1. Introduction

This document reports the discussion and findings of the Energy Infrastructure Adaptation to Climate Change Workshop held at the Institute of Mechanical Engineers on 8th July 2010. The event was chaired by Terence Tovey.

The workshop process was organised around the five key questions raised in the briefing document (Annex 1), commencing with a brainstorming session around the primary concerns and issues before considering options and choices.

Modern society in the UK depends on energy supplies 24 hours a day, 365 days a year, and expects to receive power whenever it is required, for whatever purpose.

The energy infrastructure covers the extraction and transmission of fossil fuels (coal, gas and oil), the generation and transmission of electricity from fossil fuels (gas and coal), nuclear power and renewable sources (including wind, wave, tidal and waste), and heating and cooling (both domestic and industrial).

The energy industry consists of both regulated, notably the supply of electricity and gas, and unregulated businesses. The impacts these face as a result of climate change and their responses to them may differ significantly.

2. Impacts and Operational Challenges Arising from Climate Change

The changes to climate outlined in UK climate projections (UKCP09) have multiple effects on energy infrastructure.

The URS report "Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change" (2010) identified the following high level risks to energy infrastructure.

Infrastructure components	Key risks
Fuel processing facilities/ storage of fuel/ transport of fuel	Flooding of fuel supply infrastructure due to increased storminess and sea level rise/ sea surges.
Power generation (fossil, nuclear and renewables)	Flooding of fossil fuel and nuclear 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 increased storminess.
Energy distribution systems	Reduced capacity of distribution network due to increased temperatures and precipitation/ storminess.

(source: URS, 2010. Page 3)

The workshop saw flooding of electricity generating and transmitting infrastructure as a key risk. The 2007 floods in Severn Valley saw the Walham sub-station at extreme risk of flooding[1], which would have damaged the electricity supplies to Gloucester and South Wales. With such sub-stations located in or near centres of population, and hence often on or near flood plains, the risk of flooding will increase with increased sudden rain storms.

Many electricity generating stations rely on river water for cooling. This means they too are often sited on or close to rivers, and may thus suffer from an increased risk of flooding. Conversely, greater fluctuations of rainfall may also lead to increased periods of drought during the summer months, when the continuity of a supply of water for cooling may not be guaranteed.

Increased air temperature may also reduce the efficiency of electricity generating and transmission infrastructure. Power stations become less efficient as the ambient temperature rises and cooling becomes less effective.

Current flowing through aerial transmission cables generates heat. The standard rating for transmission cables in the UK is 80°C. With higher air temperatures, less current will be transmitted before the cable reaches 80°C.

It is not expected that transmission cables or pylons will suffer from wind damage *per se*. However, if parallel cables are swinging as a result of high wind, it is possible that they may touch resulting in a short circuit requiring repair.

Rising sea levels may effect coastal installations such as conventional and nuclear power stations and oil and gas refining and storage facilities. These are frequently located in coastal areas for the ease of transport of fuel and the availability of water for cooling.

Oil and gas pipelines may be subject to damage by soil shrinkage as a result of drought.

More extreme conditions may effect renewable electricity generation. Under high winds, turbines utilising wind power need to decouple from their generators to prevent damaging them. Wave and tidal power generation may also be subject to restrictions due to extreme conditions.

The probable climate scenarios suggest that as well as factors influencing infrastructure, the effect of changing climate will change the patterns of demand for energy, with reduced winter usage resulting from higher average winter temperatures, increased summer energy usage as higher average temperatures leads to increase use of air-conditioning, and increased variability of demand.

3. Adaptation Options to Meet Issues and Challenges

It was observed that none of the potential weather impacts facing Britain in the foreseeable future are new or unique: they have all been experienced elsewhere in the world, and hence there are existing technologies which can be utilised to adapt

[1] Memorandum submitted by National Grid (FL 80) to the Select Committee on Environment, Food and Rural Affairs.
http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvfru/49/8020403.htm

to the changed conditions. There are no technological barriers to adaptation anticipated.

Primarily there is a need for detailed risk assessment for each piece of infrastructure under the likely conditions it will face so that adequate plans for adaptation and increasing resilience to meet those conditions can be prepared. Because the weather conditions predicted by UKCP09 are given in terms of probabilities, there is felt to be an increased need to develop training in probabilistic approaches to adequately assess the potential risks.

Revised design standards and building codes for the energy infrastructure need to be developed in anticipations of the conditions to ensure that the infrastructure is likely to face. Infrastructure could then be adapted as it comes up for refurbishment or replacement. Design approaches to adaptation will need an understanding of extreme of weather events and of the probabilities of specific climate conditions.

As well as a risk assessment of individual pieces of infrastructure, it would benefit operators and regulators (when appropriate) to envisage the energy supply chain between fuel supplies to delivery of energy consumers in a holistic manner to identify pinchpoints or bottle-necks in the process which may limit resilience. It is suggested that utilisation of Sankey diagrams could accomplish this at national, regional and local levels.

This deeper understanding of the supply chain could facilitate greater co-ordination and integration between operators (where allowed by prevailing legal frameworks) to manage stresses on infrastructure by, for instance, co-ordinating when significant pieces of infrastructure such as generators are taken offstream for servicing and maintenance.

Despite the utilisation of these adaptation processes, it is possible that interruptions to energy supplies will occur. Using smart meters to manage the delivery of energy to consumers and developing a smart grid to ensure supplies to specific users or communities will enable suppliers to balance demand in times of stress.

Not withstanding extremes caused by specific events, it is likely the there will be a requirement for greater electricity generating capacity at times of peak demand. This is best met through a variety of electricity generating sources and a broad portfolio of generating capacity. This will also increase the resilience of the electricity generating infrastructure by reducing reliance on any one source.

Using a variety of storage systems could also facilitate load balancing. The expected increase in the use of electric vehicles, for instance, could be managed through smart technology to charge vehicles' power supplies at times of low usage. Similarly, it would be possible for information technology systems such as personal computers and other networked equipment to use batteries charged during off-peak periods to provide power directly, removing the need to power the equipment during peak periods of energy demand.

Similarly, using hydro-electric facilities as a storage mechanism, pumping water during off-peak demand to generate electricity in peak periods could manage peaks in electricity usage. Combining these with less predictable renewable supplies would enable the indirect use of renewable resources during peak periods. The system may be more resilient if the hydro-electric storage is managed on a local basis.

Developing other distributed energy systems and generating capacity would also increase the system resilience. Infrastructure such as small scale generators could work in many different, flexible ways, functioning as back-up systems for essential services, for specific customers or for local needs whilst having capability to provide energy to other users or the grid if and when required.

4. Barriers to Implementing Adaptation Options

Many of proposed adaptation mechanisms will require additional finance. Whilst incorporating the changes required into the design standards and building codes for infrastructure may enable the adaptation to be undertaken within the normal life-cycle of maintenance, refurbishment and replacement, it is likely that the standards will be more exacting in order to meet greater extremes. They may need increased quality materials, take longer to maintain, repair and replace and require more extensive testing to ensure revised standards are met. These inputs are therefore likely to increase the costs of infrastructure. Similarly, increasing the utilisation of hydro storage facilities and other distributed capacity will require investment.

The benefit of these investments may well be separated from the finance, particularly if the perceived benefit is to the nation as a whole through a more resilient infrastructure. The supply of such “just in case” capacity – which may be seen by investors as excess capacity – would not meet usual investment criteria in a commercial, market environment.

The development of distributed capacity by commercial users might become economical if the risk of power shortages were to increase. For instance, chemical processing plants, which can be energy intensive, benefit from continual energy supplies. If the risk to energy supplies increased, the costs associated with a power failure would increase and the investment in dedicated generating capacity to guarantee supplies may become economic.

Regulation could also be used to require suppliers to provide “just in case capacity”. If the regulated parts of the energy sector had a requirement to provide energy to all consumers within specified standards, both the regulated and unregulated sectors would have economic reasons to comply – the regulated industry as part of their licence to operate, the unregulated industry to meet the needs of the regulated industry. However, the costs associated with this would probably be passed on to consumers. Some consumers may prefer to pay less for supply that met lower standards, ie supply which might be subject to outages.

Whilst the costs of incorporating smart energy management systems in new consumer goods such as electric vehicles may be absorbed, consumers may object to paying more for such systems in other electrical goods. Objections might be overcome through commercial mechanisms, for instance charging more for energy consumed at peak periods.

Regulation and legislation may also be barriers to the adaptation of infrastructure and the development of a more resilient system. Increased co-operation and co-ordination to meet the challenges of climate change may fall foul of regulatory and competition law.

In regulated businesses, there is often a focus on improved efficiency of the business within the regulatory regime, which would work against investing in spare capacity.

Existing environmental and planning legislation may also work against adaptation. This is particularly the case where national infrastructure needs are subject to local planning decisions. Local decisions can be inconsistent with national priorities, and there is no central body responsible for planning adaptation and resilience of national infrastructure. The current government's programme includes creating a presumption in favour of sustainable development in the planning system[2], but it is unclear whether this would include – or may even work against – increasing infrastructure resilience. There is a need for a broader approach to sustainability which balances economic, societal and environmental needs while simultaneously considering the legacy left to future generations.

Public opinion may also be a barrier to adapting and developing infrastructure. Whilst most people understand the need for continuity of energy supply in the abstract, they frequently object to local development – an example of NIMBYism[3]. Greater public understanding of the needs arising from climate change and the urgency of development may be required so that the public, politicians, suppliers and regulators can take part in an ongoing debate.

It is possible that the UK lacks the manufacturing base required to meet the future needs as a result of adaptation. A shortage of manufacturing capability may increase prices for infrastructure. This may be an opportunity for manufacturers.

It is not clear whether government, regulators, and businesses have sufficient forecast data available to them to plan effectively for the effects of climate change. UKCP09 provides resolution to 25 km, which might not be sufficiently detailed to undertake a risk analysis of infrastructure. It does not consider the frequency of extreme events, which are those which might impact on infrastructure. UKCP09 also does not include estimates of the effect of climate change on wind, which whilst not generally considered to have significant impact on energy infrastructure may impact specific pieces of infrastructure, particularly those involving renewable energy resources.

The skills and education of engineers will need to change to meet the demands required to fulfil the adaptation agenda. A skills mapping exercise for DECC indicated that an additional 35,000 engineers would be needed to meet the demands of the government's low carbon future – that is, mitigation for climate change. It is not certain how many engineers will be required to meet the needs of adaptation to climate change, but it is likely to be more than the number of engineers currently working in the energy sector. They will also need a different or additional skill set to deal with the probabilistic nature of the forecasts, rather different to the deterministic nature of traditional engineering education.

In order to overcome these barriers will need a lot of political will. If adaptation is successful, the energy industry should be able to meet the nation's needs; however,

[2] "We will create a presumption in favour of sustainable development in the planning system." http://programmeforgovernment.hmg.gov.uk/environment-food-and-rural-affairs/

[3] NIMBY: "not in my back yard".

it would then seem like the work was unnecessary: it is possible that it would take a crisis of some sort to demonstrate the need for adaptation. It might take considerable political will to undertake the investment and development potentially required to meet the adaptation agenda.

5. Interdependencies

Energy infrastructure is dependent on

- water infrastructure for providing a cooling mechanism for power generation and oil and gas refining, as well as protecting energy installations from flooding and ensuring staff manning installations are able to work in a healthy, hygienic environment
- ICT infrastructure for control and management systems, particularly smart grid and smart meter developments, and communications
- transport infrastructure for the supply chain of fuel for power generation and the distribution of oil and gas products, as well as enabling access for staff

Conversely, energy is required for

- water, to run water treatment plants and pumping stations
- ICT, to run all ICT equipment
- transport, to drive all transport systems

In addition, in urban environments energy, water, ICT and transport infrastructure are often co-located: for instance, power cables may be laid below roads and beside communications cables, adjacent to water and gas mains and above sewers. Failure of one form of infrastructure can lead directly to damage another and damage can also occur inadvertently during repair infrastructure work.

6. Opportunities Arising from Adaptation to Climate Change

The opportunities arising from adaptation to climate change are likely to be large but may be hard to realise. They are similar to existing opportunities arising from strategies to mitigate for climate change. In particular, developing more efficient energy systems such as power generation, power transmission and engines (electric or oil-based) would make energy infrastructure both more sustainable by reducing emissions and more resilient by making better use of the resources available.

Many of the adaptation option to climate change involve designing effective standards, codes and regulations for infrastructure. The expertise to develop these represents intellectual property which could be used elsewhere. The workshop perceived the UK as being ahead of rest of Europe on adaptation of its infrastructure, but needs to work to stay there. UK-based companies have experience of designing to these specifications currently and could capitalise on this experience.

The development of effective energy storage systems (either physical, eg storage of water for hydro schemes, or electrical) and distributed energy systems represent engineering and design opportunities. Developing both efficient storage capacity to power ICT systems for long periods and the smart systems to manage such devices recharging during off-peak periods would be highly marketable.

The UK has extensive experience of renewable energy infrastructure, which is seen as important to reduce greenhouse emissions. Renewable facilities could also be central developing distributed capacity, possibly community-based, again making the energy infrastructure more resilient.

Working with the built environment presents many opportunities. Incorporating systems to recycle waste heat from energy generation or industrial processes within communities reduces energy consumption, helping to manage demand. The extensive infrastructure between the heat source and the buildings making use of the excess heat means that recycled heat is easier to implement in new build developments rather than existing urban areas. Similarly, incorporating thermal inertia heating/cooling systems into buildings functions as both an adaptation and mitigation strategy, improving working and living conditions under climate change whilst reducing power usage and greenhouse emissions.

7. Next Steps

References

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Annexes.

1. Engineering, Infrastructure & Climate Change Adaptation. Energy Sector Discussion Paper

Assumptions

Use UKCP09 Climate Projections, which indicate there will be more extremes of weather.

Summer – Heat waves, drought, periods of no wind.

Autumn /Spring – High Winds, sudden rain storms creating flooding

Winter – Wetter, more snow both wet and dry, extremes of cold

Future UK Energy Sector will look like that envisaged by the government (DECC) 2020 and 2050 visions

Energy covers: Heating and cooling (both Domestic and Industrial)

Electricity:

- Generation: Nuclear
  - Fossil
  - Renewables
- Transmission and Distribution

Excludes transport (as covered in transport sector as interdependencies)

Common issues and approaches across all engineering based sectors in this project from brief

1. What are the issues/technical and operational impacts from climate change (focusing on the medium and long-term impacts) to the sector?
2. What are the potential adaptation options to address these issues/impacts? This should include consideration of engineering/design standards – do they need to change and if so why/how?
3. What are the potential barriers to implementing these options (including consideration of the wider context within which engineering operates)?
4. What interdependencies does the sector have with the other three sectors and will climate change impacts exacerbate these (note this should not be examined in-depth but a list of issues will be useful to the interdependency group)?
5. What are the opportunities (i.e. skills, economic, innovation) from adapting our infrastructure, in particular to the engineering profession and engineering organisations?

Discussion

The UK benefits from a very benign temperature and weather pattern and even with the worst predicted effects of climate change for this century, conditions do not exceed those already met and dealt with elsewhere. Therefore the engineering required is known even if it may not have been necessary to apply it previously in UK. From this it can be said that the problem is more one of specifying the limits which the design should meet, which then comes down to acceptable costs both social and economic (including acceptable thresholds for toleration of performance degradation). However in extreme cases where the atmospheric conditions fall outside the design conditions the process may prove to be inoperable without major modifications, the financial penalties for such a scenario may lead to further loss of manufacturing output as multinationals relocate to more cost effective locations.

Current private sector ethos in minimum required to meet specification and 'Just in time' Perhaps we need to move to a better specification giving value for money and then incentivising 'Just in case'

One of the first criteria is that of what is considered failure and what is considered survival.

Continue to operate though all extremes.

Shut down but capable of restart immediately.

Operating outside approved environmental conditions.

Shut down and restart within a period say 4 hours.

Fail but repairable within a period.

Fail and require replacement.

Should the provision of electricity supplies, which places a severe onus on the provider to keep the lights on, be reconsidered? The concept of interruptible supplies is well understood in the Gas industry, where major plant have accommodated disruption by installing alternative fuel sources. It was also used very effectively in the southern US in the 80's.

However the impact on the chemical sector of failure of the national grid is far more severe; many large sites have installed power generation equipment and are capable of operating disconnected from the grid, but this is not the case on many smaller sites, However, even with alternative power supplies sites require secure fuel sources.

Adaptation Options

Should we consider requiring a safety case for all major or critical infrastructure.

Change standards, guidance and design codes. Legislate to require resilience. Reconsider projects with climate change in mind.

Barriers

Social eg green lobby**,** economic both absolute (cost) and relative (why should I reduce current profits for someone else to benefit), technical (what degree of uncertainty are we prepared to accept in technical methods based on computational projections of future climate rather than historical measured weather data).

Independences

Communications. Supply chain including transport.

Opportunities

Increased skills required which can be home grown.

Export of methodology and management knowledge for building adaptive capacity in engineering based sectors.

Sensitivity

What happens if we are wrong both under-estimating or over-estimating? Unnecessary cost resulting in loss of international competitiveness or loss of infrastructure. Who is liable?

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