demand are being compounded by the prospect of warming climate spreading the permafrost north and deepening seasonal melt at lower latitudes (Stern, 2009). While this phenomena may open up new oil and gas exploration opportunities, it will also disrupt existing extraction and refining activity. Unstable permafrost conditions will necessitate additional trenching of 1000's of miles of pipeline and transport infrastructure and additional cost to planned projects (Renat, 2007).

Climate related changes in temperature, precipitation, water availability and distribution and extreme weather events will all have implications for power generation and distribution infrastructure internationally. Climate change in higher latitude regions will reduce heating demands while increasing summer cooling demands. The reverse will be true in lower latitude regions. The net impact of these trends across the developing world is expected to be a reduced demand for heating/ cooling power out to the middle of the century (Stern, 2005).

The dependence of nuclear and fossil power generating infrastructure on water for cooling means they are frequently located in coastal areas susceptible to extreme weather and storm surges. Power stations located away from the coast are dependent on freshwater supplies. The dwindling supplies of freshwater and the as yet uncertain redistribution of those supplies may challenge the viability of some of these power generation facilities (Paskal, 2009).

The capacity for extreme weather events to impact upon fossil and nuclear based electricity generation is already well established. The summer heat wave of 2003 saw temperature across Europe reach in excess of 40C resulting in the powering down or closure of 17 French nuclear reactors. The reduction of generation capacity and subsequent recourse to the open energy market is estimated to have cost the French government €300m (Paskal, 2009). By 2040, heat waves equivalent to that of 2003 will be common place (Stern, 2005). More frequent and extreme heat waves in the coming decades will certainly result in periodic disruption of fossil/ nuclear power generation (Reiter, 2009).

The impact of climate change on traditional fossil and nuclear based power generation has attracted greater attention to date due largely to their dominance in the UK's energy mix. However, successful mitigation efforts in the medium to longer term will be contingent on the shift to renewable forms of power generation. Much of the existing modelling and policy work on the viability of renewable appears to have paid little attention to their particular sensitivity to the impacts of climate change. The efficiency of hydroelectric infrastructure, for instance, is contingent on the ability to predict the volumes of water entering a system. Climate change is causing significant deviations from historical hydrological and precipitation patterns once thought largely predictable. Europe's glacier dependent infrastructure is likely to encounter much more variable flows of water both seasonally and inter-annually with more winter flooding and drier summers potentially disrupting power generation and damaging infrastructure (Barnett, 2004).

Wind power infrastructure will similarly be vulnerable to the impacts of climate change (Pryor, 2010). An increasing number of extreme wind events will be a feature of many regions including Western Europe and parts of the US.

However, the net effect of climate change of wind strength in different regions remains the subject of discussion. Predictions for North America, for instance, vary widely. The Hadley Centre climate change circulation model predicts minimal changes to average wind strength while the Canadian Climate Centre shows reductions of up to 15 per cent by the end of the century (Neumann, 2009). This variance is itself instructive as to the challenges facing investors and operators of infrastructures of all kinds when planning for adaptation challenges. Moreover, regardless of average wind speed, changes to wind patterns, erosion and other changes in topography, more frequent landslides and subsidence may drastically impact the productivity of wind farms in specific locations (Pryor, 2010). Studies in the US also identify climate change consequences for photovoltaic infrastructure. In addition to the threats from extreme weather and flooding to solar facilities, it is predicted that increased cloud cover may have reduced the US's access to solar resources by 20 per cent in 2040 (US CCSP, 2007).

3.3.2 Transport Infrastructure

Even more than in the energy sector, the literature on climate change and transport focuses almost exclusively on mitigation efforts. Land transport infrastructure is comprised of highways, bridges, tunnels and railways as well as the vehicles which make use of them. At high latitudes the impacts of a warming climate are already having a detrimental impact. In regions such as Alaska, which are experiencing the retreat of permafrost, it is being accompanied by subsidence which has already undermined the integrity of road and railway infrastructure (Instanes, 2006).

Increased regional inter-season variability and more intense freeze- thaw cycles have the potential to degrade road surfaces and cause the imposition of road closures and load restrictions. Periods of excessive summer heat will increase the threat from wildfires and associated infrastructure closure and damage. Extended periods of excessive heat could cause the expansion of bridge joints and the deformation of railway lines.

Coastal flooding in North America will be one of the most serious effects of climate change. US studies on the implications for transport predict that some infrastructure in the coastal areas of the Gulf of Mexico and the Atlantic may be permanently inundated by the end of the century (Transportation Research Board , 2008).

However, road transport in some regions will benefit from warming winters and the associated reductions in snow and ice removal costs. Further, the localised environmental impacts of the use of salt and chemicals in road treatment could be reduced with the road and rail construction season also being extended. In some areas the reduction of winter time transport hazards could result in improved overall levels of road and rail mobility and more safe and secure passenger and freight travel (ibid). .

More frequent flooding and inundation of terminals, warehouses and cargo may pose a serious threat to maritime transport services in the decades ahead. And while more regular storms of increasing ferocity will also disrupt shipping, it is the effect of climate change on shipping routes which will have the most profound effects (International Maritime Organisation, 2009). Falling water levels on the Canadian Great lakes, for instance, will reduce the volume of cargo which can be carried and studies have indicated that the cost of shipping on the lakes will have increased by 29 per cent by 2050 as a result (Great Lakes Regional Assessment Team , 2000). The navigability of shipping channels will also change. In the absence of expensive dredging activities access to some channels will be impaired as water levels drop and sedimentation increases. However, in some locations sea level rise will open up channels to large vessels and provide for shipping further inland. In other areas it will open up entirely new routes. Here the opening up of the North West Passage (NWP) through the Artic could be the most significant development for the UK. The prospect of shipping through the historically frozen NWP could provide a direct route between the UK and emerging markets in Asia shortening the current journey by 5500 miles and significantly reducing costs. While the IPCC does not project the NWP to be ice free until

2070, it could be regularly navigable through the summer as early as 2014 (International Maritime Organisation, 2009).

The threats of climate change to air transportation relate as much to the supporting ground infrastructure and airports as the aircraft themselves. Many of the world's largest airports have been constructed in coastal zones, by tidal waters or on reclaimed land (Oh, 2010). Their runways are particularly vulnerable to erosion and flooding from intense precipitation. Similarly to road transport, runways are also vulnerable to degradation or buckling as a result of extended periods of extreme heat. For the aircraft itself, lower air density as a result of warmer temperatures will reduce lift. At higher altitudes this will be a particular problem. In extreme cases runways will have to extended but lowered fuel efficiency, payload restrictions, flight diversions and disruptions will all become more common (ibid).

3.3.3 Telecommunications Infrastructure

The vulnerabilities of telecommunications infrastructure have come increasingly to be discussed in terms of Critical Information Infrastructure (CII), a concept which currently drives programmes of activity both among European Union member states and in the US (European Commission, 2009) (Uhl, 2003). However, analysis of CII risks largely pertains to malicious threats to data and lacks almost any attention to the future impacts from climate change and their potential to disrupt physical infrastructure. A recent paper commissioned by DEFRA, offering analysis of the UK's domestic ICT infrastructure represents an exception (AEA, 2010). Communications infrastructure is profoundly interdependent with electricity and, in the absence of substitute sources of power, will quickly fail in the event of sustained disruption to electricity networks. High profile power failures from Germany to Tokyo have been accompanied by widespread communications infrastructure failures (Richman, 2008).

Contrary to popular belief, most international communications are not routed via satellites. In fact, over 95 per cent of traffic is routed via submarine fibreoptic cables which are both cheaper and quicker than satellite. It is estimated that world-wide there is approximately 1 million km of submarine cable which will be increasingly vulnerable to under water turbulence as a result of extreme weather events (Carter, 2009).

Recently, attention has surrounded rare earth metals such as cobalt which are vital components of across communications infrastructure. Extraction of the metals is consolidated to a small number of mines, particularly in China (Financial Times, 2009). In addition to the problem of dwindling stocks, sustained disruption of mining due to an extreme, or multiple extreme weather events or flooding could impact on international communications infrastructure.

For the UK specifically, growing reliance on international on digital off-shoring and international data centre could present a significant vulnerability in the face of climate change. Changing patterns of activity and predicted trends toward ‘cloud computing’ will necessitate increasing construction of data storage sites (Bein, 2010). However, high construction costs, warm summer climate and expensive electricity make the UK an expensive location for data centres (Webster, 2009). In the private sector, these factors have already driven a significant amount of data off shoring, often to developing countries. For government, the increasing digital provision of services and moves to a ‘government of the web’ in combination with pressures to maximise cost saving will likely drive the building of international data centres. Analysts have speculated about alternative European destinations such as France or Germany (Webster, 2009).

A number of data facilities have already fallen prey to flooding, including the Vodaphone data centre in turkey whose flooding was captured on close circuit television and subsequently distributed on the internet (Youtube, 2008). Over coming decades, pressure to reduce costs further and issues of availability will inevitably drive the UK to begin storing data in a greater range of distant foreign jurisdictions exposing it to a diverse range of climate related hazards.

3.4 Climate and Other Drivers of Change on Overseas Infrastructure

In terms of the IPCC assessment reports on climate change, infrastructure falls under the heading ‘human systems’ which consist of industry, settlements and society. The Fourth Assessment report observes that climate change is rarely the main factor when considering stresses on the sustainability of human systems. Extreme weather events can be an exception, but more often it is important to think about climate change as it interacts with other types of stresses (IPCC, 2007).

In the first half of this century these stresses on human systems and infrastructure will include rapid population growth, resource scarcity, new centres of demand, continued globalisation, growing inequality and the threat from terrorism (DCDC, 2010). This section will examine the key drivers of infrastructure and how climate change, in combination with them, might influence the development of international infrastructure throughout this century.

3.4.1 Climate Change Mitigating and Infrastructure

Infrastructure is integral to all of the most carbon intensive human activities. The growing urgency surrounding carbon emissions and the international recognition of the need to mitigate climate change has the potential to be a central determinant of future infrastructure dependencies (OECD, 2006). Avoiding a rise in mean global temperatures of more than 2°C is thought critical to averting the most dangerous impacts of climate change. Avoiding this rise in global temperature will require reversing current trends of growth by 2020 and achieving reductions of at least 50 per cent on 1990 emissions levels by 2050 (DECC, 2009).

The international community has so far shown a limited consensus on how emissions reductions of this magnitude can be realised, and how responsibility can be shared between the developed and developing world.

This period of protraction will have consequences for infrastructure as owners and investors. Stern warns that an international consensus and clear long term policy commitments are critical to infrastructure development. In their absence, investors, owners and operators delay locking themselves into long-term investment decisions, unsure of the eventual appetite for emissions reductions and the implications for the cost and profitability of their infrastructure (Stern, 2005).

If agreement is finally reached infrastructure sectors such as transport and power, which have been identified as particular sources of emissions will certainly face future constraints in their operations. Transport has been the fastest growing source of GHG emissions over the last 10 years and now accounts for 23 per cent of the global emissions associated with human activity (IPCC, 2007). In the face of greatly increasingly demand in the developing world, rapid technological advances are driven by the climate change mitigation policies and energy uncertainty. Passenger jet aircraft are 70 per cent more fuel efficient than those produced 40 years ago and a further 50 per cent improvement is predicted by 2050 (ibid).

The need to mitigate climate change and the prospect of some form of carbon trading will likely work to the advantage of some existing and emerging infrastructures, such as those in the renewables sector (WEF, 2009). However, more generally it is expected that policy interventions to rationalise demand will add cost to the operation of, and access to, infrastructure. Meeting these additional costs in the investment climate described below will likely entail passing them to the end. This ‘user pays’ approach will necessitate new business models in sectors such road and water where infrastructure is currently treated as social good (OECD, 2007).

3.4.2 Demography

A number of interconnected demographic trends will shape the development of overseas infrastructure at national and regional levels. Population size and the shifting socio-economic make-up of expanding populations are the most obvious of these. The larger the population, the greater the required capacity for clean water, sanitation and other basic services. In regions like Africa and parts of Asia where the growth is predicted to be most pronounced, the extent to which these growing populations are urbanised will dictate the economies of scale it is possible to achieve. This in turn will partly dictate the range and sophistication of infrastructure which they can feasibly have access to (Heller, 2009). Income levels will also be a crucial determinant of infrastructure provision. As average income levels rise the provision of infrastructure becomes more profitable and more politically urgent (ibid). The IMF has observed the growth in demand for car ownership once a country's income crosses a given threshold. Such phenomena intensify the demand for associated road infrastructure, for instance (IMF, 2008).

The age structure of a population is a further key determinant of its infrastructure requirements. Young populations, for instance, will require more access to infrastructure associated with education. China's rapidly aging population provides a good example of the challenges of demographic transition from young to elderly populations. By 2050, it will have more than 430million people aged over 65. The task of providing the necessary social infrastructure for an elderly population larger than the entire projected population of the US is now considered one of the most urgent development issues facing the country (Jackson, 2008).

In the latter stages of demographic transition the stagnation and decline of some national and regional populations has implications for the provision of infrastructure. Overall declines in population, as are becoming more likely in Central and Eastern Europe, will manifest in disproportionate falls in the size of rural and smaller urban populations. Existing infrastructures may become inefficient, if not unsustainable, once populations drop below certain levels.

This is a phenomena already apparent in parts of Germany and rural Japan (Heller, 2009).

Closely linked is the impact of migration. Ever increasing ease of travel combined with the presumption of a more turbulent geopolitical climate raise the prospect of more rapid flows of immigration defying the long term planning cycles associated with infrastructure and variously sparking crises of either infrastructure's under-capacity or redundancy (DCDC, 2010).

3.4.3 Investment

In recent years, in response to the economic crisis, a series of high profile fiscal stimulus packages have focused significantly on improving infrastructure. In 2009 US spending on infrastructure accounted for 27.5 per cent of a $262 billion package. In emerging economies stimulus were targeted even more strongly at infrastructure which accounted for over 60% of their spending. This spending on infrastructure has been devised as a means to inject money into national economies whilst removing bottlenecks to future growth (Carter, 2009).

However, these figures are based on huge levels of national borrowing and unsustainable beyond the short term (ibid). In the face of a global infrastructure investment requirement of $35 trillion over the next 20 years, these stimuli represent an aberration in what has otherwise been characterised as an international infrastructure investment crisis (WEF, 2010). Over the last two decades public-private partnerships for large infrastructure projects has been a model increasingly subscribed to. Here, governments typically provide the initial investment before outsourcing the management and service delivery to the private sector through long-term licensing agreements. However, as the growth of developed countries has slowed, governments have had to manage the upgrading of existing infrastructure, and the initiation of new projects, in the context of worsening fiscal conditions and growing national debts (ibid).

In developing countries where growth remains good, the barriers may relate more to the extremely long-term nature of infrastructure projects, political stability and the quality of governance. Problems around governance and stability may be exacerbated further by a combination of factors, including climate change, through this century (ibid).

Going forward banks will be less willing to meet the entire cost of individual projects preferring instead to club together and spread risk. However, raising investment in this fashion is more complicated and more expensive (KPMG, 2008). Countries are looking toward new sources of finance and hope rests mainly with the considerable pools of capital managed by pension funds and insurance companies. The attractiveness of infrastructure to these investors lies in its low-risk steady return profile. This infrastructure profile may be undermined across some sectors and regions by the impacts of climate change mitigation policies and increasing insurance- related losses on infrastructure in the face of more frequent and extreme weather events over the next century (OECD, 2007).

4 Conclusion

The number of socio-economic variables, the sheer breadth of relevant data and the still limited granularity of future climate change predictions all constrain any analysis of the impacts of climate change on overseas infrastructure and the subsequent consequences for the UK.

However, a number of general trends and likely scenarios can be discerned from the data analysed in this report. The UK's historically high levels of integration with global markets is set to increase further in coming decades as its degree self-sufficiency in natural resources declines and the emergence of high growth markets in Asia and South America drive new patterns of trade. Seeking to exploit global value chains, the UK will continue to rely heavily on the regional and global movement of goods. This reliance on physical transport infrastructure will be matched by a growing dependency on communications infrastructure through which the UK will export services to a growing 'knowledge economy'. In combination, these trends point toward significantly growing UK dependencies on a wide variety of overseas infrastructure.

Historically, extreme weather events have repeatedly caused often severe, disruption and damage to the three sectors of infrastructure examined in this report. The growing frequency of extreme weather events which will be a feature of climate change are extremely likely to result in increased damage and disruption for future infrastructure. This in turn is likely to impact the global supply chains of UK business and industry and impact the overseas interests of UK firms operating globally. Extreme weather is likely both to disrupt the transmission of goods and service to and from the UK, and to disrupt the development and growth of the UK's future target markets for trade and commerce.

Climate change and its impacts on overseas infrastructure could present some opportunities to the UK. The opening up of new shipping routes such as the North West Passage (NWP) will lower the time and cost of reaching Asian markets from Europe. A well adapted resilient UK infrastructure could present UK PLC with a relative competitive advantage in the race for foreign investment.

According to most emissions scenarios, longer term gradual temperature change will present less of a direct threat to overseas infrastructures. With exceptions, such as energy infrastructure in Northern Russia, the consequences for the UK of gradual temperature change will be chronic rather than acute in nature. Gradual climate change will possibly interact with and exacerbate other stressors of international infrastructure such as rapid demographic change and an investment crisis.

Risk/Scenario	**Timescale**	**Likelihood**	**Global/Regional Implications**	**Implications for UK (opportunities as well as threats)**	
				Direct	**Indirect**
Extreme weather event disrupts delivery of energy to the UK	Short	High	Increased demand/price energy resources	Negative impacts for public health/ wellbeing. Disrupts industry/ business productivity	Impacts the relative competitiveness of UK PLC and undermines foreign investment
Extreme weather event disrupts production of electricity overseas	Short	High	Moves to diversify energy sources/ improve security of supply	Disrupts UK industry/ business supply chains. Increased demand /price regional electricity markets	Improve/ worsen relative competitiveness UK PLC
Significant increase or decrease in energy demand for cooling/ heating	Medium	Medium	Increased demand/price energy resources. Undermine long term infrastructure planning	Increase/ decrease competition in energy markets	Impedes long term energy planning
Climate change impacts exploration/ exploitation of new energy reserves	Short	High	Improve/worsen local/ regional security of supply/ energy export revenues	Work for/ against UK energy industry overseas interests. Increase/ decrease competition in energy markets	

Risk/Scenario	**Timescale**	**Likelihood**	**Global/Regional Implications**	**Implications for UK (opportunities as well as threats)**	
				Direct	**Indirect**
Extreme weather causes temporary disruption of regional transport networks	Short	High	Disrupts industry/ business supply chains. Undermine relative regional competitiveness	Disrupts UK industry/ business supply chains. Impact UK business/industry interests overseas	Impede development of UK target markets. Improves relative competitiveness UK PLC
Gradually altered access to traditional shipping routes eg. North West Passage	Medium	High	Improve/worsen local revenue from supply of access Disrupts/improve industry/ business supply chains.	Improve UK export/import access to Asian markets	
Extreme weather causes disruption of local or regional overseas telecommunications infrastructure	Medium	High	Disrupts industry/ business supply chains. Undermine relative regional competitiveness	Disrupts UK industry/ business supply chains. Impact UK business/industry interests overseas	Impede development of UK target markets. Improves relative competitiveness UK PLC
Extreme weather or flooding causes loss or damage of	Medium	Medium	Invigorate local/regional adaptation efforts	Undermine public confidence/ impede provision of	Worsen relative competitiveness of UK PLC

Risk/Scenario	Timescale	Likelihood	Global/Regional Implications	Implications for UK (opportunities as well as threats)	
				Direct	**Indirect**
internationally located UK data or digital labour				government services Disrupt industry/business productivity	
Rapid migration flows lead to under-supply of local critical infrastructure services	Long	Medium	Potential humanitarian crisis Disrupts industry/ business supply chains.	Impact UK aid and development commitments Impact UK business/industry interests overseas	Improves relative competitiveness UK PLC
Climate unpredictability/ extreme weather events add risk/ undermine the attractiveness of infrastructure investment	Medium	Medium	Failure to build/ maintain requisite infrastructure for growth/development in developing regions	Impede development of UK target markets.	Impact UK aid and development commitments
Climate change mitigation policies penalise energy and transportation infrastructure	Medium	High	Limited supply/ increased cost of infrastructure services Expedited moves toward next generation ‘green infrastructures’.	Improves/worsens relative competitiveness UK PLC	

Table 4-1: Summary Table

5 Further Work/Sign Post

Significant gaps in understanding remain around the physical impacts of climate change on infrastructure (Hall, 2006). These result partly from the uncertainty still surrounding the exact nature and extent of climate change impacts, but also from the limited impact assessment work done on the basis of current knowledge. Most developed countries have or are in the process of preparing risk adaptation strategies (UNFCCC, 2009). These documents, while having varying definitions of ‘infrastructure’, invariably do examine infrastructure as a stand-alone topic or in the context of different sectors of activity. However, none of the national climate risk assessments took a significant interest in infrastructure outside the state’s borders. Given the highly interconnected and interdependent nature of modern infrastructure networks, attempting to assess a state’s vulnerability without reference to regional and international networks and supply chains represents a significant omission.

At the regional and international level various efforts have been made to catalogue the impact assessment and adaptation efforts taking place within constituent states. However, there remains apparently no work on risks of climate change to the various connective infrastructures on which countries depend for international travel, trade and communications.

The absence of thinking about the impact of climate change in the developing world is typical of the constraints which poverty and weak governance place on the adaptive capacity (Kelly, 2005). The World Bank and the United Nations have conducted some speculative analysis about the impact of climate change on local infrastructure in parts of the developing world (The World Bank, 2010 &UNFCCC, 2007). However, almost no work could be found the impact of climate change on international infrastructure linking to or passing through those regions.

References

Acclimatise. (2009). *'Building Resilience to Inevitable Climate Change' Carbon Disclosure Project Report 2008.* Oxford.

AEA. (forthcoming). *ICT and Climate Risk.* London: DEFRA.

Auld, H., & Maclver, D. (2006). Changing weather patterns, uncertainty and infrastructure risks: Emerging adaptation requirements. (pp. 668-677). IEEE.

Barnett, T. M. (2004). The Effects of Climate Change on Water Resources in the West: Introduction and Overview. *Climactic Change , 62* (1), 1-11.

Bein, D., Bein, W., & Phoha, S. (2010). Efficient Data Centers, Cloud Computing in the Future of Distributed Computing. (pp. 70-5). IEEE Computer Society.

BERR. (2009). *New Industry, New Jobs: Building Britains Future.* London: Stationary Office .

BIS and DCMS. (2009). *Digital Britain: Final Report.* London: Stationary Office.

Boeing. (2009). *Staying Current: market outlook 2009 - 2028.* Retrieved from Boeing.com: http://www.boeing.com/commercial/cmo/

BP. (2009). *World Statistical Energy Review.* London: BP.

Cabinet Office. (2009). *Food Matters: toward a strategy for the 21st century.* London: Stationary Office.

Cabinet Office a. (2008). *The National Security Strategy of the United Kingdom: Security in an interdependent world.* London: Cabinet Office.

Cabinet Office. (2008). *The Pitt Review: Lessons learned from the 2007 floods.*

Carter , L., Burnett, D., & Drew, S. (2009). *Submarine Cables and the Oceans- Connecting the World.* UNEP-WCMC.

Crown. (2008). *Climate Change Act .* London: The Stationary Office.

CSOC. (2010). *Horizon Scanning: The cyber domain in 2015.* London: UK Cyber Security Operations Centre.

DCDC. (2010). *Global Strategic Trends out to 2040.* London: Ministry of Defence.

de Bijl, P., & Huigen, J. (2008). The future of telecommunications regulation. *TELECOMMUNICATIONS POLICY , 32*, 699-700.

DECC. (2009). *The UK Low Carbon Transition Plan.* London: HM Government.

DEFRA. (2008). *Ensuring the UK's Food Security in a Changing World.* London: DEFRA.

European Commission. (2009). *Critical Information Infrastructure Protection - a new initiative in 2009*. Retrieved from europa.eu: http://ec.europa.eu/information_society/policy/nis/strategy/activities/ciip/index_en.htm

European Commission. (2008). *Green Paper: Towards a Secure, Sustainable and Competitive European Energy Network.*

Evans, B. J.,& Steven D (2009). *Confronting the Long Crisis of Globalisation.*

Washington: Brookings Institute.

Fair, J. M., LeClaire, R. J., Wilson, M. L., Turk, A. L., Deland, S. M., Powell, D. K., et al. (2007). An integrated simulation of pandemic influenza evolution, mitigation and infrastructure response. (pp. 240-245). IEEE.

Financial Times. (2009). *16 June, Experts Warn Over Shortages of Rare Earth Metals.*

Gelb, B. A. (2006). Russian Oil and Gas Challenges.

Gheorghe, A. V., Masera, M., De Vries, L., & Weijnen, M. (2007). Critical infrastructures: the need for international risk governance. *International Journal of Critical Infrastructures , 3*, 3--19.

Great Lakes Regional Assessment Team . (2000). *Preparing for Climate Change: Great Lakes.* US Global Change Research Program.

Hall, J., Dawson, R., Manning, L., Walkden, M., Dickson, M., & Sayers, P. (2006). Managing changing risks to infrastructure systems. *Proceedings of the Institution of Civil Engineers, Civil Engineering , 159*, 21-7.

Heller, P. S. (2009). *Do Demographic Factors Influence Investment in Infrastructure?* Maple Forum, Washington DC.

Helm, D. (2007). *The Russian Dimension and Europe's External Energy Policy.* Retrieved from www.dieterhelm.co.uk: http://www.dieterhelm.co.uk/publications/Russian_dimension.pdf

IEA. (2008). *World Energy Outlook.* International Energy Agency.

IMF. (2008). *World Economic Outlook.* Washington DC.

Instanes, A. (2003). Climate change and possible impact on Arctic infrastructure. (pp. 461-466). A A BALKEMA PUBLISHERS.

Instanes, D. I. (2006). Impacts of a changing climate on infrastructure: Buildings, support systems, and industrial facilities. (pp. 47-50). IEEE.

International Maritime Organisation. (2009). Maritime Transport and the Climate Change Challenge. (p. 52). Geneva: United Nations.

IPCC. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Report of the Intergovernmental Panel on Climate Change.*

Jackson. (2008). *The Graying of the MIddle Kingdom.* Washington: CSIS.

Kelly, N. B. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *15* (2), pp. 151-163.

Kivits, R., Charles, M. B., & Ryan, N. (2010). A post-carbon aviation future: Airports and the transition to a cleaner aviation sector. *FUTURES , 42*, 199-211.

Larsen, P. H., Goldsmith, S., Smith, O., Wilson, M. L., Strzepek, K., Chinowsky, P., et al. (2008). Estimating future costs for Alaska public infrastructure at risk from climate change. *GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS , 18*, 442-457.

MacKay, D. (2009). *Sustainable Energy.* Cambridge: UIT Cambridge.

Mason, P. J. (2010). Climate variability in civil infrastructure planning. *PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-CIVIL ENGINEERING , 163*, 74-80.

Miodrag B, D. S.-R. (2010). *RFID Systems: Research Trends and Challenges.* London: Wiley and Sons.

Muzi, F. (2008). Smartgrids and distributed generation: the future electricity networks of the European Union. (pp. 243-247). WORLD SCIENTIFIC AND ENGINEERING ACAD AND SOC.

Nayyar, D. (2006). Globalisation, history and development: a tale of two centuries. *CAMBRIDGE JOURNAL OF ECONOMICS , 30*, 137-159.

Neumann, J. E., & Price, J. C. (2009). *Adapting to Climate Change: The Public Policy Response.* Massachusetts: Resources for the Future.

OECD. (2010). *Globalisation, Transport and the Enviroment.* Paris: OECD.

OECD. (2006). *Infrastructure to 2030.* Paris

OECD. (2007). *Infrastructure to 2030: Volume 2 mapping policy.* Paris

OECD. (2007). *Moving Up the Global Value Chain: Policy Brief.* Paris

Ofgem. (2010). *Electricity Interconnector Policy (Consultation).* London: Ofgem.

Ofgem. (2009). *Project Discovery: energy market senarios.* London: Ofgem.

Oh, X. (2010). Airports and Adaptation: Changing climate and business conditions. *ICAO Colloquium on Aviation and Climate Change.* Montreal: Airports Council International.

Oxera. (2007). *An assessment of the potential measures to improve gas security of supply.* Department for Business Enterprise and Regulatory Reform.

Paskal, C. (2009). *The Vulnerability of Energy Infrastructure to Enviromental Change.* Chatham House.

Perelet, R., Pegov, S., & Yulkin, M. (2007). Climate Change. Russia Country Paper. *Human Development Report , 2008*.

PriceWaterhouseCooper. (2009). *100 Percent Renewable Electricity: a Roadmap for Europe and North Africa.* London: PWC.

Pryor, S. C., & Barthelmie, R. J. (2010). Climate change impacts on wind energy: A review. *RENEWABLE & SUSTAINABLE ENERGY REVIEWS , 14*, 430-437.

RAE. (2010). *Global Water Security- an engineering perspective.* London: Royal Academy of Engineering.

Reiter, U., & Turton, H. (2009). Climate change adaptation scenario for the European electricity sector., *6*, p. 522004.

Renat Perelet, S. P. (2007). *Climate Change. Russia Country Paper.* New York: United Nations.

Richman, S. H., & Pant, H. (2008). Reliability concerns for next-generation networks. *BELL LABS TECHNICAL JOURNAL , 12*, 103-108.

Robinson, D. (2010). Oil and gas: Water treatment in oil and gas production - does it matter? *FILTRATION & SEPARATION , 47*, 14-18.

Rothengatter, B. F. (2003). *Megaprojects and Risk.* Cambridge University Press.

Scott, E. S. (2003). Computer-based functional literacy: how digital literacy projects can transform the third-world workforce. (p. 6 pp.). IEEE.

Skeie, R. B., Fuglestvedt, J., Berntsen, T., Lund, M. T., Myhre, G., & Rypdal, K. (2009). Global temperature change from the transport sectors: Historical development and future scenarios. *ATMOSPHERIC ENVIRONMENT , 43*, 6260-6270.

Stern, J. (2009). *Future Gas Production in Russia: is Concern about a Lack of Investment Justified? .* Oxford: Oxford Institute for Energy Studies.

Stern, N. (2005). *Stern Review: The Economics of Climate Change.* London: HM Treasury.

The World Bank. (2010). *The Costs to Developing Countries of Adapting to Climate Change.* Washington: The World Bank.

The World Bank. (2009). *World Development 2009 Report.*

Transportation Research Board . (2008). *Potential Impacts of Climate Change on US Transportation.* Washington, D.C.: National Research Council.

Uhl, K. E. (2003). Freedom of Information Act Post-9/11: Balancing the Publics Right to Know, Critical Infrastructure Protection, and Homeland Security. *Am. UL Rev. , 53*, 261.

Umbach, F. (2010). Global energy security and the implications for the EU. *ENERGY POLICY , 38*, 1229-1240.

UNFCCC. (2007). *Climate Change: Impacts Adaptation and Vulnerability in the Developing World.* New York: UN.

UNFCCC. (2009). *National Reports*. Retrieved May 2010, from United National Framework Convention for Climate Change: http://unfccc.int/national_reports/items/1408.php

US ARC. (2003). *Climate Change Permafrost and Impacts on Civil Infrastructure.* Washington DC: US Artic Research Commission.

US CCSP. (2007). *Synthesis and Assessment Product 4.5: Effects of Climate Change on Energy Production and use in the United States.* Washington DC: US Climate Change Science Programme.

US Congress. (2006). *A Failure of Initiative: Select Bipartisan Committee Investigation in the Preparation and Response for Hurricane Katrina.* Washington DC: US Congress.

Venables, J. (2009). Climate change, risk and infrastructure policy-making. *Civil Engineering , 162*, 3--8.

Wandel, B. S. (2006). Adaptation, adaptive capacity and vulnerability. *Global Enviromental Change , 16*, 282-292.

WBCSD. (2004). *Mobility 2030.* World Business Council on Sustainable Development.

Webster, D. (2009). Digital Britain: red electricity and server huggers stand in the way. *Database and Network Journal , 39*, 13.

WEF. (2006). *Global Risks 2006.* World Economic Forum.

WEF. (2009). *Green Investing: towards a clean energy infrastructure.* Switzerland: World Economic Forum.

WEF (2010). *Global Risks 2006*. World Economic Forum

Whyte, J. S. (2008, 2008). The future: the next 25 years - a paper from 1981[telecommunications technology]. *The Journal of the Institute of Telecommunications Professionals* , 19-22.

Wicks, M. (2009). *Energy Security: A National Challenge in a Changing World.* London: DECC.

Youtube (2008) ‘*Vodaphone Turkey Flood*’, http://www.youtube.com/watch?v=1M_QTBENR1Q

URN: 11/1023