The Irish Academy of Engineering

Critical Infrastructure
Adaptation for Climate Change

Energy Infrastructure

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Summary

Every day, we hear of new initiatives in the energy sector to mitigate climate impacts. While major changes are underway in energy infrastructure, little attention has been given to climate adaptation.

Ireland's location in the Atlantic Ocean off Northern Europe has implications for energy supply – we are heavily dependent on import of fossil fuels over long distances, but we have a favourable setting for renewable generation from wind and ocean. The Northern Atlantic is linked to the arctic, where observed rates of change are shown to be faster than the rest of the world. Future energy infrastructure development must therefore address two distinct issues:

- facilitate the exploitation of renewable energy resources
- withstand any environmental impact of climate change

The lead time from planning to operation can be 10 to 30 years in the energy sector. Although this lead time has been reduced significantly in recent years, due primarily to technological advance, projections for energy supply and demand must look forward 20 to 40 years ahead. Plans are heavily dependent on socio-economic factors and on climate change. Latter examples of major impact are flooding of gas network marshalling stations and electricity substations or the destruction due to high winds of electricity lines.

Hence there is a wide range of adaptation issues to be addressed in the energy sector.

These include:

- Socio-economic models and methodologies for integrating adaptation in future demand
- Preparation of wind and wave resource atlases for future scenarios
- Need for climate parameters that will impact on efficiency and capacity factors of energy conversion and storage systems
- Need for adaptation in Codes and Standards for design of power plants, electricity and gas network substations, oil storage and dam safety based on predictions of extreme rainfall, wind, wave and surge - standards that are higher than in most design situations;
- Analysis of the so-called "Water-Energy Nexus", the complex linkage between energy for water/wastewater and water for energy, with changes in rainfall, evaporation, river flows, sea level and surge
- Coastal protection measures at reserve oil storage, pipelines, power generating stations, network substations and seabed cables;
- Bioenergy Action Plan measures accounting for seasonal changes in crop temperature and water cycle.

Measures to address adaptation must be comprehensive and integrated with other sectors, taking account of multiple factors through national and international policies

1. Introduction

Energy is a vital service for domestic, business, farming and industrial activity. An associated quality infrastructure is essential for Ireland to attract and retain high-tech industrial investment and for the country to have competitive energy supplies and balanced regional development.

Energy asset management and infrastructure planning has to be resilient as it responds to changes in climate and other factors. The long lead-in timescales for major energy infrastructure means that this response must be factored into energy policy, in a manner that accounts for adaptation strategies so that actions are consistent and adaptable.

The objective is to integrate the results of recent climate research in Ireland into the risk reduction strategies of energy planning, operation and maintenance. Existing energy systems in Ireland need to be checked for resilience and flexibility. Priority in energy planning must be given to win-win situations, that is, measures that are robust and flexible enough to cope with changing climate conditions. Irreversible actions are to be avoided.

This paper reviews the issues that arise for the energy sector. It presents a simple 'climate check' taking account of significant uncertainty involved in climate change assessment, uncertainty that arises at many levels, from:

- complex climate models at a global level,
- downscaling to the regional level
- local hydrodynamic modelling for water environment
- social and political inputs and assumptions made over the forecast period.

Notwithstanding this uncertainty, the efficiency and effectiveness of investment decisions can benefit from this climate-check. Measures can be said to be 'climate checked' rather than 'climate-proofed', because of the level of uncertainty involved.

Particular monitoring and research programmes for energy resources and procedures will be required to improve the level of certainty, taking account of additional climate research results as they become available.

2. Energy Infrastructure – Existing & Planned

Gas Networks

The Bord Gáis Eireann natural gas network consists of 2,169km of high-pressure steel transmission pipelines and over 9,765km of distribution pipelines. The gas network is supplied through three seabed pipelines from Scotland, two to Ireland and one to Northern Ireland. In recent years, the transmission system has been extended to Mayo and North-South and many additional towns are being connected throughout the country.

National Oils Reserve Agency

The National Oils Reserve Agency is the state body responsible for the holding of national strategic oil stocks at a level determined annually by the Minister for Communications, Energy and Natural Resources. Operational stocks in Ireland are held at major ports, at the Whitegate refinery and by large oil consumer companies. Ireland's IEA Stockholding Requirement for 2008 amounted to 2 million tonnes of Crude Oil Equivalent.

Electricity Networks

The ESB electricity network consists of 150,000km of low and medium voltage networks (mainly overhead lines) and 12,000km of high voltage circuits of which 5,800km relates to the transmission grid and is operated by Eirgrid. In Northern Ireland NIE has 2,100km of transmission network and 42,000km of distribution network. By 2025, the electricity transmission grid will carry 60% more power to cities and towns across Ireland. Eirgrid's strategy "GRID25" is an essential initiative to facilitate reliable, secure and affordable electricity supplies throughout Ireland. Without it, within the next five to ten years key parts of the grid will have reached capacity with likely overloading increasing risk to supply security. The total expenditure on network capital infrastructure during the period 2001 - '10 incl. is €6.5 billion, which is the largest undertaken by any electricity distribution company in Europe.

The demand level forecasts in 2025 are based on the Economic and Social Research Institute's long-term forecast of moderate growth in economic activity. The projections allow for reductions through energy efficiency and savings and for impacts of climate mitigation such as an increase in the share of electricity in the transport market, through electric vehicles.

Electricity generation in 2020 is projected to maintain present generation from coal, peat and hydro, to phase out oil, to maintain natural gas at about 50% and to increase substantially the amount coming from renewables. Renewable energy will contribute a total of 40% comprising primarily wind power, biomass and a small contribution from ocean energy. Accommodation of wind generation is a significant driver of transmission expansion. Energy storage as a complement to renewable variability is also being evaluated.

General

Contingency plans are in place to mitigate energy supply disruptions in line with Ireland's EU and IEA obligations.

A comprehensive White Paper was published in 2007 [4], setting out the Government's Energy Policy Framework to 2020. While climate adaptation is not specifically mentioned, it addresses issues that are relevant under the headings Strategic Goals for Security of Supply and Sustainability of Energy Supply. These are listed below.

Actions to Ensure Security of Energy Supply

- Ensuring that electricity supply consistently meets demand
- Ensuring the physical security and reliability of gas supplies to Ireland
- Enhancing the diversity of fuels used for power generation

- Delivering electricity and gas to homes and businesses over efficient, reliable and secure networks
- Creating a stable attractive environment for hydrocarbon exploration and production
- Being prepared for energy supply disruptions.

Actions to Promote the Sustainability of Energy Supply and Use
- Addressing climate change by reducing energy related greenhouse gas emissions
- Accelerating the growth of renewable energy sources
- Promoting the sustainable use of energy in transport
- Delivering an integrated approach to the sustainable development and use of bioenergy resources
- Maximising Energy Efficiency and energy savings across the economy
- Accelerating Energy Research Development and Innovation Programmes in support of sustainable energy goals.

The "All-Island Grid Study" [9] was published in January 2008. For a range of electricity generation portfolios, it provides a review of theoretical and practicable renewable energy resources and analyses the grid strengthening measures required to support each portfolio. Up to 42% renewables was considered.

In Northern Ireland, Department of Enterprise, Trade and Investment has recently published a Pre - Consultation Scoping Paper, "Northern Ireland Strategic Energy Framework 2009"[5].

The present level of new build and upgrading of energy infrastructure represents a major shift in scale from today's levels and presents significant challenges to all involved in its delivery. Future infrastructural development will take place in an environment different to todays due to climate change and their delivery must take such changes into account.

3. Parameters Affected by Climate Change

Summary predictions are presented below for key parameters [6], [7], together with their links to energy infrastructure.

Air Temperatures – linked to higher summer and reduced demand, prolonged growing season for bio energy, drying of peat lands
Temperatures are likely to increase everywhere relative to the present with greatest increases suggested for the summer and autumn of up to 1.2 – 1.4 ^{o}C (relative to 200) by 2060 and to 3.4^{o}C by the end of the century. With increases in average temperatures a change in extreme events is to be expected with an increase in the intensity and duration of heatwaves and a decrease in frost occurrence likely.

Sea temperatures – linked to thermal power plant cooling water systems
Sea temperature generally mirrors temperature trends over land. However, over the Irish Sea the satellite measurements suggest a more rapid warming rate (0.6-0.7°C per decade).

Precipitation – linked to hydro, bio energy and energy for water pumping

Precipitation remains an uncertain variable with differences in the extent and spatial distribution of changes between different modeling approaches. A robust signal of increased seasonality is evident with wetter winters and drier summers likely. No clear direction of change is evident for spring and autumn.

Wind speeds – linked to wind power
Increases of 8-11% at 60m height average wind speeds are likely in winter by around mid-century [7], with decreases of between 14-16% in summer but assessment of this variable to date has been subject to high levels of uncertainty [7]. McGrath notes that the Irish observational records indicate that average annual wind speeds decreased in the 1990s, with this trend continuing in the early years of the 21st century.

Sea level rise and storms – linked to seabed cables, coastal power plants and substations on reclaimed land, ocean energy, ports with oil reserves
IPCC scenarios suggest a likely sea level rise of between 0.28 to 0.43m by the end of the century relative to 1980-1999. However, recent thinking suggests that this may be too conservative with increase of over 1m suggested.
The likelihood of increased storminess, higher sea levels and wind speeds will result in a subsequent enhancement of wave heights and storm surges, when combined with riverine flooding will pose serious flood risks in many of our coastal cities.

River flows and flooding – linked to hydro, dam safety, cooling water, water supply
In relation to stream flow robust increases in winter and spring flows in the order of 20% in winter are likely by mid to late century. Reductions in summer and autumn months of over 40% are likely in many catchments. Catchments show different signatures of change depending on characteristics determining runoff response.

Flood events are likely to become more frequent with the current 50 year event likely to be associated with a ~10 year return period by mid to late century. While uncertainty remains low flow events are also likely to become more frequent.

Sunshine/cloudiness – linked to solar thermal and photovoltaics
No significant trends. However, these elements are particularly difficult to model.

Relative humidity – linked to thermal power generation efficiency
No significant trends.

Landuse – biological processes, peat extraction
Changes in species composition are predicted for many habitats, arising from a combination of temperature increase, changes in nutrient cycles and productivity, and soil moisture. Climate change induced drying of heaths and peat lands are likely to increase fire risk. Drying also increases the possibility of wind erosion, particularly on degraded sites, while extreme rainfall events also increase erosion risk and suspended solids loadings to downstream watercourses.

4. Vulnerabilities

Vulnerabilities are reviewed below in four categories.

Infrastructure	Relative Severity of Climate Change Adaptation
Efficiency and Capacity Factors of Power Generation	**Very High**
Water – Energy Nexus	**High**
Coastal	**Medium**
Networks, Storage	**Medium**

Table 4.1 Relative Severity of Climate Change on Energy Infrastructure

Efficiency and Capacity Factors of Power Generation

Significant vulnerabilities relate to power generation.

For fossil-fuelled power plants, optimisation of efficiency of energy transformation from primary energy to electricity is critical to the design and operation, not only from the point of view of economics but also in reducing the amount of carbon and other emissions. The higher the efficiencies of Ireland's power plants, the fewer plants are needed and total emissions are lower. Rising ambient temperatures reduce efficiency of the necessary air or water cooling systems within the power plants.

In addition, a plant using cooling water from rivers or from the coast has an overall plant efficiency approximately 2-3% higher than air-cooled systems. Water cooling is dependent on mixing in river flows or tidal currents and is subject to environmental constraints such as fisheries movement. A number of power plants on the Danube River shut down during a heat wave across Central Europe in 2003, when river temperatures increased beyond acceptable limits.

The efficiency of intermittent renewable power plants such as wind, run-of-river hydro and wave, will change as changes occur in the average wind speed, river flow and wave height. Increased wind speed can on the one hand lead to greater electricity production from wind turbines, but on the other hand, in storm situations wind turbines must be shut down to avoid storm damage and distribution lines suffer.

Another criterion is power plant capacity factor. This is the annual average output in MWhrs as a percentage of the output if the plant was running continuously. Increased downtime due to extreme weather conditions and to additional maintenance can affect both the efficiency and the capacity factor. For intermittent renewable plants, called non-despatchable plants, there are knock-on inefficiencies in start/stop of other supporting plants.

Energy - Water Nexus

Hydropower will become less efficient as winter flows are increased and summer flows are reduced. Standards for dam safety during extreme floods will need to be reviewed and operating procedures modified. The predicted 40% reduction in low flows will probably mean that other uses will take priority rather than hydropower for large parts of the year, such as public water supply and downstream environmental flows. Cooling water may be subject to constraints as mentioned above. Reduced low flows will also constrain the possible locations of new thermal plants, close to larger rivers where sufficient assimilative capacity is available for effluents.

In the future, substantial energy may be required for increased pumping of water supplies and wastewater systems for populations and industry, due to reduced local low flows. Irrigation pumping may be required. This is practised at present in the low-rainfall vegetable growing region of north Dublin and its widespread use in the future has been mentioned [6]. A higher standard of wastewater and/or sludge treatment may be required which may be energy intensive.

Coastal Infrastructure

Large energy infrastructures are located on the coast, close to jetties for import of oil and coal, and close to cooling water and to centres of population. Oil reserve storage is also on the coast. Most are on reclaimed land. Extensive wave and tidal plants are planned, under test at present off the coast and they are dependent on marine support services from local ports. Seabed cables and pipelines are located on the east coast, across the Shannon Estuary and planned for Co Mayo.

This infrastructure is vulnerable to sea-level rise and especially to storm surge and wave height. One parameter is worth noting in particular - the modelling results indicate an increase in the frequency of storm surge events and a significant increase in the height of extreme surge, with most of the extreme surges occurring in wintertime. There is also some evidence of significant increases in wave height extremes. (The 0.9m height that occurred during the 2002 storms may increase to 1.5m).

Networks and Storage

Higher average temperatures are expected to reduce the need for heating in winter and perhaps increase the need for cooling in summer.

In common with other critical infrastructure, the energy sector has facilities located throughout the country that are vulnerable to flooding and extreme wind loads. These include wind farms, substations, overhead lines, gas stations, oil terminals, offshore drilling rigs, etc. Codes and standards may need to be reviewed, similar to the Pitt Review report and the Energy Networks Association report in the UK, which followed the severe Gloucestershire flood in 2007. This recommended that the 1000-year risk should be considered.

In the longer term, infrastructure reinforcement measures may be required and in extreme scenarios, relocation to more secure locations may be appropriate. Health and safety response policies will be required to deal with catastrophes.

5. Adaptation Measures

The approach to adaptation in engineering infrastructure could be commenced by:

- Applying a probabilistic approach that provides the basis for a risk assessment due to climate change, with potential constraints on future energy options
- Examining approaches to integrating the impacts of climate change in design
- looking for opportunities to monitor key parameters at existing infrastructure to improve our understanding of climate change trends and impacts.

Plants and networks can be adapted to a certain extent to altered climatic conditions. While the existing energy infrastructure is not expected to be affected by the climate changes expected in the next 20–30 years temperature and sea level rise will need to be addressed. Towards the end of the century the effects will become more pronounced.

Energy infrastructure planning has a lead time of 10 to 30 years. Changes in the next 20 to 40 years are more readily identified than longer-term changes that depend on many social and political assumptions. Changeover and adaptation of plant capacities to address them should be implemented as required.

Predictions indicate that measures are required related to:

- Demand – seasonal changes, irrigation pumping, etc
- Supply – changes to renewable resources, to efficiency and capacity factors of conventional fuel conversion, and to risks at networks and storage facilities
- Local physical setting requiring modifications common to all infrastructure (coast, floodplains).

Measures can be categorised as win-win, no-regrets, regrets, and adaptation actions.

Win-Win Solutions are robust measures in the context of climate change. For example, increasing measures for energy storage provide security of supply and also contribute to climate adaptation.

Table 5.1 Win-Win Solutions

Measure	Contribution to adaptation to climate change
Energy Storage –CAES[1], hydro, electric cars	Protection against disruption and extremes
Network Renewal/Smart Networks	Facilitates renewables, energy efficiency
Increased water Impoundment	Pumping supplied at base load rather than at marginal high-emission supply

[1] Compressed Air Energy Storage

No-Regret Solutions are measures that are robust and flexible enough to be viable under different climatic scenarios and thus will not be affected later by climate change.

Table 5.2 No-Regret Solutions

Measure	Benefit of measure under changing climate
Demand Management	Climate change neutral

Regret Solutions are measures that bear a high risk of being counter-productive regarding adaptation to climate change, because the adaptive capacity of other sectors is reduced in relation to effectiveness, increases costs, etc.

Table 5.3 Regret Solutions

Measure	Potential problems under changing climate
Siting critical infrastructure in floodplains	Increased flood protection

Many initiatives in the 2007 Energy Policy White Paper [4] are 'win-win' solutions, such as storage for security of supply. This type of analysis highlights the advantages of an integrated approach to energy management within spatial planning and an adaptation strategy. It strengthens future engineering and science policy, linked on climate change by identifying research needs, communicating them to the research community and making best use of available research results.

Interaction with Other Sectors
Management action to address one climate pressure may increase the risk of not achieving objectives for another pressure. Climate change may increase this risk further, highlighting the need for integrated thinking.

6. Research

Research in adaptation covers a very wide field of problem areas.

The greater part of research efforts up until now have been directed at understanding and describing the impacts of the changing climatic conditions. There has been only limited focus on solutions to the specific challenges connected with future climate change.

Specific research for the energy sector will involve:

- Socio-economic models and methodologies for integrating adaptation in future demand
- Preparation of wind and wave atlases for future scenarios
- Need for identification of climate parameters that will impact efficiency and capacity factors of energy conversion and storage

- Need for adaptation in Codes and Standards for design of structures, power plants, electricity and gas network substations, oil storage and dam safety based on predictions of extreme rainfall, wind, wave and surge - standards that are higher than in most design situations;
- Analysis of the so-called "Water-Energy Nexus", the complex linkage between energy for water/wastewater and water for energy, with changes in rainfall, evaporation, river flows, sea level and surge
- Coastal protection measures at reserve oil storage, pipelines, power generating stations, network substations and seabed cables;
- Bio energy Action Plan measures accounting for seasonal changes in temperature and water cycle.

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