Ofgem LENS Project

Interim Report

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1 Executive Summary

This report presents draft Long Term Electricity Network scenarios that have been developed to explore and understand the implications for the electricity transmission and distribution networks of Great Britain in 2050. These scenarios have been developed using the information gathered and presented in the LENS Scenario Development Inputs report of November 2007 [1] and via techniques set out in the published methodology [2].

Themes entitled: ‘environmental concern’, ‘consumer participation’ and ‘institutional governance’ were selected following an extensive period of background research and stakeholder consultation. These themes are used to explore possible attitudes and approaches towards sources and uses of electrical energy. The themes were used to develop five ‘energy scenarios’ and these are summarised below.

Energy Scenarios

‘Switch me on’: Passive and Active Consumers, Moderate Environmental Concern, Market Led Institutional Governance.

- Consumers demand abundant supplies of electricity that require minimum participation on their part.
- Free markets persist as the main mechanism to service the energy requirements of the nation. Society is broadly consumerist and capitalistic.
- The importance of environmental issues to society in general does not grow significantly higher but there is continued debate and policy development geared towards reducing carbon emissions.
- Fossil fuels are used widely for electricity generation, domestic and commercial energy supplies and transport with ongoing and increasing risks of scarcity in primary fuel supplies and reserves.
- Centralised larger scale power generation (fossil, nuclear and/or renewable) dominates electricity production.

‘Fix it for me’: Passive Consumers, Acute Environmental Concern, Both Market and Government Led Institutional Governance.

- Consumers remain relatively passive towards their energy supply and while the majority of people are concerned about the environment they strongly believe that it is the duty of government and the market to address the issues.
- Although the belief persists that markets are best placed to service consumer demands at the same time as meeting social and environmental needs, strong intervention is not ruled out to address environmental issues.
- The potential for markets to meet the energy services demands of consumers is met through the emergence of energy service companies (ESCOs).
- Centralised electricity generation persists but alongside a relatively strong development of on-site and local/community scale demand side participation and smaller scale generation (e.g. combined heat and power) through the energy service companies.

‘Government Led Green Agenda’: Active Consumers, Acute Environmental Concern, Government led Institutional Governance.

- The belief develops that stronger Government intervention is required in the energy sector to meet consumer demands for energy services and to make a full contribution to the global action to reduce fossil fuel emissions. This move from more market delivery oriented policies is due to perceived market failures in areas such as delivery of climate change policies and targets, energy security matters and energy prices. .
- The decision is made to push for a hydrogen economy as part of a cohesive EU initiative.
- Consumers are active in their electricity supplies because of attitudes to the environment and a desire to secure the best possible supply of electricity based on price, service and reliability.
- There is a strong development of larger scale clean power generation, renewable power generation and a relatively high penetration of hydrogen fuel cells in vehicles.
- There are consumer moves towards energy self sufficiency through efficiency measures and self generation.

‘Dynamic Green Markets’: Active Consumers, Acute Environmental Concern, Market Led Institutional Governance.

- The belief persists that markets are best placed to service consumer demands at the same time as meeting external needs such as tackling environmental issues. Active consumers operate within widespread liberal markets.
- Global action to reduce fossil fuel emissions creates strong incentives for low carbon energy via a firm carbon price and efficient carbon markets.
- Active and concerned consumers radically change their approach to energy and become much more participatory in their energy provision. They are driven by the twin desires to be served at competitive prices and service levels while addressing their desire to have a benign impact on the environment.
- Markets respond to the new demands of consumers and, with supportive frameworks and incentives from Government, broadly liberal, free markets rise to the challenges of economic energy supplies with low environmental impacts
- Renewable generation is prominent and there are relatively high volumes of microgeneration creating the potential for a radically reformed electricity market with diverse types of generation.

‘Reactive Approach’: Increased Environmental Concern but never quite acute. Fluctuating Institutional Governance and Consumer Activity.

- There is a pervasive feeling of uncertainty and a resulting ambiguity within society towards environmental issues and the influence this has on energy infrastructure development. Environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental observations and reports/statistics.
- A lack of global consensus on environmental issues contributes to the uncertainty regarding environmental action.
- There are various market led and Government led approaches pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of fuel supplies and immediate economic concerns.
- Differing attitudes towards energy consumption develop among consumers resulting in varied types and levels of consumer participation depending on the geographic area, social demographics and services provided by energy companies.
- There are many types of generation in the national portfolio with centralised thermal generation and offshore renewables both prominent groupings. Combined heat and power and microgeneration are deployed in areas with

the right mix of public investment, services from energy companies and demand from consumers.
- There is a strong potential for stranded assets and investment redundancy in the power sector.

The second stage of the scenario development process identifies the implications of each energy scenario for electricity generation, demand and quality of supply. It was found that each energy scenario could be supported by more than one plausible network architecture so a mapping process was developed and utilised to identify commonality and group the implications for power networks into a small set of 'network scenarios'. These identified scenarios were then developed with reference to the detailed LENS project inputs. The outcome of this second stage was five network scenarios directly influenced by the implications arising from the chosen energy scenario themes. The network scenarios are summarised below:

Network Scenarios

'Big Transmission and Distribution'

- Transmission and distribution (T&D) infrastructure development and management continues largely as expected from today's patterns while expanding to meet growing energy demand and developing renewable generation deployment.
- Network capability enhancing technologies are deployed to meet the growing demands for network services arising from demand growth. The T&D infrastructure is developed with a focus on enhancing capability for integrating renewables at all levels (larger transmission connected renewable generation and smaller distribution connected renewable generation).
- The geographical reach of the transmission network is expanded to connect offshore and rural on-shore renewables sites and to provide interconnection with European mainland power systems.
- Moderate behaviour change by customers leads to little active demand management. Hence demand growth is unhindered and relatively unmanaged in an operational sense.
- Network companies continue to take the responsibility for providing security and quality of supply.

‘Energy Services Market Facilitation’

- The main role for power networks is to support a vibrant energy services market. The transmission and distribution infrastructure is required to support a super-supplier or energy services company (ESCO) centred world.
- ESCOs do all the work at the customer side and the transmission and distribution networks contract with ESCOs to supply network services, allowing the network companies to operate the networks more actively.
- There are wide ranging developments and vibrant markets in energy services including micro-generation, on-site heat and power, demand side management, telecommunications and electric vehicles.
- The services supplied by the networks include transmission system connection to strategic, large scale renewables and also access to municipal scale CHP and renewables tailored to local demands.
- System management is aided by the degrees of flexibility provided by ‘empowered’ customers with high capability information and communications technologies (ICT).

‘Distribution System Operators (Lean Transmission)’

- Most electricity production facilities are connected to distribution networks thus reducing the role for the transmission network which then only serves to connect the strategic and economic larger scale renewable resources in certain parts of the country.
- Distribution System Operators (DSOs) take much more responsibility for system management including generation and demand management, supply security, supply quality and system reliability.
- Demand side management provides greater options for DSOs in system operations but also leads to a generally reduced demand to service.
- DSOs balance generation and demand in local areas with the aid of system management technologies such as energy storage and demand side management. Dynamic loads and generation sources make local and regional balancing a key activity for DSOs.
- The transmission system acts to provide connections between DSOs and to strategic renewables deployments.

‘Microgrids (Small Transmission and Distribution)’

- The self-sufficiency concept has developed very strongly in power and energy supplies with electricity consumers taking very much more responsibility for managing their own energy supplies and demands. This leads to a greatly reduced role for the bulk power networks.

- Individually and collectively customers actively manage their own energy consumption against their own or locally available supplies and minimise exports to and imports from the local grid.
- Microgrid System Operators (MSO) emerge to provide the system management capability to enable customers to achieve this with the aid of ICT and other network technologies such as energy storage.
- Customers take a lead role in their own energy provision and the security, quality and reliability of the supply with the support of the MSO.

'Multi-Purpose Networks'

- Attempts have been made to exploit many energy technologies over time and there exists a large diversity in electricity production and demand side management initiatives implemented.
- The network is characterised by diversity in network development and management approaches as a result of changing energy policies and company strategies over time.
- Substantial differences exist in network capabilities with excess capability in some areas and constraints in other areas.
- Electricity networks fulfil different roles including bulk transfer, interconnection, backup and security and meeting renewable and demand side objectives.
- Challenges in managing diverse system architectures are accompanied by opportunities from the diversity of generation, network and demand side provision.
- The commercial implications of the lack of consistency in energy policy and the subsequent diverse network infrastructures that emerge means that the stranding of certain power system assets becomes more apparent over time.

The next steps in the development of the LENS project scenarios are to consolidate the energy and network scenarios. This will exploit the clear links between pairings of energy and network scenarios (e.g. the 'switch me on' energy scenario and the 'big transmission and distribution' network scenario). This next step will develop comprehensive, diverse and plausible scenarios incorporating the energy and network content as detailed in this report. The scenarios will also be explored further through quantitative modelling which will test the plausibility of the scenarios and add a further layer of detail to them.

The separate energy and network scenarios presented in this interim report can now be used by stakeholders to explore the long term implications for power networks and their regulation. However the next step of the project will provide strong benefits in terms of a single set of five comprehensive scenarios. One of the issues of particular interest is the transition from today's GB energy and power networks to those future energy and power network scenarios. An essential feature of the scenarios is not only that the scenarios are plausible in 2050 but that the pathways from the present to 2050 are also plausible and internally consistent. For example, in the 'Microgrids (Small Transmission and Distribution)' network scenario described in this report, some of the transitional issues to be explored (and plausibility checked) would include the initiating events and timescales over which microgrids would develop and the scale of adoption of microgrids given the relatively high inertia of legacy assets in capital intensive infrastructure sectors such as power networks.

The transitional issues and also the implications of the scenarios for networks and the regulation of networks will be investigated further in the third phase of the LENS project in parallel with the quantitative modelling of the energy scenarios using a MARKAL model of the GB energy sector. The end result will be a consolidated set of scenarios that have been thoroughly reviewed and enhanced through external stakeholder and expert input and that have benefited from quantitative modelling and additional consideration of their implications.

2 Introduction

2.1 Background

Following the publication of the LENS Scenario Development Inputs Report in November 2007 [1] the LENS project has progressed into the next phase as set out in the published methodology [2].

This document describes the recent stages of the scenario development process, describing the evolution of proposed inputs and themes then going on to describe how these have been used to draft a set of initial network scenarios.

In the LENS Scenarios Methodology [2] the following stages were listed as an approach to scenario development:

1 Define the recipient
2 Frame the focal question
3 Information gathering
4 Identify themes
5 Sketch possible pathways
6 Write scenario storylines
7 Model scenarios
8 Identify potential implications of scenarios on the focal question
9 Identify and develop potential strategies

This report is primarily focussed on stages 4 to 6 and presents revised inputs, themes and draft scenarios. As described in Section 10, modelling has not taken place at this stage. The modelling exercise will be completed in the third phase of the project where it is now deemed to add most value. As a result this report presents a qualitative set of scenarios and the process behind their development. A final report will be published on the culmination of the project containing final scenarios that are both qualitative and quantitative, 2025 milestones towards 2050, data tables and illustrations.

2.2 Process

The LENS project commenced with the open letter of June 2007 [3], initial workshop and consultation [4]. The project methodology was then defined [2] and an information gathering process completed, culminating in the inputs report [1] and subsequent workshop and consultation of December 2007 [5]. Consequently the workshop outcomes and consultation responses were reviewed and incorporated into the thinking of the LENS team during the stages of scenario development described in the following sections of this report.

The process started with a review of the proposed inputs. This resulted in the definition of a revised set of inputs based on stakeholder feedback and discussions within the LENS team. Using these inputs and the stakeholder feedback on themes, an iterative process of identifying the most suitable themes for scenario development followed. With a finalised set of themes, scenario generation tools, as described in the methodology, were used to produce a range of possible scenarios. From this range of scenarios a subset was chosen that was deemed to be (a) the most plausible in the way the themes interacted and (b) the most likely to produce interesting and useful network scenarios.

A detailed explanation of this process, the revised inputs and themes and the proposed draft scenarios is contained in the following sections of this document.

2.3 Document Structure

This report is the second of three to be produced by the LENS project team and follows the publication of the LENS Scenario Development Inputs Report in December 2007 [1]. On completion of this consultation a third report will be published containing a final set of scenarios from the LENS project.

Section 3 of this document updates and further explains the scenario methodology used in this project. The concepts of “network scenarios” and “energy scenarios” are also set out in more detail.

Section 4 presents the finalised list of inputs and describes changes from the previously published version.

Section 5 presents the finalised proposal for themes, the process of choosing these themes and how the academic teams’ thinking evolved in light of stakeholder feedback.

Section 6 explains and justifies the process of moving from themes to a set of draft energy scenarios.

Section 7 presents the initial set of draft GB energy scenarios for 2050.

Section 8 introduces the concept of network scenarios and how these have been derived from the draft energy scenarios.

Section 9 presents the initial set of draft GB network scenarios for 2050.

Section 10 details the next steps of the LENS project including the planned quantitative modelling activities and integration of stakeholder feedback.

Appendices providing supporting detailed material used in the scenario development process and references are provided towards the end of the report in sections 11 – 16.

2.4 Glossary of abbreviations

ANM	Active Network Management
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCTV	Closed Circuit Television
CHP	Combined Heat and Power
CO2	Carbon Dioxide
CSR	Corporate Social Responsibility
DG	Distributed Generation
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSM	Demand Side Management
DTI	(GB) Department of Trade and Industry
EU	European Union
EPRI	Electric Power Research Institute (US)
ESCO	Energy Supply Company
FACTS	Flexible AC Transmission Systems
GB	Great Britain
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
H2	Hydrogen
HVDC	High Voltage Direct Current
ICT	Information and Communications Technology
kW	Kilowatt
LENS	Long-term Electricity Network Scenarios
MARKAL	Market Allocation (model)
MSO	Micro Grid System Operator
MW	Megawatt
OECD	Organisation for Economic Cooperation and Development

PIU	Performance and Innovation Unit (of the GB Government)
PPP	Public Private Partnership
R&D	Research and Development
RCEP	Royal Commission on Environmental Pollution
SO	System Operator
T&D	Transmission and Distribution
TNO	Transmission Network Operator
UK	United Kingdom
UPS	Uninterruptible Power Supply

3 Scenarios Methodology

The LENS methodology [2] identified stage 4 of the development process as “identify themes” and stated “*A qualitative assessment of the issues and prospective themes or driving forces will underpin the process of identifying the main themes that will form the basis for the scenarios*“.

The qualitative assessment mentioned here relates to the process of gathering and identifying relevant information described in the LENS inputs report [1].

The inputs report employed a specific terminology to describe the information gathering process and differentiate between stages of the process. This terminology is further clarified here.

3.1 Issues, Inputs and Themes

Issues are the ideas, trends, problems, concepts, developments, or changes that are expected to be important in considering the future of the electricity sector and more specifically power networks. Although important in and of themselves, issues are regarded as low level data in the context of scenario development.

Inputs refer to the issues, *prospective* themes and data that are of specific use to the LENS project. A finalised set of inputs is described in Section 3. These inputs all had an influence on the scenario narratives, and were an important part of the process of identifying and choosing themes.

Themes describe long term societal dynamics that provide the backdrop against which all actors make their decisions. A theme might be conceived of as an axis with two more or less opposite extremes at either end of it, in which case a theme could generate more than one type of scenario. The function of defining themes is to give a coherent and internally consistent basis for making simultaneous assumptions about the numerous inputs in each scenario. Hence themes are the broad and high level dynamics that differentiate the scenario storylines from one another and allow a rich description of the circumstances and driving forces that shape the development of power networks in GB.

Inputs vs. Themes is a comparison that may not initially be clear as they can appear similar in nature. Inputs cover the full range of influences used to develop the scenarios. Themes are the two or three key driving forces that once identified, are used in the inductive scenario development process to produce an initial set of possible scenarios [6]. A chosen theme may be a specific input that was deemed to be a key driver or it may represent a group of issues from the inputs that together were viewed as a key driver.

The process of identifying LENS themes with respect to the finalised list of inputs is described in Section 4. In order to focus on *network* scenarios it was necessary to carefully choose themes that were influenced by our inputs however it became apparent they could not simply be recycled versions of the *prospective* themes contained in the list of inputs.

3.2 Scenario Development Tools

When the main themes that will form the basis of a scenario exercise have been identified, recognised scenario development tools are then used to explore the interactions between the themes and identify the potential scenarios they create. The scenario development tools identified in the methodology [2] are reviewed below.

3.2.1 Orthogonal Axes

Describing the themes in terms of axes with two more or less opposite extremes creates a 2x2 matrix (if two themes are used) or 2x2x2 (if three themes are used) and so on. Each possible scenario occupies a distinct space in terms of the axes as shown below in Figure 1. A feature of this approach is the scope for variation within each scenario space. For example, scenario 1 is in the Theme 1 High, Theme 2 Low space. However, High and Low are the relative extremes of the axis and scenario 1 actually occupies a space that includes a range of states for both Theme 1 and 2. This approach therefore creates an initial high level definition of the scenario that encompasses several possible more detailed definitions.

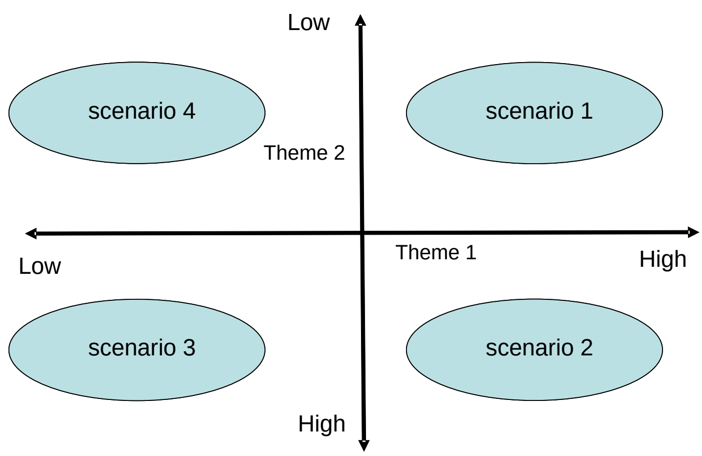


Figure 1: Orthogonal axes view of themes and scenarios.

3.2.2 Pathways

Pathways are essentially a method of representing the interactions between the main driving forces (themes) of scenarios. They allow a qualitative assessment of the combinations of driving forces necessary to arrive at a given scenario end point. This assessment can result in valuable insights about the plausibility of scenario endpoints in the light of the coincidence of various driving forces required to produce that end point.

The simple example in Figure 2 below demonstrates that three themes, each with only two possible states, create eight possible scenario endpoints. The branching points at A, B and C are not sequential in time but simply pathways that are followed during the period from present day to the horizon year. It is acknowledged that this is a simplification of a much more complex issue and the diagram is intended to illustrate the effect of moving in different directions between now and the horizon year.

Of course each theme would in reality have more than two states and the resulting amount of possible endpoints could be considerably greater than eight.

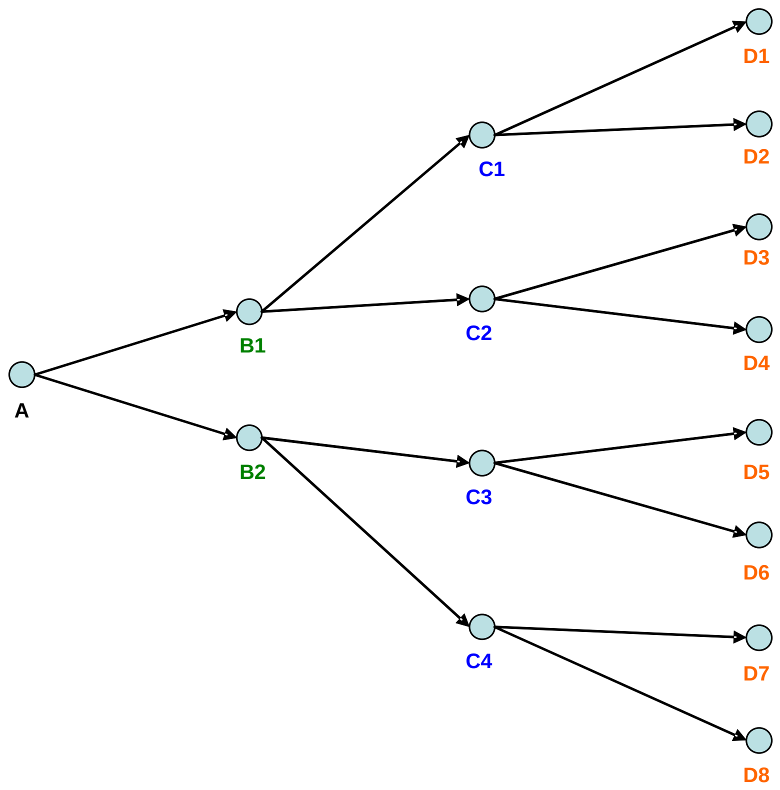


Figure 2: Pathways view of themes and scenarios.

3.3 LENS Scenario Development

It is clear that both scenario development tools reviewed above are valid methods of achieving a similar end result. The use of axes defines scenarios that are a little more vague in nature. i.e. a “space” which conveys a general impression of the interaction between themes such as the High/High or High/Low examples above. However, within each space there are many more detailed possible interactions between themes. Pathways could be used to define scenarios with a greater degree of detail. The degree of detail (i.e. the possible states allowed for each theme) defines the number of endpoints produced by the pathways.

Each scenario space produced by the axes approach could be thought as consisting of multiple end points that could be reached by the pathways approach. This comparison helps demonstrate the similarity and difference between the two approaches.

For reasons expanded on in Section 6 the primary tool for LENS scenario development was the axes approach.

3.4 Energy Scenarios to Network Scenarios and Consolidated Scenarios

At this point it is worthwhile reiterating the aim of the LENS project which is to develop long-term electricity network scenarios. The majority of scenario work reviewed to date focus on what could be called energy scenarios i.e. they are concerned with the overall use of energy in certain futures and many are focussed on delivering specific environmental targets. The Supergen scenarios [7] went a step further and created high level network scenarios starting with a description of the overall energy environment then focussing on the implications for electricity demand, generation and future network architecture.

The purpose of the LENS scenarios is to take an increased focus on networks and produce scenarios that provide an additional layer of abstraction and a more detailed picture of potential future electricity networks.

With this aim in mind, a method is proposed in Section 8, where initial energy scenarios are used to derive an independent set of network scenarios. The proposed approach, represented simply by Figure 3, develops high level energy scenarios that consider the key drivers for the use of energy and the resulting implications for electricity use and generation. From these scenarios, network scenarios are developed that describe the long term implications for electricity networks in GB. The principle is that a comprehensive range of possible network scenarios are considered and a final set of robust and plausible scenarios developed as a direct product of social, behavioral, political and technical developments.

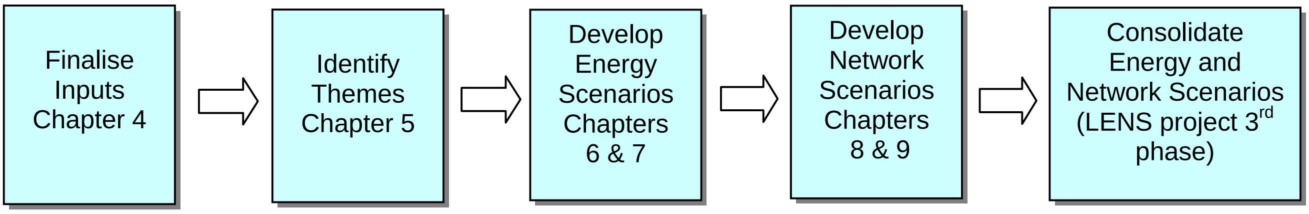


Figure 3: Process for developing network scenarios.

Although the process of developing energy scenarios then network scenarios was deemed successful in exploring a wide range of possible outcomes and a necessary part of demonstrating the plausibility of the network scenarios; a step of consolidation was felt necessary to avoid an overly complex final product. It became apparent during the development of energy scenarios and network scenarios that there was good potential to merge the two sets of scenarios into one set of scenarios retaining all the diversity, plausibility and detail developed thus far. The final block in Figure 3 shows this intended next step of development which is being undertaken in the third phase of the LENS project. The principal objective of the consolidation is to improve the usefulness of the final scenarios to their end users. Identifying the underlying driving forces of different network scenarios could be problematic with separate energy and network narratives and consolidation creates a single set of electricity network scenarios clearly set within the context of their high level driving forces.

Modelling the consolidated scenarios with the MARKAL model is currently being progressed to provide quantitative and detailed insight into the plausibility of the draft scenarios from an energy system point of view.

4 Identification of Scenario Inputs

This section sets out a revised and final proposal for LENS Inputs based on feedback received at the 14 December workshop, written consultation responses and continued analytical work and review of relevant literature (See Appendix A for a brief review of related literature used to inform the development of the LENS inputs and used further in the development of the scenarios themselves). Further information can be found in the published summaries of the 14 December 2007 workshop and of the consultation responses received by the 18 January 2008 deadline [5].

A list of proposed inputs to the LENS project was published in the LENS inputs report of December 2007 [1]. Stakeholder feedback to the proposed list of inputs was broadly supportive. There was a significant debate as to whether the network specific inputs were really inputs or in actual fact outputs that were a product of some of the drivers captured by the high level inputs. This is a valid point and the issue is clarified here. Network specific inputs are influenced by higher level drivers; however they are important issues that need to be captured in a scenario narrative seeking to say something significant about the network. Therefore, the network specific inputs are retained here as inputs that will be used to **construct** the scenario narrative rather than **shape** it.

The revised list below contains no completely new inputs reflecting the positive level of support received in the various forms of feedback. In general, all contributions from the workshop and consultation are added as additional detail under existing input headings. Two of the headings have been amended to reflect the feedback received.

4.1 High level LENS inputs

The high level inputs describe the context and landscape within which the electricity supply sector and, more specifically, the GB power networks sector exist. These inputs reflect trends and developments in society and the world at large that networks must respond and adapt to.

- ***Consumer Behaviour –*** This input represents the influence of individuals, businesses and society in general, including consumer trends and the accompanying use of energy, lifestyle patterns, demographics, population and employment movements, leisure pursuits, people and goods transportation, building preferences and business trends. In addition the commercial imperatives for different types of behaviour, individual and collective response to the climate change agenda, economics, supply security and quality expectations and the general level of consumer interest and participation in their energy and electricity supplies are also part of this group of inputs.

- ***Economic Landscape*** - This is essentially about the vibrancy of the national economic situation and there is a clear effect of this on demands for energy services, consumer behaviour and the political scene. Infrastructure investment funds available and research and development funding is driven in part by the economic situation. There is also a link to 'International Context' as the global economy and global markets drive the GB national economic position. The investment framework and the support or otherwise this gives to different types of investments throughout the electricity supply chain is also included.

- ***Energy Demand and Other Energy Supply Networks*** – Leading on from 'Consumer Behaviour' and 'Economic Landscape' the resulting national, regional and sectoral energy demands will directly influence the electricity demand profile (which is identified separately below and has a more direct influence on electricity networks). In addition, new uses for energy in different forms (e.g. transport) and alternative energy supply chains (e.g. natural gas and hydrogen) will also influence electricity demand. The impact of energy pricing structures and the resulting consumer prices along with the impact of smarter energy metering and control in consumer premises must also be considered. The effect of growing demand for cooling should be considered.

- ***Environmental Landscape*** – This title encompasses issues such as environmental changes due to climate change and their effects on networks, concerns such as the pollutants from power equipment and aesthetics of overhead lines, the level of importance placed on environmental issues by society and environmental assessments of generation and network development. The influence of environmental issues on the political and regulatory frameworks is of importance.

- ***Political/Regulatory Landscape*** – This input describes the extent of Government involvement in the energy market including the use of regulation and incentives, the political response to consumer behaviour and environmental landscape and the level of regionalisation within policy making. Town planning and regional development and planning strategies are of significance particularly where the level of coordination between planning frameworks provides for a wide range of outcomes. Policies providing incentives to preferred generation technologies and penalties for undesired generation developments are an important part of this input grouping. The effect of policy on investment and commercial frameworks is important. The key role of the political framework in bringing forward the required human resources for the electricity and/or electricity sector is another important consideration. The degree of centralisation of decision making and planning is a key issue for Government involvement in the energy sector. On the political front there is a strong influence from the 'International Context' input since international and European agreements strongly influence the GB political position.

- ***International Context*** - Linked to 'Political/Regulatory Landscape' and 'Environmental Landscape' is the influence of international legislation and regulation and markets. Key issues here include international energy and carbon markets, electricity via interconnectors and national energy security concerns (which are directly linked to international resources and markets). The international dimension is important to the peak oil and gas phenomena since demands for and resources of oil and natural gas are global and future availability and prices of fossil fuels are key international issues.

4.2 Network Specific LENS inputs

The network specific inputs describe the groups of issues that have a more direct influence on the development and operation of GB power networks.

- ***Electricity Demand*** – Heavily influenced by overall energy demand this input will give more detail on factors such as location, variability, peak load, patterns of usage, efficiency, new demands (e.g. transport), and the demand patterns dictated by consumer behaviour. The result of the development of distributed generation on changing (e.g. flattening) demand profiles is a component of this input. The effect of demand side management programmes on electrical demand will be of potentially increasing significance *en route* to 2050 and is a key part of this input.

- ***Electricity Generation*** – A key driver of future network requirements, this input will inform the generation mix, geographical and electrical network location, technology and proximity to demand. The availability, price and security of fossil fuel resources are important parts of this input. The electricity trading arrangements with the demands for electricity will influence the deployment of generation sources and their operation. Complementary deployment of energy sources might be important (e.g. wind with CHP, variable sources with energy storage). Emerging and future generation technologies (e.g. fuel cells and nuclear fusion) will have an influence on the overall generation mix by 2050.

- ***Security, Quality and Performance of Supply*** – This input describes the requirements placed upon the network in terms of resilience and quality. The nature of this will be dictated by consumer expectations, regulation (by way of set standards of security and performance), environmental changes, technology (use of new technology or technological restrictions) and perhaps even social instability or terrorism.

- ***Transmission and Distribution Network Architecture –*** This input deals with some of the more technical aspects of network architecture such as the respective role and size of transmission and distribution networks, the extent of undergrounding (perhaps stemming from land value), deployment of generation sources in different voltage level networks, communications for monitoring and control, design and performance standards, interconnectors and offshore grids. The resolution of potentially conflicting network architecture requirements is a key issue, for example, networks optimised for large scale wind power developments versus mass development of micro-sources.

- ***Network Technology Development and Deployment*** – Technological developments and their deployment in areas such as superconductors, microgrids, energy storage, demand side participation, smart metering, advanced protection and control and FACTS will directly influence possible future network architectures and development pathways. Non-network enabling technologies are seen as a key area for development of networks. Potential increased focus on planning and operational analysis in distribution networks may emerge.

- ***Power Network Sector Structure and Strategies*** – The role of energy supply companies and other commercially driven changes to power sector participants, distribution system operators, private networks (with various ownership models), the incentives framework for innovation and performance, network planning frameworks and regulation will all shape future power network developments.

- ***Transitional Issues*** – Factors such as the legacy power system (with ageing assets and the potential for stranded assets), level of legislation, use of standards, resources and skills will influence the ability of the network to adapt and meet the demands placed on it. These transitional issues will influence the pathways along which the electricity networks sector develops.

5 Development of Scenario Themes

The LENS Inputs Report of November 2007 [1] included an initial discussion and proposal of three themes for LENS scenarios. These were presented and discussed at the stakeholder workshop of December 2007 [5].

The discussion and proposal in the published report is reviewed here before subsequent steps and proposals are described.

5.1 Review of themes in inputs report

Two key direct driving forces of the shape of future GB power networks could be identified as generation and demand. What is meant here is that the physical shape of future power networks and the mechanisms for their operation and management are driven directly from the demands that must be served and the generation sources that are exploited to meet those demands.

However it is important to recognise that generation and demand are very strongly influenced by both the external landscape (of the political, economic, technological situation in an international context) and the role that electricity consumers will play both as users of energy and also as members of society. As users of energy, consumers present a very wide variety of lifestyle, employment and residential characteristics and as citizens their attitudes and behaviour influence the political and regulatory situation. Consumers may also take on a role as small and micro scale generation operators. To adequately address and place the appropriate emphasis on the network specific inputs a theme focused on networks is required. It was proposed that this is entitled ‘network role’ to provide a broad focus on what networks will be required to deliver and how they will be structured (in a technical and commercial/regulatory sense).

While the academic team believe the reasoning behind these proposed themes was sound, subsequent discussions and feedback from stakeholders highlighted weaknesses that merited a re-examination of possible themes.

On review it became clear that the External Landscape theme had developed quite a wide scope, including many important and distinct drivers and as a result had become quite vague in nature. The stakeholder feedback conveyed a significant amount of uncertainty as to what this theme represented and how it could be used without becoming cumbersome. These challenges highlighted some drawbacks and raised the prospect of breaking down this theme into something more specific.

The choice of Network Role as a theme also struggled to stand up to robust challenge. This related to the discussion on network specific inputs and questioned whether the network role is actually a product of higher level drivers that define the challenges the network must meet. Stakeholder feedback indicated a general agreement for this point of view and as a result the academic team concluded that network role was not suitable as a theme and was a topic that would be expanded upon later in the scenario development process.

In order to move towards a final set of themes some key tasks were identified to facilitate the re-examination of possible themes. The principal aim underlying these tasks was to identify the two or three key drivers or "critical uncertainties" that will shape future networks:

1) A comparison of themes and definitions used in the previous scenario studies reviewed in the LENS Inputs Report of November 2007.
2) An analysis of the high level inputs and the preferences expressed in the voting exercise in Stakeholder workshop of 14th December 2007/
3) A comparison of all suggested themes from various stages of the LENS project.
4) A classification of potential themes in relation to importance and uncertainty for networks.

The results of these tasks are described in the sub-section below.

5.2 Themes and definitions from previous scenario studies

The themes used in previous scenario studies provide a solid example of the type of themes that can successfully be used in energy related scenarios and as such provide an ideal starting point from which to review and revise the choice of LENS themes.

The themes reviewed in this section are summarized in Table 1 below. Appendix B provides a short review of the themes in each of the selected scenario studies.

As noted in the inputs report some studies are targetive and set a specific objective such as 60% reduction in CO_2 emissions while others take an exploratory approach encompassing diverse environmental, political and economic eventualities that are used to forecast possible futures. The summary table demonstrates that the studies using an exploratory approach commonly used themes to generate scenarios. This type of approach is conceptually aligned to the LENS methodology.

The majority of themes reviewed here describe long term social dynamics and are often described as an axis with two more or less opposite extremes at either end of it. This aligns with our definition in Section 3 of themes as "the broad and high level dynamics that differentiate the scenario storylines from one another and allow a rich description of the circumstances and driving forces that shape the development of power networks in GB".

Scenario Study	**Themes**	**Focal Areas**
SuperGen 2050	Economic Growth. Technological Growth. Environmental Attitudes. Political and Regulatory.	More, Same, Less Revolution, Evolution. Much Stronger, Stronger, As Present, Weaker Liberalised, Interventionist.
DTI Foresight	Social Values. Governance Systems.	Consumerist, Community. Globalisation, Regionalisation.
PIU Energy Review	Social Values. Governance Systems.	Consumerist, Community. Globalisation, Regionalisation.
RCEP	No themes.	Back-casting from 60% target.
Decarbonising the UK (Tyndall)	No themes.	Back-casting from 60% target.
Energy Markets Outlook	Regulatory approach to Carbon.	Tough Carbon, Central, Easy Carbon.
Decentralising UK Energy	Centralised generation. De-centralised generation. Level of CO2 reduction	Not used. Themes used to define 2 paths.
The Role of Electricity	No themes.	Modelling approach.
EPRI	Evolution of fuel markets. Societal Values.	High prices, Low prices. High price of CO2, Low price of CO2.
Energy Pathways in California	Is energy diversity important? Does Govt lead new activity? Are changes driven by external forces?	Yes, No. Yes, No. Yes, No.

Table 1: Review of themes used in relevant scenario activities.

5.3 Proposed LENS Themes

Appendix C summarises the different themes proposed at different stages of the LENS project and sets out some evidence for the selection of themes for the LENS project by way of graphically presenting the strongest candidates from the potential themes as highlighted from sources including the stakeholder consultation, stakeholder workshop and reference to selected experts for input. This stance is explored further below and an argument set out for which of these themes should be used for LENS scenarios.

A governance theme could explore many different areas of policy that significantly affect the source and use of energy in GB. The extent and method of Government involvement in the market could be a key driver in the choice of primary fuels for space/water heating and generation. Policies regarding security of supply, environmental impact, decision making and planning will all have a major influence on energy use in general and on the electricity sector. More specifically, the way these policies are implemented is of particular interest as contrasting issues like cooperation, light regulation and market-driven policies versus protectionism, heavy regulation and centrally driven policies could result in very different results for the electricity industry in GB. It could also include international aspects such as the impact of global politico-economic trends on GB

The environment is likely to have a very significant impact on attitudes towards energy and hence on the development of future electricity networks. The climate change issue has been steadily climbing the public and political agendas and could be said to have provoked more debate on the source and use of our energy than any other single issue in recent times. Depending on how society's environmental concerns develop over time, there could be very different implications for the amount and type of electricity generation that is required. It could also be argued that this theme would influence to some extent politicians/policy-makers as they respond to public attitudes and voter pressure.

A consumer focussed theme could encompass the attitudes of consumers towards energy as they respond to various external influences such as the environment, their economic situation and trends in employment and leisure. More specifically for electricity networks, this theme could include consumer participation in generation and demand and also consumer participation specifically in relation to networks. The impact of consumers' requirements from a network could be a major influence on the size, reliability, performance and security of electricity networks.

Economics as a theme could produce interesting results as it captures strong influences such as the likely increases in energy demand and the level of investment finance. These factors will have a direct result on the requirements for, and potential development of, electricity networks. However, it could be argued that unless extreme economic disasters are considered then long term assumptions could be made on the stability of economic growth. It could also be argued that although energy demand is influenced by the level of economic growth, more dramatic influences will come from consumer attitudes and Government policy that could drastically affect they we use energy in this country.

Technology and substitution effects are thought to be an important aspect of the scenario narrative. The technical capability and the extent and level of innovation are key uncertainties to the shape of future networks and will be one of the main topics used to describe the role and nature of the network. However this aspect could be used to shape the scenario without explicitly defining it as a theme. For example, the rate of technological development could potentially be a product of increased/decreased investment. The motivation to invest and develop particular technologies and solutions can be described in terms of other factors such as Governance, the level of Environmental Concern and Consumer demand.

Fuel availability is an important issue affecting future energy use and shortages of fossil fuel or uranium would have a major impact on security of supply and energy prices in a scenario similar to today. These issues could force energy supply to move in very different directions (e.g. high use of renewables). However, this is perhaps an overly detailed issue to be fully suitable as a theme. Environmental issues and Government and society's response to these issues could result in drastic shifts in the way we source and use energy regardless of the availability of fuel.

International/National Culture is highly likely to have a strong influence on the British Politico-economic climate. The influence of international legislation, regulation and international energy and carbon markets will affect the policy of GB Government and the attitudes of domestic, commercial and industrial energy users. National energy security concerns could also be captured in a theme of this type.

Social Values as a theme could capture many diverse aspects of the way people live and behave. However, to be of value as a theme for LENS scenarios this theme would need to specifically focus on the influence of social values on the source and use of energy in GB. A shift in social values towards more efficient use of local natural resources and community living as opposed to strongly consumerist attitudes could produce diverse energy scenarios and resulting electricity networks. This theme touches on aspects of the other proposed themes such as environmental attitudes and consumer behaviour which could both be considered social values.

It is acknowledged at this point that many different views and interpretations of the value of particular themes are possible and the various options presented here all have potential as LENS themes. Each potential theme could be said to have a greater or lesser relative influence on the future of electricity networks and the above discussion intimates an argument for some themes as stronger candidates than others. This argument is summarised below.

Environmental issues (and specifically global warming) are at the root of current debate on the source and use of our energy and have driven more change than any other single issue in recent times. The extent of environmental concern within society could have a huge impact on the role of electricity and hence electricity networks.

The role of governance cannot be overlooked. The approach taken by Government to issues such as carbon emissions, security of supply and technological development will dramatically affect the role of electricity and the requirements on networks in the coming years.

Consumers create the demand for energy in general and electricity specifically. The attitudes of consumers towards their electricity supply and what they expect from their network could place entirely new demands on the electricity industry.

Technology is thought to be an important aspect of future networks but one that can influence the scenario without being explicitly defined as a theme.

Although economics is acknowledged as an important influence it is argued that as a theme this may not provide as interesting results as environmental, governance and consumer based themes.

While fuel availability, International/National Culture and Social Values are important issues, it is suggested that these are linked to and could all be captured to some extent by themes such as environmental concern, governance and consumer behaviour.

Figure 4 is an influence diagram representing the perceived relationships between the strongest candidates for themes and their influence on electricity networks. The diagram demonstrates the suggested significance of the environment, governance and consumers to future electricity networks.

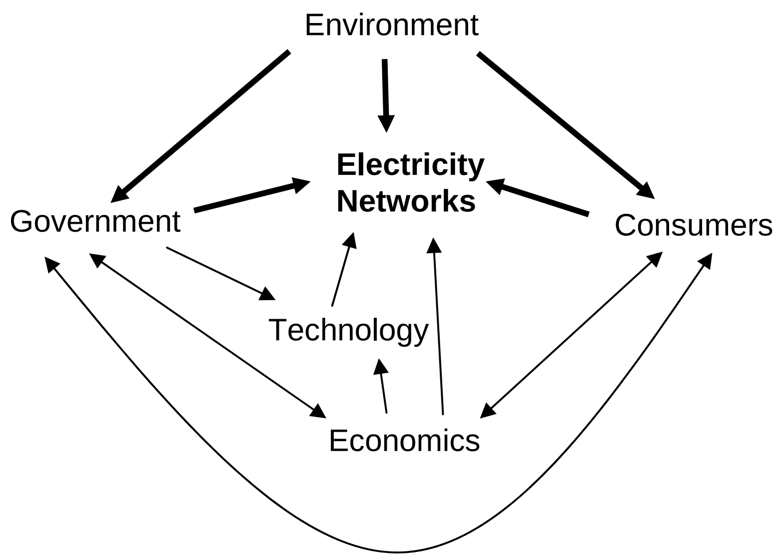


Figure 4: Influence Diagram of potential high level themes.

In light of the above discussion, three LENS themes reflecting the critical uncertainties for GB electricity networks were defined as:

- **Environmental Concern**
- **Consumer Participation**
- **Institutional Governance**

5.4 LENS Themes Definitions

Each of the proposed LENS themes may be thought of as an axis with two more or less opposite extremes at either end of it. Within the boundaries of these extremes there are potential focal points that could be identified as the areas within which the scenarios will be written. These are summarised in Figure 5 and developed further in the subsequent sub-sections.

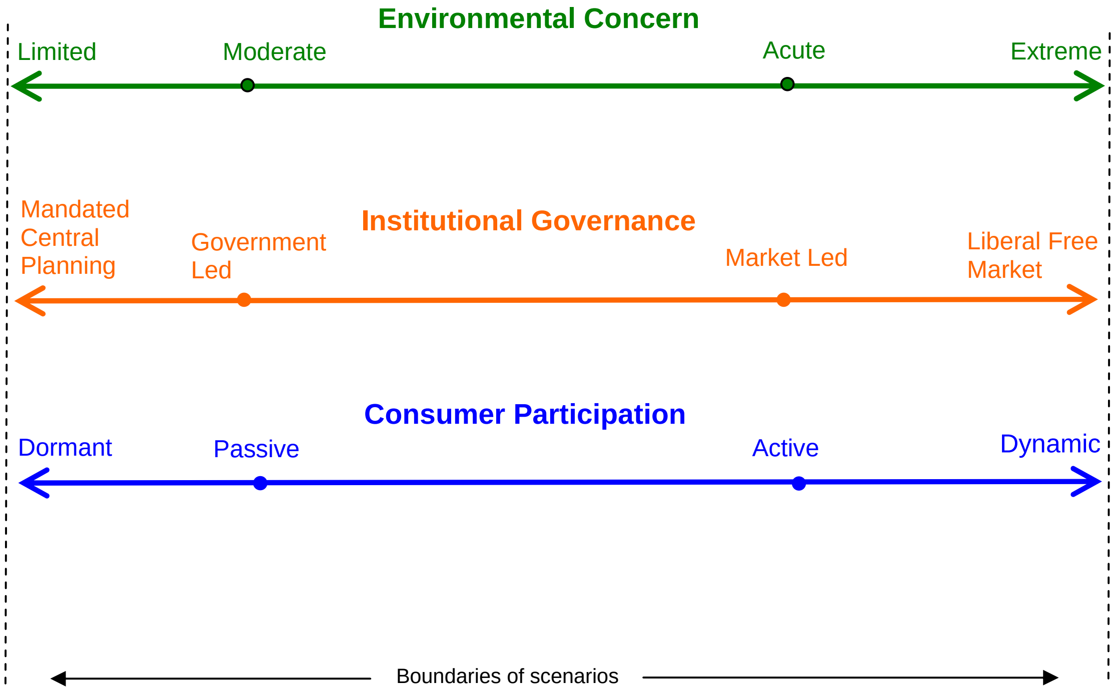


Figure 5: LENS themes and focal points.

The following discussion provides a more detailed description of the proposed themes, boundaries and focal points.

5.4.1 Environmental Concern

Environmental Concern is the level to which the environmental situation affects the decision making of individuals, communities, private companies, public institutions and the Government (on a UK and global basis). High environmental concern implies that environmental issues are of a high priority and are one of the primary influences on the decisions of the above parties.

Environmental concern is intrinsically linked to climate change. Although environmental issues have been raised in the past, society in general (UK and Global) has not placed environmental issues high on their agenda. Climate Change (Global Warming) has changed this and we can take the justified step in saying the level of Environmental Concern is primarily caused by the level of climate change. Of course the influence of climate change will be offset by other factors such as the economy.

The 'level of climate change could be broken down into three elements:

- The extent to which scientific evidence and warnings about climate change effects are increasingly severe
- The increase in actual experiences of sudden and very dramatic weather events which cause serious damage and can be strongly linked with climate change.
- The change in media-political-cultural debate and awareness - clearly linked to the above, but also arguably to more random factors like celebrity endorsement

Although environmental concern may be primarily driven by climate change, a by-product of a more environmentally aware society would be increased focus on other environmental issues. These other environmental concerns also have a more direct impact on individuals where they live, work and have leisure. In addition to CO_2 specific concerns, other issues affecting networks would be attitudes towards: visual pollution, the impact of onshore windfarms, biomass crops, hazardous materials used in network infrastructure and the nuclear option.

The boundaries on the Environmental Context axis are defined as extreme and limited.

Extreme Environmental Concern would imply climate change develops in line with some of the more extreme predictions. There is a wealth of undisputed scientific evidence backed up by dramatically changed weather patterns. It is not completely catastrophic and has not drastically realigned the world order. The impacts are being felt globally and there is International political consensus and action against C02 emissions. In the UK, climate change is at the forefront of public awareness and is the single most important issue in decision making for individuals, communities, private companies, public institutions and the Government. Other environmental issues also receive high levels of attention but take second place to climate change issues.

Limited Environmental Concern would imply climate change has not developed past today's situation. The spotlight is removed from CO_2 emissions and environmental issues remain around the same priority as today. There is no International consensus on emission reduction. In the UK, environmental issues do not significantly affect the decision making of individuals, communities, private companies, public institutions and the Government.

The focal areas for generating the LENS scenarios will be:

Acute Environmental Concern would imply climate change develops to a serious degree. Temperature increases and changed weather patterns are apparent and indisputably linked to GHG emissions. There is International political consensus and action against CO_2 emissions. In the UK, climate change is at the forefront of decision making for individuals, communities, private companies, public institutions and the Government. Other environmental issues such as the impact of network infrastructure also receive high levels of attention and are taken into account when considering solutions to climate change issues. Electricity generation sources must be environmentally friendly. Nuclear generation has equal amounts of supporters and detractors for environmental reasons. Energy efficiency is considered to be essential and a matter of national strategic importance.

Moderate Environmental Concern indicates climate change develops only to a small degree. Concern only grows slightly past today's levels. Emission reduction has been tackled gradually and is still a concern. However, it is not one of the main influences in decision making for the majority of individuals, communities, private companies, public institutions and the Government. Other environmental issues such as the impact of network infrastructure receive high levels of attention on a regional basis and the more immediate nature of these issues provoke stronger reactions from local communities than climate change.

5.4.2 Consumer Participation

Consumer Participation is the level to which all types of consumers (commercial, industrial, domestic and public) are willing to participate in the energy market as a whole and specifically the electricity market and electricity networks. Participation could be motivated by economic, technical or environmental factors. Domestic economic participation would imply individuals who were highly active in choosing their supplier, shopping around for the best deals and demanding additional services to enable informed easily implemented choices. Individuals would demand accurate real time information on their electricity supply and would regulate use on a cost basis. Self generation would be a possibility if it had economic benefits.

Domestic environmental participation would imply individuals who demanded the ability to participate in their electricity supply in order to play their part in reducing CO_2 emissions. They would require additional services to allow informed choices based on environmental impact. They would be willing to make sacrifices and regulate energy use for environmental reasons. These individuals would be particularly keen to generate green energy at home and would be prepared to pay to develop the capability for self generation. They would demand sophisticated connections to the electricity network that provided the integration of self generation, automated demand response, balancing services, and dynamic pricing, buying and selling of power.

At the commercial and industrial level, participation would be most likely due to economic influence, although pressure from environmentally concerned society and shareholders could also have an impact. The level of concern around security of supply may motivate industry to be active in their choice of energy sources. Reliance on foreign gas and oil may not be the preferred option if more serious concerns over availability of primary fuel supplies emerge. Industrial participation would take the form of DSM schemes with companies prepared to manage consumption in response to the right incentives. They would also consider participating in micro grids and power parks. Companies would also demand sophisticated connections to the electricity network that provided the integration of self generation, automated demand response, balancing services, and dynamic pricing, buying and selling of power.

The boundaries on the consumer participation axis are:

Dynamic Consumer Participation would imply all consumers are highly motivated to participate in the electricity market and interact with the electricity networks. They demand the capability and flexibility to make informed choices regarding their electricity supply and use. Self generation would be common. All consumers would have sophisticated network connections that enabled advanced levels of interaction with the network. Participation in demand side management and carbon markets would be prevalent.

Dormant Consumer Participation would imply the majority of consumers are not motivated to participate in the electricity market by either economic or environmental factors. Any dissatisfaction regarding cost or emissions would be regarded as a Government or industry problem to solve. These consumers would demand a reliable, high quality supply of “unlimited” energy at reasonable cost. They would not be prepared to regulate their energy use or participate in DSM and would be unlikely to adopt self generation technology.

The focal areas for generating the LENS scenarios will be:

Active Consumer Participation would imply a large proportion of consumers are highly motivated to participate in the electricity market by either economic or environmental factors. They would be receptive to demand side management schemes and carbon markets and many would be actively participating. Sophisticated network connections would be utilised to enable advanced levels of interaction with the network. A good proportion of these consumers would have deployed self generation and would exploit flexible services for using, storing and exporting power in addition to integrating with local and national networks. These consumers are likely to be active in all areas of the energy sector beyond electricity markets and electricity networks.

Passive Consumer Participation would imply a large proportion of consumers are not motivated to participate in the electricity market by either economic or environmental factors. Dissatisfaction regarding cost or emissions would provoke some response but these consumers would look for solutions provided by a 3rd party that did not require significant additional activity on their part. These consumers would demand a reliable, high quality supply of “unlimited” energy at reasonable cost. They would not be easily persuaded to regulate their electricity use or participate in DSM unless 3rd party services could make this happen in an undemanding manner and at a reasonable cost. They would be unlikely to adopt self generation technology.

5.4.3 Institutional Governance

Institutional Governance is the extent to which institutions will intervene through a variety of mechanisms in order to address specific societal concerns or further overarching policy goals relating to energy use and the environmental and economic implications. The Institutional Governance arrangements will address electricity specific areas such as policy on generation portfolio, the use of liberal markets, the approach to natural monopolies, network access, planning, and infrastructure investment.

In relation to CO2 emissions, a firm, widely accepted carbon price may emerge and a sophisticated carbon market developed that operates within individual, regional, national and international emission obligations. Alternatively a carbon tax and associated hard targets could be applied to individuals and institutions to ensure emission targets are met.

The level of investment available and the appraisal of investment could either be based on shareholder return, market climate, short term fund availability, consumer demand, or on overall benefit to society and long term plans to meet Government policy targets.

Institutional Governance could vary on a regional, national and international level. There could be complex interactions between regions and nations using a mix of centrally directed and planned approaches and free market approaches.

The arrangements for incentivising new energy and associated technologies and energy efficiency could be based on liberal markets or on a more interventionist approach. This could see technology and energy use develop in quite different ways with potentially wide ranging implications for networks.

The boundaries of the Institutional Governance axis are:

A ***Liberal Free Market*** approach would place comprehensive trust and responsibility in the hands of the market. The political approach is to use very light regulation and minimal incentives, allowing the market to run its course. This approach assumes competitive markets will meet any International, national and regional environmental targets that may be in place. The adoption of renewables, energy efficiency and self generation technology will depend on market economics and the value placed on environmental concern. Network investment and technological development will occur only in areas attractive to the market and justified by private investment appraisal. If environmental concern is high then a firm carbon price would likely emerge and carbon markets would be developed. Significant changes could be seen in the electricity industry as have been seen in other liberalised industries such as telecoms where rapid technological change, strong competition and innovative services developed in a short period of time.

Mandated Central Planning would imply a centralised approach that tightly controls the operation of the energy sector in order to achieve specific political goals and targets. This is likely to be in response to serious environmental or fuel security concerns. There could be a regional aspect to this response as devolved areas of Government take tighter control of regional markets. A carbon tax could be introduced to force consumer behaviour and hard emission targets backed up by strong regulation imposed on industry. Competition would not be a high priority and natural or regulated monopolies could be encouraged. Nationalisation of strategically important sectors could be considered. Planning regulations for generation plant and network infrastructure would be overhauled to allow speedy deployment of solutions deemed essential by the governing institutions. Energy efficiency measures and stringent building regulations could be mandated to ensure demand reduction. Subsidies could be provided to certain technological solutions deemed the best option by the governing institutions.

The focal areas for generating the LENS scenarios will be:

A ***Market Led*** approach would imply a broadly liberal approach that places significant responsibility in the hands of the market. Light regulation and market incentives would be used to address any environmental issues, promote competition and protect the interests of consumers. This would include market mechanisms to promote renewables, energy efficiency and self generation technology should there be pressure to reduce emissions. The types of technology developed and deployed would be left to the market to decide. If environmental concern is high a firm carbon price would emerge and carbon markets would be developed. Many types of innovative markets would emerge in diverse areas of the electricity sector in response to consumer preferences. Planning regulations would become more efficient and not be preferential to any specific technologies.

A ***Government Led*** approach would imply a planned approach where the electricity market is a controlled mechanism for achieving the generation, supply and transmission of power in line with the environmental and economic requirements of society. The governing institutions would tend to “pick winners” and use subsidies to aid the development of particular technological solutions. Planning regulations are likely to be modified to support the deployment of these solutions. Energy efficiency measures in other sectors such as buildings and transport would also have planned approaches to deliver specific goals depending on the environmental situation.

6 Developing Energy Scenarios

6.1 Approach

As discussed in Section 3, two scenario development tools were proposed in the methodology. Since publication of the methodology, the concept of network scenarios and how to achieve them has evolved throughout the stages of information gathering, finalising inputs and establishing themes. As a result, a process to develop network scenarios has been developed that includes an intermediary stage of energy scenarios. The intention behind this process was to create energy scenarios that provided a high level view of the world in which electricity networks exist, creating a clear link between the interactions of our chosen themes and the general outline of the scenario. With this stage complete, the implications for networks could be explored. It was considered possible that several types of networks could plausibly emerge from one energy scenario and also that the same type of network could emerge from more than one energy scenario.

As the requirement of the energy scenarios was to create an outline picture of the “context” within which networks exist and subsequently identify implications for electricity use and generation, they needed to be developed to a degree of detail that allowed the interactions of the themes to be explored but were not so detailed that possible interactions were ruled out at an early stage. For this reason the orthogonal axes approach was chosen as it was felt the pathways approach would produce too tightly defined energy scenarios. By developing broadly defined scenarios a rich and varied set of implications for networks is created and explored. This ensures the resulting network scenarios represent a comprehensive range of possibilities that directly arise from the theme interactions.

The value of this approach is that robust and plausible network scenarios are developed as a direct product of social, behavioral, political and technical developments whilst also recognising the possibility of multiple network solutions to the challenges of a particular future shaped by these developments.

Alternative approaches may have resulted in combined energy and network scenarios of a more intuitive nature or a set of network scenarios that had no direct link to social, behavioral, political and technical developments.

6.2 LENS Themes as Axes

When the axes of the three themes are represented graphically as in Figure 6 we can conceptualise a three dimensional space comprising of eight octants. Each of these octants contains a unique combination of themes and hence there are eight possible scenarios as illustrated in Figure 7.

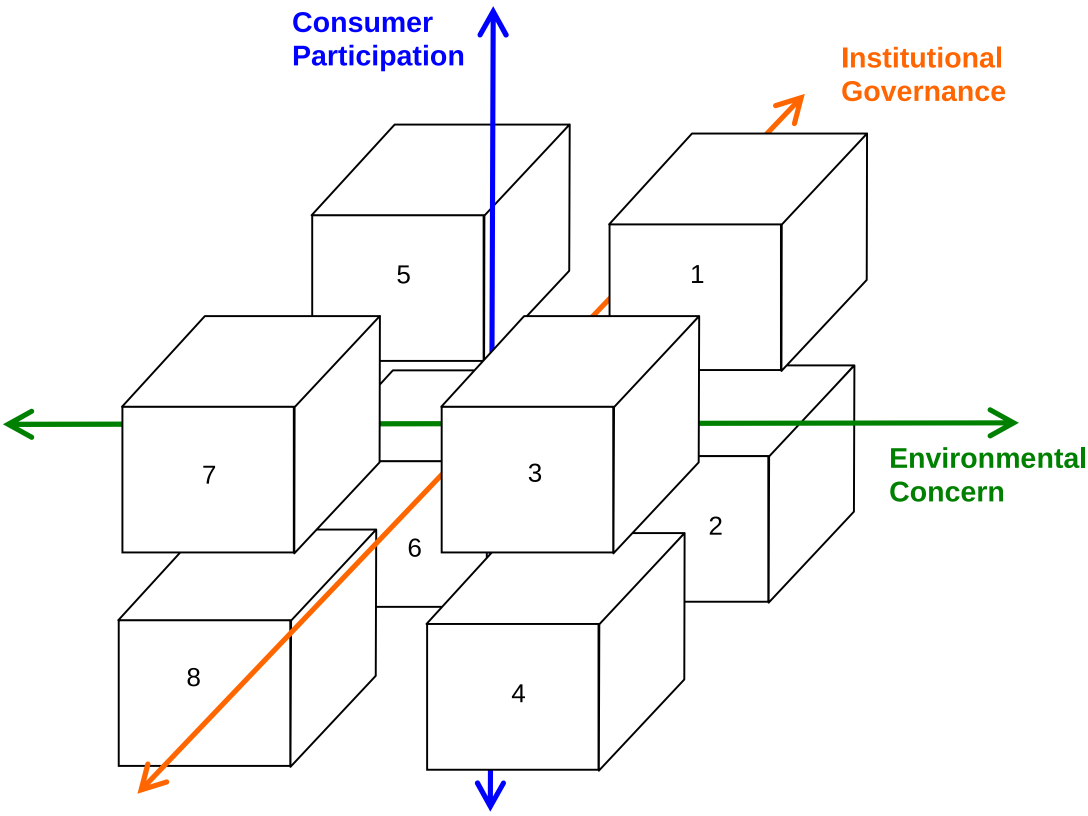


Figure 6: Interaction of three LENS themes.

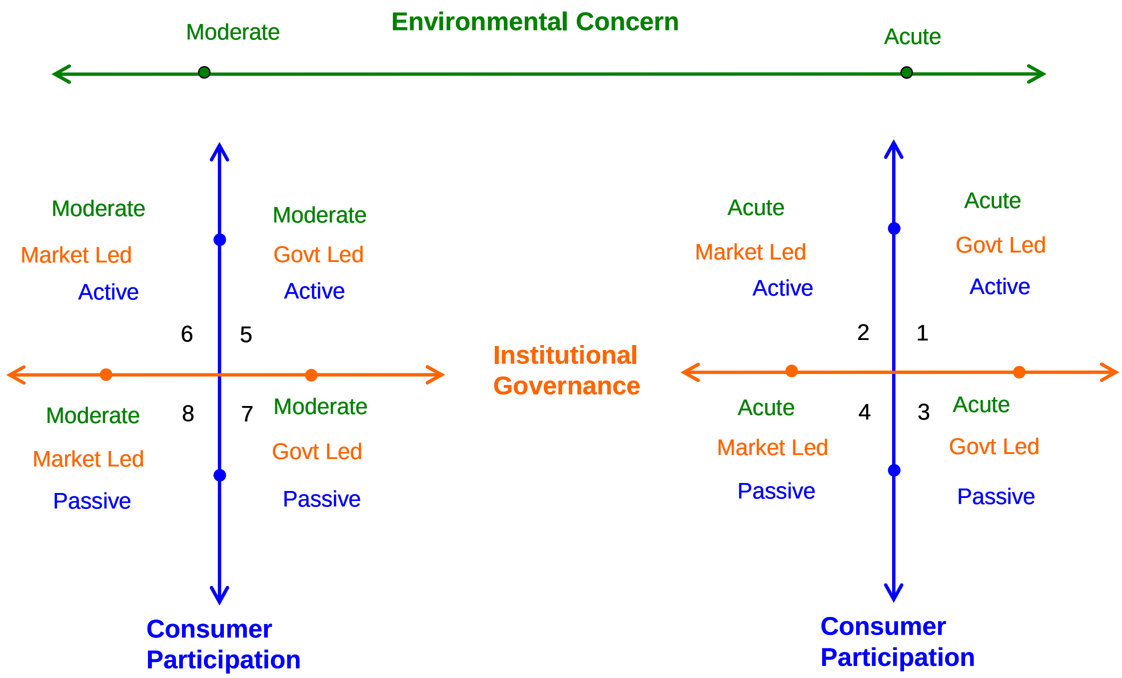


Figure 7: Eight possible initial scenarios identified from themes.

From this range of possible scenarios a manageably small set must be chosen that indicate potential to develop into plausible, interesting and useful scenarios that address the focal question. Each of the eight potential scenarios is briefly discussed below with a view to selecting those with the best potential to meet these objectives of plausibility, interest and usefulness.

1. <u>Acute Environmental Concern, Active Consumers, Government led Institutional Governance.</u>
   In this potential scenario it could be argued that environmental concern has grown to become a dominant factor in decision making at all levels of society. This motivates highly active consumers and prompts strong action from Government. Initial approaches based on liberal market mechanisms fail to achieve the desired results prompting increased intervention.

2. <u>Acute Environmental Concern, Active Consumers, Market Led Institutional Governance.</u>
   In this potential scenario it could again be argued that environmental concern has grown to become a dominant factor in decision making and this motivates highly active consumers. However in this scenario market measures are successful and liberalisation increases. Strong and diverse markets dominate in all areas of the electricity sector.

3. Acute Environmental Concern, Passive Consumers, Government led Institutional Governance.
This combination of themes pairs a Government led approach with acute environmental concern. An initial observation here is that environmentally motivated intervention is likely to have a partial focus on energy efficiency given current information on wasteful attitudes to energy. This does not seem to intuitively fit with a passive consumer theme, however, there is also the possibility that interventionist approaches do not require consumer participation.

4. Acute Environmental Concern, Passive Consumers, Market Led Institutional Governance.
It could be envisioned in these circumstances that as concern grows, innovative markets develop and service companies meet demand by providing a variety of energy efficiency services. Consumers are concerned and are prepared to pay for services. They are passive in that they hand the responsibility over to a 3rd party.

5. Moderate Environmental Concern, Active Consumers, Government led Institutional Governance.
In this potential scenario environmental concern is not much higher than today. Without an environmental motivation why are consumers active in this case? There could conceivably be economic motivation, however should this be so, a market response would seem to be more plausible than any interventionist approach.

6. Moderate Environmental Concern, Active Consumers, Market Led Institutional Governance.
Again, environmental concern is not much higher than today and economic factors may motivate active consumers. A healthy market is likely to respond with strong competition and diverse services.

7. Moderate Environmental Concern, Passive Consumers, Government led Institutional Governance.
In this potential scenario it is more difficult to envisage reasons for a mandated approach and hence this seems to be a less plausible eventuality. There is little environmental motivation for intervention, however it is possible that intervention could occur for non-environmental reasons such as security of supply.

8. Moderate Environmental Concern, Passive Consumers, Market Led Institutional Governance.
Here environmental concern does not increase significantly, consumers are largely inactive and there is a liberal market. This is in many ways

similar to today's situation and could be viewed as the scenario that examines the development of current trends.

From the brief analyses of potential scenarios above, it is clear that a plausible case could be made for most of the options at this stage. Only scenarios 5 and 7 initially seem to contain less plausible interactions between themes.

Before proceeding to a rationalised set of scenarios a few key points regarding scenario development are reiterated. Firstly, the use of themes and axes are tools to identify the types of scenarios that could be explored. As such they are flexible and can be used in a fluid way as required during the process. Secondly, the impact of scenarios is at its most effective when the final scenario set is limited to small number, as reflected in the majority of previous scenario work. Thirdly, as discussed previously, the final product of the LENS project is network scenarios. Therefore this intermediate stage of developing energy scenarios should allow sufficient scope for varied network scenarios with several network scenarios potentially emerging from each energy scenario.

In light of the above statements the following discussion sets out the reasoning behind a rationalised set of energy scenarios that include a wide range of interactions between the themes and hence the potential for diverse network scenarios.

It was proposed that examining scenarios with acute environmental concern and active consumers could produce some very interesting results. A forceful environmental agenda combined with active consumers could hugely change the way electricity is used and generated and the resulting requirements for networks. A comparison between an interventionist and market led approach in this setting could also be significant. Therefore, potential scenarios 1 and 2 were proposed.

Continuing with the view that acute environmental concern will contain interesting implications for networks it was thought worthwhile to include a scenario that involves acute concern and passive consumers. Rather than specifying the institutional governance at this stage, this scenario could potentially contain a combination of intervention and market led approaches. Therefore this scenario would be a combination of potential scenarios 3 and 4.

Finally to include a good range across the scenarios, an option with lower environmental concern was necessary. The combination of moderate environmental concern and market led approaches seem more plausible therefore potential scenario 8 is proposed. However discarding too many options at this stage is possibly premature; therefore it was proposed that this last scenario should also retain the possibility of active consumers (i.e. potential scenario 6) as well as passive. This allows some flexibility as the scenario narrative is developed.

6.3 *Initial Energy Scenarios*

It is again emphasised at this stage that the purpose of scenarios is not to cover every single possible future outcome but to encourage “thinking the unthinkable” and to move away from only considering the “official” future. Hence, the choice of scenarios is not required to cover all possibilities. However, it is also thought important to allow an element of flexibility that permits the scenarios to evolve throughout the iterative process of creating the narratives and provides scope for varied network scenarios. The above discussion sets out the justification for a set of four scenarios that include many aspects of the initial eight potential scenarios. The only potential scenarios that have been fully discarded at this point are 5 and 7. These scenarios covered theme interactions between Moderate Environmental Concern, Active/Passive Consumers and Interventionist Institutional Governance and were deemed less plausible after a brief analysis. The above discussion places a greater value on scenarios with an acute level of environmental concern as this will provoke greater change, however moderate environmental concern is included in one scenario to provide contrast. It is proposed that the range and variation within the proposed 4 scenarios includes sufficient scope to explore Active/Passive consumers and Interventionist Institutional Governance and the addition of the less plausible scenarios 5 and 7 do not add significant value.

The proposed four initial scenarios are therefore:

- A – Moderate Environmental Concern, Active and Passive Consumers, Market Led Institutional Governance. (Influenced by potential scenarios 6&8)
- B – Acute Environmental Concern, Passive Consumers, Government and Market Led Institutional Governance. (Influenced by potential scenarios 3&4)
- Ci – Acute Environmental Concern, Active Consumers, Government Led Institutional Governance. (Influenced by potential scenario1).
- Cm - Acute Environmental Concern, Active Consumers, Market Led Institutional Governance. (Influenced by potential scenario2).

The ‘space’ that these four scenarios occupy is illustrated in Figure 8.

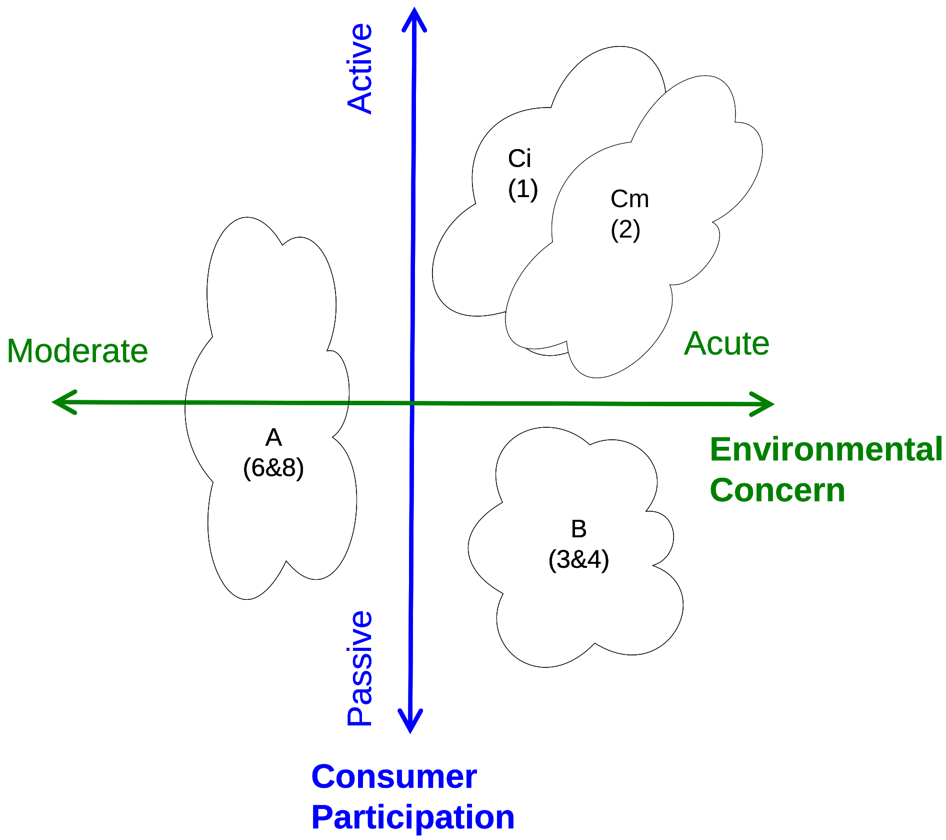


Figure 8: Illustration of four initial scenarios selected.

This iterative process of identifying initial scenarios prompted further discussions on potentially important areas that may not be fully explored in the chosen four initial scenarios. The approach of using axes is a valuable tool in defining potential scenarios and has been successfully used to produce an initial set of four scenarios. However, the nature of the axes approach can have slightly polarised results. The proposed scenarios assume a clear position at one end of an axis, the possibility of a middle ground is not considered (e.g. where environmental concern is nearly but not quite acute). There is potentially significant value in the inclusion of a scenario that is not easily defined by a position on the axes. A scenario where the level of environmental concern is unclear, the activity of consumers fluctuates and the governance approach includes both market and interventionist measures could provide a valuable perspective and highlight the potential for stranded assets and investment redundancy.

- Scenario D This additional scenario considers the possibility that environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental reports/statistics. This leads to various market led and Government led approaches being pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of supply and the immediate economic concerns. The resulting overall uncertainty creates varying levels of activity across the electricity consumer base. The result is a lack of continuity and a long term strategic approach. The interesting aspect of this scenario is the fluctuating nature of policy and strategic approach and the impact this could have on network investment and development.

With a set of five initial scenarios defined, the next stage was to develop each of the five into a draft scenario via an iterative process of narrative writing. An outline plan for each narrative was defined that specified a background section covering the majority of the high level inputs from Section 4 and an energy section which focussed on energy specific issues and implications for electricity generation and demand. To initiate the narrative writing a set of questions was produced for each high level input that explored how that input would be shaped by the interaction of environmental concern, consumer behaviour and governance for that scenario. When each of these questions had been answered to provide the backbone text of the narrative a fluid process of writing, reviewing and redrafting took place.

The draft scenario narratives are set out in the following section.

7 Draft Energy Scenarios

The five scenarios identified in the previous section are now developed further through the presentation of a narrative based on the themes and key issues arising from the LENS inputs.

Table 2 provides a summary of the scenarios and their characteristics.

Energy Scenario	**Environmental Concern**	**Consumer Participation**	**Institutional Governance**
Switch me on (A)	Moderate	Active and Passive	Market Led
Fix it for me (B)	Acute	Passive	Market Led and Government Led
Government Led Green Agenda (Ci)	Acute	Active	Government Led
Dynamic Green Markets (Cm)	Acute	Active	Market Led
Reactive Approach (D)	Increased but below Acute	Active and Passive	Market Led and Government Led

Table 2: Energy scenarios characteristics.

The following subsections provide narratives for the five scenarios.

7.1 'Switch me on'

'Switch me on': Passive and Active Consumers, Moderate Environmental Concern, Market Led Institutional Governance.

- Consumers demand abundant supplies of electricity that require minimum participation on their part.
- Free markets persist as the main mechanism to service the energy requirements of the nation. Society is broadly consumerist and capitalistic.
- The importance of environmental issues to society in general does not grow significantly higher but there is continued debate and policy development geared towards reducing carbon emissions.
- Fossil fuels are used widely for electricity generation, domestic and commercial energy supplies and transport with ongoing and increasing risks of scarcity in primary fuel supplies and reserves.
- Centralised larger scale power generation (fossil, nuclear and/or renewable) dominates electricity production.

In this scenario the environmental concern of society in general does not grow significantly past today's levels. Consumers remain relatively passive towards their electricity supply and the belief persists that markets are best placed to service the energy requirements of the nation. A key feature of this scenario is that for various reasons fossil fuels for electricity generation, home and commercial energy supplies and transport continue to be dominant for some time; prices rise and scarcity of reserves develop.

7.1.1 Background

Climate change does not develop significantly past the effects we are seeing today. This is either due to inaccuracy of current predictions or because other innovative solutions are found outside of the energy sector. There is some change in temperature and weather patterns but they do not accelerate and there is no major impact. An alternative possibility that would have the same effect is that tolerance to climate change increases amongst developed nations with means to adapt and although effects of climate change increase, concern doesn't. Either way, the current level of urgency will increase in the early years and some international agreements will be achieved in the short term, however, these will be less stringently adhered to as environmental concern plateaus. There will be initial emissions capping agreed internationally and this will be broadly adhered too. Nonetheless, there will be a lack of urgency to take further action. There is continued debate over the urgency to reduce fossil fuel emissions and although low carbon energy continues to be developed and some countries move away from fossil fuel use, there is little international political consensus and coordinated approach. In the long term, power struggles to secure decreasing fossil fuel supplies are likely to emerge as worries over security of supply increase – this could be observed through international tensions, diplomatic incidents, and skirmishes and conflicts. These security concerns will promote long term planning for sustainable energy sources, especially for countries without fossil fuel reserves. There is likely to be a considerable nuclear element to this. OECD countries will be highly active in securing long term fossil fuel supply contracts and sources. Fossil fuel will continue to be widely used but it is likely that to meet existing targets for emission reduction CCS capability will also be developed. In the long term, developed countries continue to hedge their bets and keep renewable and nuclear capability on the agenda as a solution to depleting fossil fuel. Nuclear fusion and hydrogen are seen as potential long term solutions but remain in developmental stages as the urgency to invest in these technologies does not materialise.

Overall, attitudes are moderately environmentally friendly. There is acknowledgement that the environment is important and should be protected, however, commitment to this is loose and other factors such as economics and lifestyle preferences outweigh environmental consideration frequently in the decision making process. Climate change is still seen as a serious issue but serious action has failed to materialise for the reasons identified above. Consumers see this as a Government and industry problem to solve. The initial high levels of concern identified above created groups of consumers who took a more proactive approach to their energy requirements, however the majority of consumers maintain a passive attitude to energy use. They desire an uncomplicated energy supply but are also moderately opposed to developments with environmental impact. In particular, network infrastructure developments with high environmental impact receive high levels of attention as their effect is more immediate and provokes emotional local responses. Although weather patterns are slightly altered the climate change effects such as increased temperature and unpredictable storms are not significant enough to impact electricity network deployment.

The primary factors for decision making will be economic, social welfare, consumer and voter lifestyle preferences. Attitudes and behaviour will be predominately consumerist and capitalistic with some underlying commitment to social justice. There could also be sizable minority sections of the population that prefer alternative lifestyle choices with a focus on sustainability and global justice. These social groups would also be likely to develop active attitudes towards energy. A prevailing passive attitude will also manifest itself in a low sensitivity to energy price increases although there may be sections of the population that are sensitive to price increases.

Government involvement is directed towards achieving economic and social policies. An element of this would be environmental policy; however this would not be the strong force it is in other scenarios. There is still regulation to oversee the operation of, and to promote competition in, the energy markets; however the regulator will not be called upon to address environmental issues. The Government would identify areas of importance such as electricity generation and transport and provide general incentives to help overcome the natural barriers in those areas and to promote growth in them according to their economic targets. This would not be in any way prescriptive and the market would be left to make its own choices within the soft boundaries set by the Government.

Light regulation and market incentives would be used to address the moderate environmental issues, promote competition and protect the interests of consumers. This would include market mechanisms to promote renewables and energy efficiency in the early years; however as environmental concern plateaus the focus would shift away from environmental issues. The types of technology developed and deployed would be left to the market to decide and the long-term security issues might find their way into markets through price premiums for secure sources of energy. Initial development of technology to address the environmental issues would fall away and development will then be focussed on competition and efficiency.

Carbon trading schemes would continue in a similar form as today but would not develop into sophisticated markets with a firm carbon price without the strong environmental focus. Planning regulations would not be optimised for dealing with environmental issues and would be similar to today.

Government would be relaxed about the importance of achieving current targets for CO2 emissions and would feel on track to meet them with initial measures or would be less concerned about the impact of not meeting them. Public expenditure in this area is likely to be limited by a reduced urgency to meet environmental goals. Energy generation and use will not undergo a dramatic change in direction in that the focus will remain on centralised solutions. Energy policy will be mainly addressing the demands of the economy and consumer lifestyle. The environment will remain a consideration and will not be sacrificed for the sake of the economy but it will not be the overriding consideration. Government will set boundaries to ensure environmental issues are considered, however energy policy will be mainly addressing security of supply, competition and quality of supply.

The economic situation is moderately healthy with slightly lower levels of growth than recently. This and the lack of a strong focus on environmental issues will hinder investment in new low carbon energy technology. There is no strong Government lead to promote investment in alternative generation technology or consumer energy efficiency measures and there will not be any strong driving forces within the market to invest in new areas of energy production and use. Investment will continue in the area of optimising fossil fuel resources, improving efficiency and reducing cost. The deployments of other generation technology that come about in the early years i.e. nuclear and offshore renewables will see investment to drive competitiveness and maximise returns. The slower economic environment combines with lower investor confidence and a focus on optimising existing technology rather than innovation and developing new technology. Consumers are largely passive but would need to be careful of their spending on energy and would look for increased efficiency to translate into reasonably priced energy. An increased price of fossil fuel and continued heavy use of this energy source contribute to lower economic growth. By 2050 these issues start to push attention towards alternative energy sources.

7.1.2 Energy

Society in general will become slightly more environmentally conscious and reducing emissions will have been a high priority in the early years. However, as concern ceases to accelerate and initial measures have some success, the CO2 emissions factor becomes less of a priority. Most types of consumers will be reluctant to significantly change their behaviour or make an individual effort. This type of attitude will apply in leisure activities and consumerism where people will persist with current behaviour trends and insist any environmental problems are solved elsewhere. As indicated above, there may also be significant minority groups that continue with the early focus on emissions and actively pursue alternative energy sources. Despite mainly passive attitudes the majority of consumers will be aware of environmental issues and may take small steps to address them however will not be prepared to make major changes in their lifestyle. People will continue to desire older, spacious, less efficient housing and private car use will remain the main choice for transport. This will predominately stay fossil fuel based although efficiency will be improved and hybrid electric vehicles will slowly penetrate the market providing much improved emissions levels. Rail will gradually become totally electric. Public transport will be improved and there will be some movement to increased use in urban areas. Fully electric cars that are mains charged do not develop beyond a niche market.

Places of employment do not adhere to any strict guidelines on energy efficiency and there will be continued high demands for electricity and space and water heating. Increasing prices of fossil fuels (Oil and Gas) will have some impact and motivate some energy saving behaviour, however reasonably priced electricity will still be available from coal, nuclear and renewable generation for which there is high demand. Increased fuel prices and the availability of advanced ICT solutions to the home promotes widespread home working for the majority of desk based roles.

A large proportion of consumers will not be motivated to participate in the electricity market by either economic or environmental factors. Initial environmental concern would result in consumer demand for agencies that serve and represent them to minimise environmental impact. As the electricity generation industry moves towards lower emissions, consumers will be satisfied that environmental issues are being addressed and become less concerned about the source of their energy. Customers of the aforementioned agencies could value and hence continue with the services provided and there could be a continuing small market for those customers with undiminished environmental concern. Most consumers will demand a reliable, high quality supply of energy at reasonable cost. Despite the activity of minority groups, it is unlikely there will be significant efficiency improvements and there will be a continuation of today's high energy use behaviour as powerful drivers and strong government leadership to change consumer behaviour are not present.

In the early drive for low carbon a mix of generation sources will be developed including nuclear, renewables and possibly some larger community CHP plants. This would only supplement the continued use of CCGT and Coal with and without CCS and centralised generation would dominate. It is likely in this scenario that there will also be installations of renewable generation in the form of offshore wind/wave/tidal and large onshore wind farms as this is considered the best way of meeting initial environmental targets with passive consumers in the short term. Offshore locations will be as per existing identified suitable sites (Thames Estuary, Wash, Morecambe Bay, North and West coasts of Scotland for wave and tidal). Onshore windfarms would primarily be located in recognised areas of resource; Scotland, Wales, Cornwall and the East Coast. Centralised plant will be built on the sites of existing power plant initially and then in similarly suitable locations near ports for coal and near the gas transmission system for gas.
Interconnectors could see some development in the early years as private assets owned by transmission companies to promote European wide liberal markets and address issues on security of supply.

Gas will be used widely for space and water heating in the short to medium term. The long term may see increased migration from gas to electricity as security of supply concern starts to account for depleting fossil fuels and starts to encourage use of electricity generated by a diverse generation portfolio

Metering and charging will be a passive process for consumers. Their supply company will be given responsibility and the consumer will pay little attention as long as costs remain within expected boundaries. Consumers will be unlikely to be looking for additional services from their supply company to reduce environmental impact. There may be a gradual development towards more detailed metering providing accurate usage information and using developments in home telecoms to automate readings and billing. This will mainly be a result of natural technological development and a desire from supply companies to optimise efficiency rather than as a result of consumer demand, however there will be groups of consumers who embrace this as an opportunity to help regulate energy consumption. Consumers could be amenable to gas powered CHP as a replacement option for a boiler, this would need to be an uncomplicated, competitively priced option that was a natural lifecycle replacement for central heating boilers. This would only have a small impact on electricity demand as the CHP units would only generate supplementary amounts of power.

Overall, consumers are unlikely to change their behaviour and there is no long term strong, cohesive environmental agenda. There are some environmental concerns but this is just one of many driving issues. The elements of the scenario driving consumers are more likely to be economic and any large scale adoption of demand management schemes would be motivated by rising electricity prices.

The majority of consumers would be reluctant to interact with their supply and the network. They would have a “switch me on” attitude and be keen for the most economical option. Larger consumers could agree to basic demand management agreements. It is possible that a centralised, largely automated demand management scheme could be implemented if it requires little input from consumers and helped mitigate the impact of any rising costs of power.

Objections to network infrastructure are unlikely to diminish and with no great driver for change there may be no pressure to change planning procedures, hence any network upgrades or new generation build would be subject to lengthy procedures and become a protracted process.

7.2 'Fix it for me'

> **'Fix it for me': Passive Consumers, Acute Environmental Concern, Both Market and Government Led Institutional Governance.**
>
> - Consumers remain relatively passive towards their energy supply and while the majority of people are concerned about the environment they strongly believe that it is the duty of government and the market to address the issues.
> - Although the belief persists that markets are best placed to service consumer demands at the same time as meeting social and environmental needs, strong intervention is not ruled out to address environmental issues.
> - The potential for markets to meet the energy services demands of consumers is met through the emergence of energy service companies (ESCOs).
> - Centralised electricity generation persists but alongside a relatively strong development of on-site and local/community scale demand side participation and smaller scale generation (e.g. combined heat and power) through the energy service companies.

In this scenario consumers remain relatively passive towards their energy supply despite increased levels of environmental concern. Although liberal markets are still preferred, strong intervention is not ruled out to address environmental issues. Consumers have a desire to see environmental issues addressed, however strongly feel this is the responsibility of industry and Government to solve. This high level of passivity from consumers is one of the defining features of this scenario with the majority of people being concerned about the environment but strongly believing that it is the duty of others to sort it out.

7.2.1 Background

The background to this scenario has climate change developing to a serious degree. Temperature increases and changed weather patterns are apparent and indisputably linked to green house gas (GHG) emissions. There is international political consensus and action against CO2 emissions which gathers pace in the short term. Global initiatives will slowly reach full agreement and impose strong mandates for emissions reduction. The current level of urgency will increase steadily and international agreements on emissions capping will be achieved in the medium term. Countries without fossil fuel reserves will be early adopters of low carbon energy in response to energy security concerns. Developing countries will have to respond to their economic needs and will continue to use fossil fuel while it is initially cheap and available unless they have access to development aid from OECD countries targeted at environmental concerns. International agreements leading to firm carbon markets will allow developed countries to incentivise low carbon energy in developing countries. As the west develops new energy technologies and reduces their cost, opportunities will arise to deploy this technology worldwide. The more developed non-OECD countries such as China and India will recognise the long term insecurity of fossil fuel and start developing alternative fuel sources in the medium term.

In the UK, climate change will be a high priority in decision making for individuals, communities, private companies, public institutions and the Government. For consumers, their decision making will be equally influenced by their relatively passive attitude to energy issues. They desire an uncomplicated energy supply that requires little involvement on their part and will also be opposed to developments with environmental impact. Consumers will balance their passive approach to their energy supplies and the electricity network with their concern for environmental issues through early market provision and government legislation taking action out of the hands of consumers. Some consumers will continue to be slightly self-centred and carry on consuming as before but with someone else tackling environmental issues. Although consumers will be passive with regards to their electricity supply, the general attitude of environmental concern would lead to opposition for any electricity generation sources or infrastructure that was not environmentally friendly. Energy efficiency will be recognised as important but passive attitudes will prevent any proactive response from consumers and the onus placed on the manufacturers of electrical goods and energy suppliers. Government will elicit a response from the market by setting energy efficiency standards for electrical goods and incentives for supply companies to provide energy efficiency as a managed service. In this way, environmental concern will shape the market place which will respond to consumer demand for environmental acceptability and low involvement. Government will play a part by ensuring economic barriers do not prevent the market responding to the challenge.

Although weather patterns will be notably altered the climate change effects will not be catastrophic. The general social structure of the country will not be hugely altered and the environmental circumstances will not greatly affect electricity infrastructure. However, the level of environmental concern would create resistance to transmission towers and lines in some areas.

Government will respond to increasingly tough targets for CO2 emissions set in response to strong EU and global mandates. Policy is directed towards achieving environmental targets and protecting consumers. Hence there would still be regulation to oversee the operation of, and to promote competition in, the energy markets. The Government would identify areas of importance such as electricity generation, transport and energy efficiency and provide general incentives to help overcome the natural barriers in those areas and to promote growth according to their environmental targets. This would not necessarily be prescriptive and the market could be left to make its own choices within soft boundaries set by the Government.

Moving energy generation and use in a new direction via new markets would be part pull by private actors in those markets and part push by Government through setting market frameworks with targets, penalties and incentives. Light regulation and market incentives would be used to address the environmental issues, promote competition and protect the interests of consumers. This would include market mechanisms to promote renewables and energy efficiency. Energy efficiency measures would be targeted towards improving the efficiency of products and other electrical loads rather than patterns of use. The types of technology developed and deployed would be left to the market to decide. A firm carbon price would emerge and carbon markets would be developed. Many types of innovative markets would emerge in service areas of the electricity sector (for example carbon accounts) in response to consumer passivity and environmental concern. The carbon market will penetrate to the level of larger consumers and industry and will incentivise these parties to adopt low carbon technology and solutions to avoid the cost of buying carbon certificates on the open market. This will drive activity in green electricity generation as consumers will be too passive to engage in energy efficiency schemes. By being passive, consumers will be prepared to accept some increased cost for additional services that "assuage their guilt" with minimum effort on their part.

The economic situation will be fairly strong overall with GDP growth rates at or above long term averages. The economic environment will be healthy enough to provide investors with the confidence necessary for new markets to develop amid innovation and entrepreneurialism. Although there is a broadly liberal market structure, there will be elements of intervention to encourage markets in new energy technologies to develop. This approach of targeted intervention will be focused on areas where the market may be reluctant to invest and innovate in new technology as consumer attitudes are passive to new developments. The market opportunity for managed energy efficiency services will stimulate private investment as will any policy requirement for centralised clean renewables alongside suitable market incentives. Investment decisions taken by individual companies will be based on the projected return to shareholders. However, the return to shareholders will be influenced by any incentives and penalties used in developing the market along environmental lines. Investment in the electricity industry and networks specifically will become a less centrally planned process with increased competitive tendering and negotiated contracts between buyers and sellers of energy and network services.

Interconnectors would be developed strongly as private assets owned by transmission companies to allow international electricity trading as consistent with a market led future.

7.2.2 Energy

Society in general will become significantly more environmentally conscious and reducing emissions will become a high priority. However, consumers at all levels will be reluctant to significantly change their behaviour or make an individual effort. They will be caught between concern for the environment and their passive attitude to energy. For environmental issues they will see this as a problem that Government and industry should solve. These consumers would be unwilling to use private cars less until a highly efficient, wide reaching public transport system was available. Consumers would be reluctant to reduce home energy use and would instead look for product manufacturers to increase efficiency and electricity suppliers to provide cleaner power. This type of attitude will apply in work, leisure and purchasing patterns with individuals persisting with current behaviour and insisting the problems are solved elsewhere. The passive attitude will also manifest itself in a low sensitivity to energy price increases. People will continue to desire older, spacious, less efficient housing and while Government set targets for energy efficiency in housing this continues to be restricted to new and developed properties. Property sector efficiency codes will be on a voluntary basis and the information packs that evolve to contain home energy use information will not be seen as the important criteria in house buying decisions.

Transport will continue to use fossil fuel predominantly and private car use will be prevalent due to the barrier of changing consumer behaviour. However, the environmental concern in this scenario will mean highly improved efficiency and the development of electric hybrid vehicles. This does not require much change from consumers and addresses environmental concerns. Without consumer demand or other strong drivers, fully electric cars that are mains charged do not develop. Biofuels may also play a part in fleet vehicles. Rail will move slowly to become fully electric, public transport will be improved and there is some movement to increased use of public transport in urban areas where good services will be provided and where consumers respond as much to the convenience as the environmental credentials of public transport. Hydrogen will start to emerge as an energy carrier as the fossil fuel industry starts to diversify but by 2050 it has not penetrated significantly.

A large proportion of consumers will not be motivated to participate in the electricity market by either economic or environmental factors. Dissatisfaction regarding cost or emissions would provoke some response but these consumers would look for solutions provided by a third party that did not require significant additional activity on their part. These consumers would demand a reliable, high quality supply of energy at reasonable cost. However, they would express their environmental concern by accepting changes in the industry aimed at reducing emissions and they could be persuaded to regulate their electricity use or participate in DSM if third party services could make this happen in an undemanding manner and at a reasonable cost. They would be unlikely to adopt self generation technology.

The environmental concern within society as a whole translates into pressure on the Government to ensure emissions targets are being met and on the market to provide innovative services that consumers demand. Consumers would have a largely “switch me on” attitude with the caveat that they want the energy source to be green.

The resulting solutions in terms of the generation deployed and management of energy use are likely to have certain key elements in common. Low carbon energy generation will be a priority and demand management is a provided service rather than a consumer activity.

Generation could contain a strong centralised focus as CCS for existing fossil fuel thermal generation is developed in conjunction with increased use of nuclear power deployed by large energy companies at large scales to serve the market demand for centralised low carbon electricity.

It is also likely this scenario could see large developments of renewables – offshore and large scale wind as this would be considered the best way of meeting environmental targets with passive consumers in the short to medium term. There is not likely to be widespread development of self generation since the appetite of consumers for such products will be relatively low. However, energy service companies (ESCOs) could potentially begin to build local/community CHP and renewable distributed generating plants to provide the low hassle, green energy that consumers desire.

Natural gas will remain an important fuel in this scenario and will be the preferred fuel source for CHP with reserves dedicated to efficient use in CHP in the longer term. There is likely to be continued use of CCGT in the short to medium term and this will continue to some extent with CCS in the long term. Gas will be used widely for heating in the short to medium term. Space and water heating would either gradually become an ESCO provided service or would migrate from Gas to network provided electricity as low carbon electricity production increases. Biofuel use also develops in this scenario but there continue to be serious issues of sustainability for large scale biofuel exploitation and this limits the overall penetration of this fuel source. Generation from waste and synthetic organisms is the most plausible development.

Overall electricity demand is likely to increase moderately in all sectors, reflecting the economic growth and continued high energy use of consumers. In the absence of willingly active consumers, demand management is a significant challenge and without automated DSM schemes provided by the network or managed services from ESCOs, demand will remain high with significant peak levels.

Metering and charging will be a passive process for consumers. Their energy supply company will be given responsibility and the consumer will pay little attention as long as costs remain within expected boundaries. Consumers will be looking for additional services from their supply company to reduce environmental impact. They will expect electricity to be generated in an environmentally friendly manner as the Government shapes the generation industry.

Any impact on demand will come from services from the network operator or ESCOs. Larger consumers could agree to basic demand management agreements that could become a growing trend as economic benefits from this behaviour materialize. It is possible that network operators could implement automated demand management schemes requiring little input from consumers.

Some efficiency provisions could emerge as a market develops for third party services through ESCOs who would promote the concept of contracts for service levels or “a level of comfort” rather than for units of electricity. ESCOs would either take the place of a supply company but with added value services including efficiency measures and DSM schemes or they would incorporate a local CHP generation source and manage the supply and demand within an autonomous area.

7.3 'Government Led Green Agenda'

'Government Led Green Agenda': Active Consumers, Acute Environmental Concern, Government led Institutional Governance.

- The belief develops that stronger Government intervention is required in the energy sector to meet consumer demands for energy services and to make a full contribution to the global action to reduce fossil fuel emissions. This move from more market delivery oriented policies is due to perceived market failures in areas such as delivery of climate change policies and targets, energy security matters and energy prices. .
- The decision is made to push for a hydrogen economy as part of a cohesive EU initiative.
- Consumers are active in their electricity supplies because of attitudes to the environment and a desire to secure the best possible supply of electricity based on price, service and reliability.
- There is a strong development of larger scale clean power generation, renewable power generation and a relatively high penetration of hydrogen fuel cells in vehicles.
- There are consumer moves towards energy self sufficiency through efficiency measures and self generation.

In this scenario strong Government intervention occurs in the energy sector in response to perceived market failures in areas such as energy prices, energy security matters and delivery of climate change policies and targets. A feature of this scenario is a decision to push for a hydrogen economy as part of a cohesive EU initiative. Consumers are active in their electricity supplies because of attitudes to the environment and a desire to secure the best possible supply of electricity based on price, service and reliability.

7.3.1 Background

The background to this scenario sees global climate change developing to a serious degree leading up to 2050. Temperature increases and changed weather patterns become apparent and indisputably linked to GHG emissions. There will be international political consensus and action against CO2 emissions. The Kyoto protocol will be modified and gain universal ratification. The environmental situation only reinforces this in the medium to long term and OECD countries will take a lead in targeting emissions and moving away from fossil fuel. Developing countries will have to respond to their economic needs but will reduce emission in accordance with international agreements with firm emissions capping. As the west develops technology and reduces cost, opportunities will arise to deploy this technology worldwide.

As a result, climate change will be at the forefront of decision making for individuals, communities, private companies, public institutions and the Government in the UK. Other environmental issues such as the impact of network infrastructure will also receive high levels of attention and will be taken into account when considering solutions to climate change issues. There will be a strong perception that electricity generation sources should be environmentally friendly and energy efficiency is an essential matter of national strategic importance.

Although weather patterns will be notably altered the climate change effects will not be catastrophic. Global emissions targets would be on track and the more drastic predictions avoided. The general social and economic structure of the country would not be hugely altered and the environmental conditions for implementing power networks would also be stable.

Moderate public and international pressure combined with lack of progress from liberal market mechanisms will prompt the Government to take interventionist action. In so doing, the Government will reflect public opinion and set the priorities for climate change over local environmental concerns such as habitat destruction, landscape scarring and visual amenity issues. Policy would be aimed at manipulating markets to deliver environmental targets and protect consumers. There will still be a desire to employ liberal market approaches when possible, however there will be specific cases of strong intervention where market mechanisms are not delivering or are judged to be unable to deliver in the necessary timescales. Regulation would play its part in controlling the market and enforcing some of the interventionist policies. The Government would identify areas of importance such as the hydrogen economy and energy efficiency and provide strong leadership, funding and legislation to enable and drive through particular solutions. The electricity market would be a controlled mechanism for achieving the generation, supply and transmission of power in line with the environmental and economic requirements of society. Emission capping will be applied and a firm price on carbon will be set. A carbon market will emerge that is more a highly controlled mechanism for emissions reduction than a free market. The governing institutions would tend to "pick winners" and use subsidies and taxes to aid the development of particular technological solutions such as undergrounding and offshore transmission links.

A hydrogen economy develops due to strong Government lead and EU wide initiatives on R&D and infrastructure development. There is partnership with the oil and vehicle industries as these industries gradually migrate their business away from fossil fuel to hydrogen. As the market develops, Government intervention becomes less necessary and hydrogen production, storage and transportation becomes a huge industry to satisfy transport and fuel cell demands. Hydrogen will mainly be produced from centralised sources and as a result of the government led push for hydrogen infrastructure large central plants are preferred and give good early economies of scale. Financing is through public private partnerships (PPP) and primary fuels for hydrogen production could be nuclear and fossil fuels.

The economic situation will be fairly strong growth overall. The economic environment will be healthy enough to provide Government with the confidence to prompt private investment and fund public investment. There would be low levels of uncertainty in the projected returns from investment encouraging the Government to prompt the development of new technology and solutions. The use of public-private type partnerships would be common as Government seeks to draw private funding into the high expenditure required in meeting its targets for climate change. Government guarantees would help keep cost down under these type of arrangements. Consumer energy spending remains fairly constant as financially comfortable consumers invest in energy efficient products, self generation and new transport methods. Consumers will see long term economic benefits in new technology and energy solutions and have the financial means and confidence to provide the initial investment. They will not be averse to bearing some cost for new development.

Investment will either be public funded or prompted by Government policy. Decision making here would be more focussed on public benefit and achieving Government targets. Return on private investment would also be important; however it is not the primary approach to appraisal of funding. Low discount rates for energy projects become more common as the message sinks home that long term effective solutions are worth paying extra for. There will be specific cases of strong intervention to facilitate new technology/solutions development. An example of this would be the further development of existing interconnectors (potentially with public subsidy) to allow national electricity trading.

7.3.2 Energy

Society in general will have become much more environmentally conscious; energy efficiency will have become much more of a priority in all areas of life led by Government targets and mandates as well as individual consumer action. Leisure activities and consumer preferences will be influenced by environmental attitudes. Attitudes towards transport and housing will reflect the desire for "green" lifestyle choices. Consumers will desire energy efficient housing and be prepared to modify their lifestyles accordingly; i.e. by placing more value on smaller, modern, energy efficient housing. Older housing would be modified for energy efficiency to attract buyers and to fit with possibilities for taxing houses at sale based on energy efficiency or similar environmental impact measures. This change would happen quickly on the back of strong building regulations imposed by the government on new build due to a strong environmental focus on building policy. Standards of insulation and energy efficiency will also be mandated for older property. Government building regulations on energy efficient housing will be welcomed and consumer preferences see the housing market change dramatically. Smaller, more efficient modern housing will be preferred and smarter controls (e.g. timers, zonal temperature control) allow the older housing stock to be made more energy efficient. The energy "rating" of a home will be a key part of the house buying process and Government makes this a legal requirement. Attitudes to transport would change. Use of public transport would be more common as the Government invests substantial amounts of public money into improving services. Private car use would still be common with the hydrogen fuel cell powered car prevalent. Cars become more of a short journey transport method. Rail transport will become fully electrically powered as the technology is established and is heavily invested in during the early attempts to reduce emissions. Hydrogen powered buses would also become more and more widely used in urban areas.

Flexible working will become more common as home telecoms advance and virtual offices materialise. In certain industries policy on building estate and working practices may be heavily influenced by energy matters. Companies would weigh the availability of large energy efficient buildings with a local CHP source against large numbers of home workers and the increased home energy use. Government action would mean public institutions take the lead in drastically improving office energy efficiency and self generation via hydrogen CHP with the aim of becoming largely self sufficient. This policy would result in public bodies locating themselves in large sustainable office parks or promoting home working where employee home energy efficiency is of a high standard.

Energy efficiency mandates and carbon taxes from the Government will force industry to prioritise energy use leading to a mix of home working and sustainable power parks. This will be an economic decision based on the availability of premises, ICT at home and the cost of energy use.

Active consumers with high environmental concern require transparent, public representative planning processes. With the Government more prone to an interventionist approach, planning decision-making will be primarily at a national level with significant overriding power. The desire for centralised planning and rapid deployments may result in clashes with public opinion and local pressure groups. This could prompt public funding/Government mandating of undergrounding or offshore North South connectors.

The governance approach of strong intervention to drive through particular technologies and solutions will have a major impact on the source and use of energy in GB. The two strongest features of this approach will be the strong promotion of renewable generation and the push towards a hydrogen economy.

As a result, society's energy needs in this scenario would be met primarily via hydrogen fuel cells and renewably generated electricity. The proportion of demand met by the two main fuel sources will depend on the extent to which Hydrogen CHP fuel cells develop and penetrate into the domestic, commercial, public and industrial sectors.

Hydrogen production would occur at primarily centralised plant with a variety of technologies such as: fossil fuel reformation with CCS, electrolysis via nuclear and renewable generated electricity. Distribution would be either facilitated by investment in a hydrogen pipeline network or road/rail transportation and advanced storage techniques.

Variable renewable generation comes to dominate the electricity generation portfolio as Government subsidies and emission taxing make this the most economic option for generation companies. Offshore renewable generation is deployed primarily in the form of larger scale offshore wind in the Thames Estuary, Wash, Morecambe Bay etc. and large offshore wave and tidal developments located on the North and West Coasts of Scotland primarily with some development around Devon and Cornwall. Significant amounts of onshore windfarms would be located primarily in Scotland, Wales, Cornwall and the East Coast.

Public bodies (schools, hospitals, council offices) are likely to have H2 CHP and possibly wind and solar renewable sources that provide a largely self sufficient energy resource matching Government expectations for public bodies to lead in energy efficiency and self-generation. Industrial consumers will be similar but may have larger generation sources serving multiple factories – Power Parks.
The penetration of Hydrogen as an energy source will also extend to the domestic sector either via local CHP services provided by a 3rd party or via the adoption of micro CHP hydrogen fuel cells.

Gas will remain an important fuel in the short term and may initially be the preferred fuel source for CHP. This will migrate to hydrogen as Government policy makes an impact and fuel cells start to penetrate. Should domestic CHP not be available, space and water heating will migrate from gas to local CHP providers or network supplied electricity.

Demand will be significantly affected by the hydrogen economy and the Government promotion of energy efficiency and demand management schemes.

Although consumers would be primarily active due to their environmental concern, given the Government support for environmental protection measures, there will also be an economic driver for consumers adopting low, clean energy practices. The Government investment in a hydrogen economy would be welcomed and new practices adopted readily by consumers.

The majority of domestic consumers will respond positively to Government initiatives that push the efficiency agenda and mandate smart meters to encourage/empower consumers to regulate demand. This strong lead from government would parallel EU wide policy and overcome initial ambiguity on where responsibility for smart meter deployment lay. By 2050 everyone is likely to have a smart meter networked via advanced ICT technology that will have become the standard communications network service provided to most homes. DSM for the domestic consumer will be in response to mandated roll out of smart meters and energy efficiency targets. A dynamic/automated approach to DSM within commercial agreement with their electricity supplier/local network operator would be welcomed especially if it was recognized as a means of facilitating intermittent renewable generation. This approach could be supported by Government imposed standards for domestic appliances that align with smart meter use.

The penetration of H2 micro CHP into the domestic sector will heavily influence energy use. If domestic self generation were to become common, a culture of self sufficiency could emerge, where the individuals H2 supply becomes the primary energy concern and demand for network supplied electricity would decrease.

Within the domestic consumer sector, population growth, increased affluence and associated growth in dwellings would seem to indicate increasing levels of demand. However, the Government action on energy efficiency and the hydrogen economy would reduce the demand for network supplied electricity.

The larger public and industrial consumers would participate in DSM schemes similar in form to the existing commercial agreements with the transmission system operator to limit demand at certain peak times, and be available for stepped or emergency load shedding. As H2 CHP and self generation becomes common these larger consumers will have a focus on self-sufficiency but will still have a grid connection and will want an import/export capability. The export capability of these consumers could become quite significant and the dual generator/load nature becomes a significant challenge for the network operators. The level of motivation to export will depend on the balance of market based incentives for consumers to actively trade energy against targets and mandates to be energy self-sufficient and carbon neutral.

For consumers with fuel cell CHP capability, a new factor may emerge in DSM. It could potentially incorporate on-site H2 production where in times of low demand, excess renewable generation on the grid could be used to produce H2 for later use. This could become an important feature of matching supply to demand.

7.4 *'Dynamic Green Markets'*

'Dynamic Green Markets': Active Consumers, Acute Environmental Concern, Market Led Institutional Governance.

- The belief persists that markets are best placed to service consumer demands at the same time as meeting external needs such as tackling environmental issues. Active consumers operate within widespread liberal markets.
- Global action to reduce fossil fuel emissions creates strong incentives for low carbon energy via a firm carbon price and efficient carbon markets.
- Active and concerned consumers radically change their approach to energy and become much more participatory in their energy provision. They are driven by the twin desires to be served at competitive prices and service levels while addressing their desire to have a benign impact on the environment.
- Markets respond to the new demands of consumers and, with supportive frameworks and incentives from Government, broadly liberal, free markets rise to the challenges of economic energy supplies with low environmental impacts
- Renewable generation is prominent and there are relatively high volumes of microgeneration creating the potential for a radically reformed electricity market with diverse types of generation.

In this scenario consumers become much more participatory in their energy provision. Twin desires to be served at competitive prices and service levels while having a benign impact on the environment might seem contradictory, however consumers actively try to balance them by choosing economic energy services with low environmental impact. Active consumers and widespread liberal markets are enabled by a healthy economy with reasonable levels of growth (similar to long term averages for the GB economy). This scenario presents the biggest test for markets where they are challenged to deliver against both global good and local self-interest. Society recognises that perfect free market conditions do not exist but with the correct frameworks and incentives from Government broadly liberal, free markets can rise to the challenges of economic energy supplies with low environmental impacts.

7.4.1 Background

The background to this scenario has climate change developing to a serious degree leading up to 2050. Temperature increases and changed weather patterns become apparent and indisputably linked to GHG emissions. Global initiatives will be slow to reach full agreement and impose strong mandates on emissions. However, the current level of urgency will increase steadily and international agreements on emissions capping will be achieved in the medium term. OECD countries will take a lead in targeting emissions and moving away from fossil fuel. International agreements leading to firm carbon markets will allow the west to incentivise low carbon energy in developing countries. As the west develops technology and reduces cost, opportunities will arise for private companies to deploy this technology worldwide. The rapidly developing countries will recognise the long term insecurity and environmental issues of fossil fuel and start developing alternative fuel sources.

All of these factors mean climate change will be at the forefront of decision making for individuals, communities, private companies, public institutions and the Government in the UK. Other environmental issues such as the impact of network infrastructure also receive high levels of attention and will be taken into account when considering solutions to climate change issues. The balance between global and local environmental concern will be one of the defining elements of the development of electricity networks. There will be a strong perception that electricity generation sources should be environmentally friendly and energy efficiency is essential and a matter of national strategic importance. This will be delivered through markets with appropriate frameworks and bounds.

Although weather patterns will be notably altered the climate change effects will not be catastrophic. The general social structure of the country will not be hugely altered however, the environmental regulations and constraints on infrastructure development would be strongly influenced by environmental attitudes. Environmental concern will shape the market place which responds to consumer demands not only for energy at attractive prices but also for environmental acceptability and the ability for consumers to play their role in their energy and electricity supplies. Government will play a role by implementing policy that addresses market structures to ensure that barriers do not prevent the market responding to the environmental challenge.

Government will be responding to increasingly tough national targets for GHG emissions set in response to strong EU and global mandates. Policy would be directed towards achieving environmental targets and protecting consumers. There would still be regulation to oversee the operation of and to promote competition in the energy markets. The Government would identify areas of strategic importance such as electricity generation, transport and energy efficiency and set the market framework to provide incentives to overcome the natural barriers to desired developments in those areas and to promote growth according to their targets. This would not be in any way prescriptive and the market would be left to make its own choices within the soft boundaries set for the market by the Government. Moving energy generation and use in a new direction via newly structured markets would be part pull by private actors in those markets and part push by Government through setting market frameworks with targets, penalties and incentives. Emissions trading will develop and a firm price on carbon will be set with all sectors of the economy participating fully. The carbon market will penetrate to all levels of society and will incentivise consumers and industry to adopt low carbon technology and solutions. Private expenditure would fund extensive R&D and innovation for low carbon solutions to reduce the cost of meeting carbon reduction obligations. The outcomes of this innovation push will be seen in diverse, vibrant market offerings in energy services.

Planning approaches will be modified to address the demands of developing new generation, network upgrades, self generation capabilities, new building standards, improving efficiency of older buildings and transport systems among others. Planning policy will be developed to address the often conflicting objectives of speeding up decisions, reflecting local views and concerns, addressing environmental impacts, promoting competition and supplier/user negotiations and allowing quicker investment decisions. Streamlined planning processes will be introduced that achieve the above and have set decision timescales. This may involve incorporating independent public representation into planning decisions and avoiding the need for lengthy public enquiries. There will be a focus on user engagement and competitive tendering for new investments and substantial refurbishments. Planning decision making will be primarily at a regional level (since this is seen as the most effective way of delivering large scale changes and addressing a more active citizenship) with significant devolved power and planning policy that may vary significantly between regions.

The increased regionalisation of planning may result in difficulties in planning for long distance transmission links. Innovative solutions such as HVDC using existing routes and off shore North-South connectors may be a product of this. The decision on which infrastructure to use in terms of overhead lines vs undergrounding, and switchgear etc will involve user engagement and competitive tendering on a regional level.

The economic environment would be healthy enough to provide investors with the confidence necessary for new markets to develop amid innovation and entrepreneurialism. There would be low levels of uncertainty as a result of stable carbon trading prices and hence lower levels of uncertainty in the projected returns from investment and this encourages the private market players to lead in the development of new technology and solutions. Investment decisions taken by individual companies will be based on the projected return to shareholders so shorter term thinking and planning is evident in the market. However, the return to shareholders will be influenced by the incentives and penalties used in developing the market along environmental lines. Although there is a broadly liberal market structure, there will be some elements of intervention to encourage markets in new energy technology to develop. This is expected to be fairly limited though and as change gathers pace, new markets will develop naturally through innovation and entrepreneurialism. The market will respond to demands for environmentally friendly, keenly priced goods and services on the one hand but also be constrained by legislation and regulation to maintain momentum in addressing the acute environmental concerns. Investment in the electricity industry and networks specifically will become a less centrally planned process with increased competitive tendering and negotiated contracts between buyers and sellers of network services.

Interconnectors would be developed strongly as private assets owned by transmission companies to allow international electricity trading as consistent with a market led future. This would be done to promote European wide liberal markets and address issues on security of supply.

Consumer spending remains fairly constant as financially comfortable consumers invest in energy efficient products, self generation and new transport methods. Consumers will see long term economic benefits in new technology and energy solutions and have the financial means and confidence to provide the initial investment. They will not be averse to bearing some cost for new development in line with their objectives of high level of competitiveness in service and low environmental impact.

7.4.2 Energy

Society in general will become more and more environmentally conscious; energy efficiency will become more and more of a priority in all areas of life. Leisure activities and consumer preferences will be influenced by environmental attitudes. Attitudes towards transport and housing will reflect this. Consumers will desire energy efficient housing and business will likewise seek opportunities to continue migrating towards more efficient buildings and processes. Consumers will be prepared to modify their lifestyles to match their desire to be both economic and environmentally benign. More value will be placed on smaller, modern, energy efficient housing and older housing would be modified substantially for energy efficiency to attract buyers. In general there would be a greater turnover of housing stock with moves towards more energy efficient properties.

It is likely that the environment will be a stronger motivation for individual and public consumers with economics the stronger motivation for commercial and industrial consumers. This combines to produce a consumer population who strongly desire price competitiveness and environmental protection.

Attitudes to transport would change and use of public transport would be more common for longer journeys and commuting. Private car use will still be widespread, mainly used for shorter leisure journeys. Transport migrates towards electric power in this scenario. Hybrid electric vehicles will be the initial preferred choice moving to fully electrified vehicles by 2050. This is driven by a consumer desire for clean transport and market provision but this is supported by government led frameworks for the introduction of electric vehicles. Initially the pressure for efficiency and emission reductions sees high growth in electric hybrid vehicles, as stated above. The efficiencies in these new vehicles (and an assumed low carbon electricity generation fleet) help hit CO2 targets in the shorter term and are achieved with the support of the respective industries as they diversify to protect revenue and meet the environmental challenge. Home charging of electric vehicles could become common creating a new source of electricity demand. Electrified rail transport will become widely used and will be a booming market, especially for longer journeys and commuting. Buses will also become more and more widely used in urban areas. Alternative fuels will develop for buses, potentially biofuel and niche applications of hydrogen. The market will lead these developments by responding to consumer demand and Government prompting.

Flexible working will become more common as home telecommunications advance and virtual offices materialise. In industry, policy on estate and working practices will be heavily influenced by energy considerations. Availability of large energy efficient buildings with a local CHP source would be weighed against large numbers of home workers and the increased home energy use. Voluntary Corporate and Social Responsibility (CSR) policy would aim for energy efficiency. Energy efficiency standards of buildings (domestic and industrial) would be slower to improve without strong Government mandate and would be constrained by natural lifecycles and financial appraisal. Voluntary codes formed by builders and property developers for sustainable homes are not mandatory but the Government does have strong mandates for information on energy matters in buildings for buyers.

The majority of consumers would be actively looking for ways to implement energy efficiency. They would also desire that those agencies that serve and represent them also work to minimise environmental impact. Consumer demand creates diverse market opportunities which are assisted by Government promotion of energy efficiency and the introduction of strong environmentally targeted supply and demand side targets and incentives. As described above, these targets and incentives plus the influence of a carbon market induces consumers and industry to adopt low carbon technology and solutions.

These factors highly influence the type of generation that attracts investment and the consumer demand profiles that generation must serve.

Generation is almost exclusively low carbon due to the above influences. The market pressures on generation companies will create a strong focus on the deployment of renewable generation which is often of a distributed nature. Any centralised generation will be either large-scale off shore renewables, Nuclear or fossil-fuel with CCS. Fossil fuel CCS development would primarily be in the south in suitable locations for the transport of the primary fuel. New nuclear plant would be developed near existing plant locations. Offshore renewable generation would primarily be larger scale offshore wind in the Thames Estuary, Wash, Morecambe Bay etc. and large offshore wave and tidal developments located on the North and West Coasts of Scotland primarily with some development around Devon and Cornwall. Significant amounts of onshore windfarms would be located primarily in Scotland, Wales, Cornwall and the East Coast.

Within the domestic sector there could be widespread deployment of micro CHP and renewable micro generation. Public bodies (schools, hospitals, council offices) may have developed CHP, storage and renewable energy sources that provide a largely self sufficient energy resource. Industrial consumers could be similar but may have larger generation sources serving multiple factories – Power Parks. In certain settings these institutions will be central players in community energy solutions, possibly trading within a local microgrid[1]. Many companies would service consumer demands for a variety of self generation technologies and products.

Active consumers will be motivated to develop their own supply of energy and the capacity to grow their demand for energy without purchasing from the market as this may be restricted by DSM schemes and possible carbon market penalties for unconstrained energy demand growth. Consumers will also be using storage technology to promote self sufficiency with the option of generating their own power or using stored energy. The potential to export low carbon energy and be rewarded fairly by the market would be additional motivation to develop self generation technology. As this consumer belief and behaviour develops and innovative markets emerge and mature, consumers could see economic benefits from their activity in their energy supplies and their initial environmental motivation would be reinforced by economic motivation.

Gas is likely to remain an important fuel in the short to medium term and would be used for space and water heating, increasingly in the form of CHP. Biomass will gradually replace Gas as a CHP fuel due to environmental and security of supply reasons. There is likely to be continued use of CCGT in the short/medium term and this may continue with CCS in the long term. Hydrogen does not develop greatly in this scenario as a result of substantial barriers to the development of a hydrogen market such as a lack of end use technology, social acceptance and the necessary infrastructure requirements. Hence, there are no strong interactions with the electricity network. Biofuels are transported only locally and so have little substitution effect on electricity networks.

[1] Microgrid: small scale, mainly autonomous but still grid connected power system with demand, energy storage and generation resources and advanced controls to operate the system against objectives.

Demand will be significantly affected by the high levels of efficiency in consumer energy use and their willingness to participate in DSM schemes.

In industry, electricity will continue to be the main source of energy and economic growth will correlate to a growth in energy requirements. Public bodies and Industrial consumers will initially participate in DSM in the form of existing commercial agreements with transmission system operator to limit demand at certain peak times. By 2050 the contracts that cover this would have developed to see such peak management as a more routine rather than an exceptional occurrence, and be available for stepped or emergency load shedding.

The commercial and public sector energy service demands continue to grow but with the national move for economic and environmentally led activity by consumers of all types this overall demand for energy services will be met by more efficient processes and behaviours leading to an overall status-quo in energy consumption.

Characterising features of the domestic consumer sector will be population growth, increased affluence and associated growth in dwellings and electronic consumables. The advent of home charged Electric Vehicles will create a new demand source. These features indicate a significant growth in demand, however the stringent energy efficiency measures of this scenario limit the net growth in demand. As noted above, it is likely that the majority of space and water heating would be served by either micro or local CHP. The overall result is that many domestic energy consumers could become largely self sufficient, using CHP for heating and reducing electricity take from the network through efficiency measures and self generation.

Electricity metering will be a dynamic real time process (on half-hourly settlement or even lower resolution), providing advanced levels of information, allowing informed decision making and facilitating various innovative markets such as managed demand, energy consumption capping and scheduling energy use to periods of low prices or high renewables availability. Consumers could make real time decisions to export excess energy depending on the price available from the local/national network. This could potentially be automated or a managed service from an ESCO. Domestic consumers will use the advanced levels of information and advanced control technologies to make better decisions on when to use electricity and how best to participate in dynamic local markets. This will result in behavioural DSM and peak smoothing. Automated systems for appropriate domestic appliances may be in place where the system operator has an agreed contract to monitor requirements and balance demand in specific local areas.

7.5 *'Reactive Approach'*

'Reactive Approach': Increased Environmental Concern but never quite acute. Fluctuating Institutional Governance and Consumer Activity.

- There is a pervasive feeling of uncertainty and a resulting ambiguity within society towards environmental issues and the influence this has on energy infrastructure development. Environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental observations and reports/statistics.
- A lack of global consensus on environmental issues contributes to the uncertainty regarding environmental action.
- There are various market led and Government led approaches pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of fuel supplies and immediate economic concerns.
- Differing attitudes towards energy consumption develop among consumers resulting in varied types and levels of consumer participation depending on the geographic area, social demographics and services provided by energy companies.
- There are many types of generation in the national portfolio with centralised thermal generation and offshore renewables both prominent groupings. Combined heat and power and microgeneration are deployed in areas with the right mix of public investment, services from energy companies and demand from consumers.
- There is a strong potential for stranded assets and investment redundancy in the power sector.

The defining feature of this scenario is the pervasive feeling of uncertainty of society towards environmental issues. Environmental concern increases but never quite reaches a point that could be called acute. The uncertainty in this area creates a fluctuating level of concern and associated response from Government and consumers. This leads to various market led and Government led approaches being pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of supply and the immediate economic concerns. The result is a lack of continuity and no long term strategic approach.

7.5.1 Background

The international situation will be an underlying cause of GB's inconsistent direction as increasing environmental concern does not force a consensus approach. Although all countries agree action must be taken, what form this should take will be the subject of strong debate. International treaties will be undermined by fluctuating national policies and approaches. Several OECD countries take different directions leading to a wide variety of approaches and technological solutions. In the EU, member states will pursue a personal agenda and EU wide policy would fail to materialise. The lack of focused development in alternative energy sources will result in periods of greater dependence on imported gas and nuclear fuel. As a result, although progress will be made with emissions targets they will not be met and global climate change develops to a significant degree. Some dramatic and concerning effects will materialise, however there is debate over the likelihood of further, more disastrous impact. The result will be a range of conflicting attitudes within various sections of society and although on the whole there would be a significant level of concern, a "tipping point" where society as a whole has an acute level of concern will not be reached. There will be acknowledgement that the environment is important and should be protected, however opinions on how this can best be achieved will be mixed and short term approaches in one direction often lack commitment and would quickly be replaced by another approach. The fluctuating attitudes within society will also apply to other environmental issues affecting networks. Significant infrastructure developments will be approved or opposed depending on the attitudes of society and Government at the time that proposals for developments are brought forward.

Government would be responding in a reactive manner to changeable international influences and this will affect the clarity of long term policy. Successive administrations will take diverse approaches to achieving environmental targets and attitudes to markets and regulation will reflect this. Significant sources of emissions such as electricity generation and transport and other measures such as energy efficiency will receive intense focus in relation to the policy of the time. Although the prevailing approach is that of liberal markets, instances of strong intervention will occur where heavy subsidies and taxes are used to drive through specific policies but such initiatives and interventions will usually not be sustained over time. By 2050 this has created widespread uncertainty in the energy sector which translates into attitudes of scepticism and even antagonism from private actors in the market towards the latest policy measures. The lack of long term vision and strategic planning results in a variety of technologies and solutions being deployed with varying degrees of success.

In a fluctuating scenario where environmental concern does not reach a "tipping point" and Government policy swings with successive administrations, consumers will suffer an element of confusion and policy fatigue. There is likely to be a range of conflicting messages creating uncertainty on priorities and the actual impact that any consumer action would actually have. Doubts over the contribution from other individuals, businesses and Government may create a "drop in the ocean" perception. There will be information gaps for consumers, and it will be difficult to weigh costs and benefits of different courses of action. Also, most people will find it hard to make rational choices given the level of uncertainty and the perception that consequences are far in the future.

Consumers will be concerned about a sustainable future and some will have become active at various times in response to a particular policy. However, the fluctuating policies and lack of critical momentum on the environmental front will have prevented consumer activity becoming a strong influencing force.

Carbon reduction policies including emissions capping and trading would also suffer from short term approaches with regular chop and change approaches preventing any mechanism from gathering momentum. The fluctuating nature of Government policy will be partly driven by periods of high anxiety regarding emissions targets. The challenging targets of today will remain and as a succession of approaches only have limited impact before they are replaced, concern over reaching targets will increase. This results in increasingly serious measures as 2050 approaches. These include, carbon limits for participants in different sectors with high penalties for breaching limits and event rationing of energy use.

The economic situation would suffer under these circumstances as the uncertainty and lack of direction in the energy sector unsettles other areas of industry and commerce. Concerns over security, quality and reliability will grow. Businesses will feel pulled in several different directions regarding their energy requirements as long term costs for both traditional energy supply and renewable or CHP generation will be unpredictable due to the uncertainty surrounding fuel costs, emission targets and subsidies. There would be a lack of investor confidence by 2050 as projected returns would be difficult to predict in the changeable political environment. Despite being initially amenable to increased spending that resulted in environmental benefit or potential long term economic benefit, consumers will become disillusioned by policy inconsistency and increasingly reluctant to bear the cost of any policy related spending. This will apply to both taxation to finance public spending and cost recovery through energy billing.

Investment will either be publicly funded or prompted by Government policy depending on the preferred approach of the time. By 2050 investment is increasingly public sourced as private investors are discouraged by the level of uncertainty. Decision making will lack a long term vision and will tend to focus on addressing perceived failures of recent policy and achieving political commitments for short term gain.

Planning approaches will be unclear and laborious. Continuous change to priorities and process will create inefficiency and a lack of clarity for both planning authorities and applicants. This will result in lengthy delays within the planning application processes and a bottleneck for new developments. There will be regular public protests and protracted consultations with local pressure groups taking a leading role as a result of a lack of coherent strategy to address concern and gain local buy-in. These issues will create uncertainty in the private sector that stifles investment in network infrastructure and new generation plant. Infrastructure developments requiring a long term strategy and substantial financial support such as HVDC and offshore connectors will be mooted at certain times but there would be a lack of the required commitment to see them implemented fully. There may be periods of intense infrastructure development but not against a clear long term vision and this leads to disjointed infrastructure with various different technologies preferred at different times and regional differences in capability.

International interconnectors would not be developed to a significant degree past current capability as long term planning to justify such an investment would not be in place. Also the lack of coherent EU direction will create uncertainty on the long term use of interconnectors.

7.5.2 Energy

Society in general will become more environmentally aware but in a slightly inconsistent manner. In the lead up to 2050 there will be periods of strong environmental activity in response to information campaigns and energy efficiency policy from Government. However these periods will not last long enough to build enough momentum to create a truly environmentally focused society. By 2050 a sense of frustration will have developed at the perceived constant “changing of the goal posts”. Leisure activities will be influenced by a general desire to be “green”. Attitudes towards transport and travel will include strong desire to have a benign environmental impact, however this will be countered by confusion over appropriate action and a perceived lack of choice. In addition, sections of the populace do not become environmentally active at all. There will be varied attitudes towards housing and home energy efficiency. Various spells of focus on home efficiency will result in sections of the housing stock becoming more energy efficient. New housing especially will have greatly improved efficiency as once improved standards have been implemented they will stay part of accepted practice. Modifications to older housing will vary as available incentives for improved efficiency measures and use of energy efficiency based tax at point of sale fluctuate with Government policy.

Attitudes to transport will also fluctuate with trends moving towards public transport when periods of investment occur and gravitating back to private car use as schemes flounder due to redirection of investment. A generally positive attitude towards the use of public transport will be frustrated by the lack of consistent infrastructure investment. This only serves to amplify difficulties in effecting change in the transport area due to the habitual nature of people. Hence by 2050, transport patterns are still dominated by private cars. Pilot schemes for alternative fuels such as hydrogen and bio diesel are common in fleet vehicles and see some success in regional deployments. Hydrogen as a replacement for fossil fuel in transport fails to make further impact beyond pilot schemes due to a lack of consistent political will. Private cars will predominately remain fossil fuelled although efficiency will be improved and hybrid electric vehicles will slowly penetrate the market providing much improved vehicle emissions levels. The move towards efficiency and hybrid vehicles will be a product of the motor industry responding to the levels of environmental concern within society rather than consistent political approaches. There are sporadic periods of policy support in this area but the key driver will be consumer demand. This demand comes from consumer desire to reduce emissions through travel and a lack of viable public transport alternatives. Rail transport will become fully electrically powered and the rail network is substantially developed as the technology is developed and deployed and is heavily invested in during the early attempts to reduce emissions.

Flexible working will become more common as home telecommunications advance and virtual offices materialise. In industry, policy on estate and working practices will be heavily influenced by energy. Employers will respond to Government policy of the day and will utilise flexible working practises to minimise cost either from standard energy supply costs or Government incentives. The relative cost of an employee working from home or in an office park will depend on the availability of large energy efficient buildings (with CHP) and home energy efficiency in addition to energy costs for different types of buildings/locations. The way that home working is incentivised through remuneration, home infrastructure development, travel allowances and company financial, energy and carbon accounting will vary depending on the vision and resources of different companies.

The variety of policies and approaches towards energy supply will result in extremely varied generation mix. Generation development will see at various points a focus on centralised fossil (with and without CCS), nuclear, large off shore renewable deployments, onshore renewables (wind farms and gas/biomass CHP) and domestic self generation. A proportion of this generation would become redundant or suboptimal as the role it played is fulfilled by the subsequently preferred technology. However, there would also be a desire to maximise return in investment and where the plant/infrastructure has been privately funded, the generator would be kept active and producing as long as the market makes it economical.

The location of generating plant will be distributed all over the country reflecting the varied technology and primary fuel source. i.e. centralised in the south, offshore renewables around Scotland/Irish Sea/East Anglia, windfarms in Scotland, biomass CHP in rural communities.

Small amounts of consumers will have installed CHP and self-generation at times of policy focus in this area, other consumers will still have traditional natural gas fired central heating and grid supplied electricity. Community scale CHP will have been deployed in some locations – most likely in new housing developments and Power Parks. Other regional areas may have high quantities of renewable DG which meet considerable quantities of local electricity demand. All of these generation technologies will be deployed on a highly locality specific basis as policy and strategy for particular solutions saw most success in the localities best equipped for early adoption of that technology. Large amounts of centralised generation would also be required as the deployments of more distributed generation only meets a moderate overall portion of demand. The mix of strategies and technologies in these specific areas will lead to more complex management and trading issues.

Public bodies (schools, hospitals, council offices) are likely to have CHP and renewable sources that provide a largely self sufficient energy resource and this is due to a period of public policy where Government prompts public bodies to lead in energy efficiency and self-generation. Industrial consumers will not have the same penetration of self generation capability as uncertainty over Government policy will mean reluctance to invest. However, CHP and the use of on site renewable self generation would feature to a small extent in this sector where brief spurts of investment occur in response to various Government incentives. Natural gas will continue to be a significant primary fuel source and will be used for CHP and CCGT based electricity generation. CCGT will still be an important element of the generation mix and periods of sustained new build would occur to maintain the proportion of gas fuelled thermal generation or when new demand requires.

There will be an overall growth in demand and peak load will still be significantly greater than base as a result of the lack of coordinated, concerted management of demand. However, behind the overall picture there will be major variations in demand profile between regions and population sectors. Certain sections of the population will have responded positively will still be locked into efficiency and DSM schemes introduced over the years. The penetration of DSM will depend on the social characteristics of that population sector and also the services provided by their supply company/DNO (smart meters). I.e. not everyone will get smart meters and from those that do, not everyone will desire/be empowered to use them or even continue to use them once the focus has gone elsewhere[2]. Hence within an urban area there could be sections of smooth, low demand and sections with peaky, high demand. Also, there will be rural areas that become largely independent and manage their own demand around a local CHP/DG

[2] There is good evidence that continued DSM participation requires continued marketing and management by the DSM operator.

resource, possibly in conjunction with an ESCO. These areas will also still require a grid connection and will need to be appropriately managed. There could be a large degree of disparity between some types of consumers with a possible eventuality being those with self-generation or a community scheme linked into a good cheap supply while those dependent on the central system at the mercy of the growing expense of the stranded assets and poor coordination.

In industry, electricity will be the main source of energy and this industrial demand will be a significant area of growing demand for electricity. The commercial and public sector energy service demands will continue to grow and are only marginally tempered by environmentally focused initiatives taken by consumers.

The larger public and industrial consumers would participate in DSM schemes, similar in form to the existing commercial agreements with the national system operator at present, to limit demand at certain peak times, and be available for stepped or emergency load shedding. Where self generation is deployed by public bodies, DSM will become more sophisticated with energy storage playing a role in smoothing on-site demand. There may be an interactive element to this on-site energy management where the system operator can see the current generation output and level of stored energy available and alter national level supplies in accordance with pre-agreed contracts. Such larger consumers will have a grid connection but will focus on self sufficiency rather than any significant export capability.

The uncertainty of long term strategy would prevent any major changes in the structure of the electricity sector. Some ESCO type organizations may emerge and provide community CHP schemes, however the structure of supply companies, DNOs and TOs is likely to prevail. These companies would be conservative in approach and respond to latest policy with least cost in mind, avoiding long term investment and maximising the use of existing assets unless the Government subsidised or allowed significant investment with cost recovery from consumers.

8 Energy Scenarios to Network Scenarios

Each of the five energy scenarios described in the previous section provides a detailed narrative describing the interactions of the chosen themes. The narratives explore and develop the implications of these interactions and use qualitative descriptions to depict the plausible circumstances within which networks will need to operate in 2050. These narratives are shaped by the critical uncertainties contained within the chosen themes and draw on the high level inputs identified in Section 4 to provide a rich textual description of the influences for future GB networks. Each energy scenario could indeed be thought of as a possible "context" for future GB power networks.

The high level "context" nature of these energy scenarios means that there is not necessarily a direct mapping between the detail of the energy scenario and a specific network feature. For example, it is conceivable that more than one type of generation portfolio could fit within the context described by a particular energy scenario and therefore more than one potential future network that would fit with those different generation portfolios. A process is therefore required to achieve the ultimate aim of the project and develop long term electricity network scenarios.

8.1 Network Parameters

In order to identify the numerous potential network scenarios that may exist within each energy scenario, a method of describing the network scenarios at a sufficiently detailed yet high level was required. The approach taken was to identify a set of key network uncertainties or "parameters" that once established could be used to categorise potential network scenarios.

After a review of several relevant, current literature sources (e.g. The IET Technical Architecture project final report [8] and the EU Smart Grids Technology Platform vision [9] and strategic research agenda [10]) and the network specific inputs identified in Section 4, a series of workshop discussions within the project team identified a list of network dimensions and metrics. The detail of the potential parameters considered and the rationale for the chosen parameters is contained in Appendix D.

As a result of that exercise a consolidated list of potential network parameters emerged:

- Primary role of transmission network

- Primary role of distribution network
- Size of transmission network
- Size of distribution network
- Scale and location of generation
- Local, regional and national coordination
- Network reliability
- Network security and redundancy
- Technology and innovation in networks
- Role of active management
- Demand and generation variability and correlation
- Power flow magnitude and direction
- Size of electricity role in energy sector
  Role of enhanced pervasive communications in network operations
- Complexity of network
- Network safety
  Manual or automated operational regime

The level of detail contained within this list was deemed useful for developing the detailed content of the network scenarios but too detailed/complex for a useful mapping exercise.

After an iterative review process, the concept of "network role", originally proposed as a scenario theme, was proposed as a title that could encompass the functional requirements and desired performance of the network.

It was proposed that under the umbrella of network role, a set of parameters should be defined, influenced by the above list, that would identify the functional requirements of transmission and distribution networks and the desired performance of the system in a way that allowed a high level comparison of potential scenarios.

As this exercise progressed it quickly became clear that the network role could be described in a variety of ways but was always dependant on the key elements of generation, demand and performance. Therefore, a set of parameters that describe the generation, demand and quality profiles to be served by the network were defined. These parameters are set out and developed below.

- ***Large scale, central, dispatchable output generation***. This parameter describes the extent to which the network must accommodate large scale centralised generation of the form dominant in the 1980s, 1990s and early 2000s such as nuclear, coal and natural gas fuelled sets. Unit sizes are typically in the 100s of MW and station sizes often in the high 100s MW and GW range. This generation is also characterised by its ability to be dispatched and controlled without constraint from the primary fuel source.

In addition the transportation networks for the primary fuel allow siting of such generation relatively close to electricity demands.

- ***Large scale, renewable, variable output generation***. This parameter describes the extent to which the network is required to accommodate large power stations based on renewable energy technologies with variable availability fuel sources. The scale of such generation developments would be in the many 10s MW, several 100s MW or even GW range of capacity. The technologies would include onshore and offshore wind power but also other marine sources in the future. Such power production facilities would be characterised by their variability of power output, their often peripheral geographical locations (relative to demand) and the alternative generator types (incorporating asynchronous generation and the use of power electronics).

- ***Distributed, self generation.*** This parameter describes power generation sized to match on-site electrical demands with the main purpose of providing an alternative to grid import power. At a domestic level the generation would be at a few kW scale and might include micro-combined heat and power (CHP) and solar energy. At a community level the generation would include larger CHP units and community wind power. In a commercial and industrial setting the idea of power parks providing on-site power generation to supply local business needs would be prevalent. This type of generation is therefore characterised by its extremely close proximity to demand and its relatively small capacity matching local demand.

- ***Distributed, dispatchable, merchant generation.*** This parameter describes the extent of generation that is situated within lower voltage power networks but whose primary aim is to maximise export of energy from the generation station into power networks connecting the generation to consumers. The generation is characterised by its relatively small scale (up to a few 10s MW but potentially quite small), its electrical connection to what are currently power networks optimised for distribution of energy to consumers and the dispatchability of the generation units. Generation technologies that might fill this role are biomass and natural gas fired combined heat and power.

- ***Distributed variable output, merchant generation***. This parameter describes the amount of power generation that is connected to the distribution networks and is variable (non-dispatchable) in the nature of its power output characteristic. In addition, the generation is operated for the purposes of sale of export energy (as opposed to being primarily for on-site needs). Technologies of generation that would likely fit into this category are marine, wind and solar and in scales from kWs to a few 10s MW.

- ***Demand magnitude:*** This parameter describes the relative level of demand for electrical energy. This is an aggregated parameter for all demand types but can be disaggregated by geography and demand type within the context of a given scenario.

- ***Demand profile management***. This parameter describes the extent to which demand is managed by consumers or their agents. The parameter is relative in nature and simply describes whether demand profile management is low to high.

- ***Supply quality responsibility.*** This parameter describes who takes responsibility for the provision of supply quality within a scenario. A trend towards demand for higher quality supply is assumed given the existing and future uses of power in a digital age. It is assumed that either the consumer takes more responsibility for their supply quality or that the responsibility resides with third parties (network operator or other).

The end result of this analysis of potential network parameters is therefore a list of eight high level headings that capture the varied types of generation that could be deployed, the basic demand characteristics and an indication of where responsibility for supply quality lies.

These eight parameters allow a high level definition of the requirements placed on the network and from there the implied role of the network can be extracted.

8.2 Network parameter mapping

The next step towards draft network scenarios requires mapping the network parameters against the energy scenarios to explore the different options that existed within each of the energy scenarios. As outlined in Figure 9 below the process expects *N* possible network scenarios from the five energy scenarios. These *N* network scenarios are rationalized to a set of *M* possible network scenarios, (ideally between four and six for practicality) that are developed further into draft network scenarios.

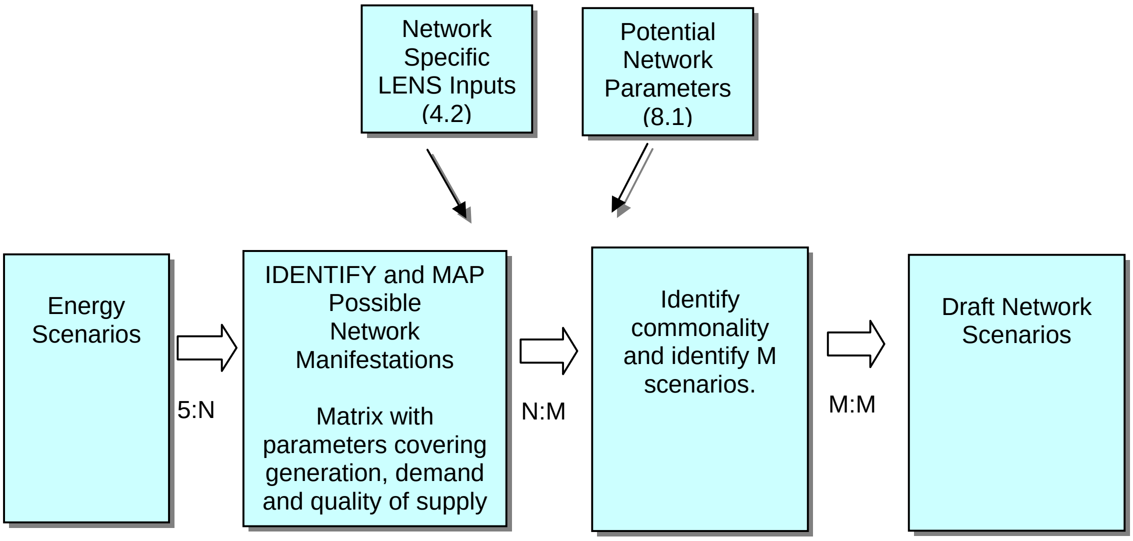


Figure 9: Mapping and development process from energy scenarios to network scenarios.

The matrix below (Table 3) details the *5:N* energy scenarios to possible network scenarios mapping process.

Energy Scenarios		Large scale, dispatchable central, (conventional) generation	Large scale renewable, variable output, peripheral generation	Distributed, self generation (microgrids, power parks, community CHP, micro-domestic)	Distributed, dispatchable, merchant generation	Distributed variable output, merchant generation	Electricity Demand magnitude	Demand profile management	Supply quality responsibility (consumer self-managed or 3rd party)
A Switch me on	A1	High	Low	Low	Low	Low	High	No	3rd party
	A2	High	High	Low	Low	Low	High	No	3rd party
	A3	High	High	Low	Low	High	High	Yes	3rd party
B Fix it for me	B1	High	High	Low	Low	High	High	No	3rd party
	B2	High	High	High	Low	Low	High	Yes	3rd party
	B3	Low	High	High	Low	High	High	Yes	3rd party
Ci Government green agenda	Ci1	Low	High	High	Low	High	Low	Yes	3rd party
	Ci2	Low	Low	High	Low	High	Low	Yes	Self
Cm Dynamic green markets	Cm1	High	High	Low	Low	High	Low	Yes	3rd party
	Cm2	Low	Low	High	High	High	Low	Yes	Self
	Cm3	Low	Low	High	Low	High	Low	Yes	Self
D Reactive approach		High	High	High	High	High	High	Yes	Both

Table 3: Energy scenarios to network scenarios mapping

8.3 *Potential Network Scenarios*

The above matrix highlights the potential network scenarios arising from each energy scenario. The nine possibilities are summarized here and further justification behind each line of the matrix is described in the following sections.

A1 Wholly centralised large scale dispatchable generation with high demand and no demand management.

A2 Centralised large scale dispatchable generation and large scale renewables with high demand and no demand management.

A3 Both centralised large scale generation and distributed renewables with high demand and some demand management.

B1 Both centralised large scale generation and distributed renewables with high demand and no demand management.

B2 Centralised large scale generation plus ESCOs providing locally controlled generation. High demand and some demand management

B3 Large scale renewables and distributed renewables generation plus ESCOs providing locally controlled generation. High demand and some demand management.

Ci1 High penetration of offshore and onshore renewables plus local CHP schemes. Lower demand in conjunction with demand management.

Ci2 Highly distributed generation from onshore renewables and large amounts of microgeneration. Lower demand in conjunction with demand management.

Cm1 Both centralised large scale generation and distributed renewables with low demand via demand management.

Cm2 Highly distributed generation with very large amounts of microgeneration and some on shore renewables and dispatchable DG. Lower demand in conjunction with demand management.

Cm3 Highly distributed generation with very large amounts of microgeneration and some on shore renewables. Lower demand in conjunction with demand management.

D A widely varied mix of generation types. Both centralised and distributed generation play an important part in the generation portfolio. There is high demand with instances of demand management.

8.3.1 Scenario A (Switch me on)

Energy scenario A contains strong indications of centralised generation that satisfies high electricity demand arising from a backdrop of moderate environmental concern.

8.3.1.1 Scenarios A1 and A2

A1 and A2 capture the possibility of a purely centralised generation portfolio consisting of conventional large scale dispatchable generation and/or large scale offshore renewables as per existing plans. There would be high demand and no demand management schemes. As a result the Transmission network is responsible for bulk transfer from Generation to bulk Distribution and overall System Stability. Distribution is passive and serves to transfer power from Transmission to load. Reliability of the Transmission network is key and Distribution is a highly planned network providing similar reliability to today.

8.3.1.2 Scenario A3

A3 captures the possibility that within energy scenario A there could also be a significant amount of renewable DG deployed and some activity in basic demand management could emerge. Transmission would be responsible for bulk transfer from Generator to Distribution and overall System Stability. Distribution mainly serves to transfer power from Transmission to load but must also integrate large amounts of variable renewables. Transmission reliability is again highly important to ensure security of supply. Distribution is a highly planned network that must now cope with additional power flows from variable DG. Demand is managed through informed behaviour.

8.3.2 Scenario B (Fix it for me)

Energy scenario B centers around consumers with a “fix it for me” attitude. This places pressure on Government and the market to satisfy high levels of electricity demand whilst responding to acute environmental concerns.

8.3.2.1 Scenario B1

B1 is based on the premise that Government strongly promotes the low carbon generation technologies currently on the horizon. As such, a centralised generation portfolio consisting of large scale dispatchable generation (fossil fuel with CCS and Nuclear) and large deployments of renewables comes to pass. Both offshore wind/wave/tidal and onshore windfarms are common. There would be high demand and no demand management schemes.

Therefore, Transmission is responsible for bulk transfer from Generator to Distribution. Distribution mainly serves to transfer power from Transmission to load but must also integrate large amounts of variable renewables. Transmission reliability is again essential to system stability. Distribution is still highly planned but will need to become active in dealing with the high levels of variable DG connected.

8.3.2.2 Scenario B2 and B3

B2 explores the possibility of ESCOs responding to the consumer demands for services that reduce the impact of their high energy use. This is in addition to, and does not replace, centralised large scale dispatchable generation (fossil fuel with CCS and Nuclear) and large deployments of offshore renewables. B3 omits centralised dispatchable generation placing more emphasis on offshore and onshore renewables.

There is a high prominence of ESCOs managing small local areas of the low-level Distribution network with Gas/Bio CHP. The high-level Distribution network serves to transfer power from Transmission to ESCO connection points and non-ESCO loads. It also facilitates inter-ESCO transfers. System stability is now a wider concern balancing generation connected to all parts of the T&D networks. The prominence of ESCOs means availability of local generation that could be relied on in case of network failure and reduces network expansion requirements Demand is managed by ESCOs through behaviour and automation.

8.3.3 Scenario Ci (Government led green agenda)

Energy Scenario Ci features the strong promotion of renewable generation and the drive towards a hydrogen economy. This is strongly led by Government and welcomed by active consumers.

8.3.3.1 Scenario Ci1

In this scenario a large majority of generation occurs locally via H2 CHP schemes. This generation is supplemented by large offshore wind, wave and tidal deployments and onshore windfarms. Demand is managed by the behaviour of active consumers and automated systems.

Transmission has therefore a reduced role focusing on bulk transfer of offshore renewable generation to Distribution. There is a high prominence of H2 fuelled local CHP plants connected to the low-level Distribution network. The high-level Distribution network serves partly to transfer power from Transmission to load. It also integrates large amounts of variable renewables and the CHP mentioned above. System stability is now a wider concern balancing generation connected to all parts of the T&D networks. The prominence of H2 CHP plants means availability of local generation that could be relied on in case of network failure.

8.3.3.2 Scenario Ci2

Ci2 takes the distributed nature of generation a step further. Micro-generation via H2 CHP is very common in addition to the widespread deployment of local/community H2 CHP schemes. Although self-sufficiency becomes common, there is also additional generation from onshore windfarms.

Transmission has very little connected Generation and hence has a minimal role to facilitate any inter Distribution network transfers. The high level Distribution network serves to integrate variable renewables and facilitate transfer between generation connected to the low-level Distribution network which connects self-gen and local CHP. System stability is now focused on the Distribution network and the prominence of self gen and local CHP reduces reliance on network. Demand is managed around personal H2 supplies and availability of renewable electricity.

8.3.4 Scenario Cm (Dynamic green markets)

Energy scenario Cm suggests strong investment in low carbon generation ranging from clean fossil fuel generation through renewables to micro-generation. Demand management schemes are readily adopted by active consumers.

8.3.4.1 Scenario Cm1

In this scenario there is significant investment in a low carbon centralised generation portfolio consisting of large scale dispatchable generation (fossil fuel with CCS and Nuclear) and large deployments of renewables. Both offshore wind/wave/tidal schemes and onshore windfarms are common. Overall demand will be reduced by widespread efficiency programs and automated DSM schemes common.

Transmission is therefore responsible for bulk transfer from Generator to Distribution and overall System Stability. Distribution mainly serves to transfer power from Transmission to load but must also integrate large amounts of variable renewables. Distribution would be a more active network that must now cope with additional power flows from windfarm DG.

8.3.4.2 Scenarios Cm2 and Cm3

Cm2 and Cm3 consider the way the market might respond to highly active, environmentally concerned consumers. Self sufficiency becomes a common goal and microgeneration proliferates in the form of CHP and micro wind and solar generation. There is also additional generation from onshore windfarms and/or dispatchable distributed generation.

The result is that Transmission has very little connected Generation and would have a minimal role to facilitate any inter Distribution network transfers. The high level Distribution network serves to integrate dispatchable DG and variable DG. System stability is now focused on the Distribution network and it highly likely there will be microgrids that manage local stability and interact to achieve overall system stability.

8.3.5 Scenario D (Reactive approach)

Scenario D describes an extremely varied generation portfolio containing centralised fossil(with and without CCS), nuclear, large off shore renewable deployments, onshore renewables (wind farms and gas/biomass CHP) and domestic self generation.

Transmission will still have a role in the bulk transfer from Generator to Distribution. Distribution serves to transfer power from Transmission to load but the high-level Distribution network must also integrate large amounts of variable renewables and dispatchable DG. The low-level Distribution network connects local CHP and self-generation. System stability is a complex, balancing generation connected to all parts of the T&D networks. Areas/individuals with self-sufficiency will be equally as common as areas/individuals who completely rely/require security and quality from the network. Demand will be managed in some locations and not in others, depending on the supply company and the consumer attitudes.

8.4 Selecting Network Scenarios

Having at this stage produced nine potential network scenarios from the mapping exercise and briefly explored each option, it was recognized that there appeared to be similarities emerging in the results. It was also noted that the final product of a scenario planning exercise has maximum impact on a wide audience when it converges on a set of scenarios limited in number [6]. Therefore a rationalisation exercise was necessary to produce a manageable set of scenarios that represents the range of possibilities identified in the mapping exercise.

The discussion in section 8.3 highlights the implications for generation and demand and touches on the implicit roles for transmission and distribution in each of the potential scenarios. The similarities in the network roles are demonstrated in Table 4 below and further discussion follows in the subsequent sections.

Potential Network Scenario	**Transmission Network**	**Distribution Network**
A1	High levels of bulk transfer	Bulk transfer
A2	High levels of bulk transfer	Bulk transfer
A3	High levels of bulk transfer	Bulk transfer and DG integration
B1	High levels of bulk transfer	Bulk transfer and DG integration
B2	Low levels of bulk transfer	Some bulk transfer and ESCO integration
B3	Low levels of bulk transfer	Some bulk transfer and ESCO integration
Ci1	Bulk transfer for renewable resources	Integration of renewables and local CHP.
Ci2	Minimal role	Local balancing of DG
Cm1	Low levels of bulk transfer	Some bulk transfer and DG integration
Cm2	Minimal role	Local balancing of DG
Cm3	Minimal role	Local balancing of DG
D	Bulk transfer	Bulk transfer, integration and local balancing of DG

Table 4: Network roles under different potential network scenarios.

The following subsections further explore the similarities between the potential network scenarios and set out the resulting five scenarios that were developed into the full draft network scenarios. This step of consolidation is summarized in Table 5 below.

Network Scenario	Potential Scenarios
Big T&D	A1+A2+A3+B1
Energy Services Market Facilitation	Cm1+B2
Distribution System Operator (lean transmission)	Ci1+B3
Microgrids (Small Transmission and Distribution)	Ci2+Cm2+Cm3
Multi Purpose Networks	D

Table 5: Network scenario consolidation.

8.4.1 Big Transmission and Distribution

Scenarios A1, A2, A3 and B1 were deemed to contain strong similarities in their tendency for large scale centralised generation and large scale offshore renewables. There is high demand in all scenarios and either no or basic demand management. The strong implication from these scenarios is for increased requirement on the transmission and distribution networks.

8.4.2 Energy Services Market Facilitation

Scenarios Cm1, and B2 showed many similarities with an implied continued role for centralised generation and the associated requirement for transmission and distribution infrastructure. These scenarios both include a climate of market managed demand differing from the A1, A2 and B1 scenarios. There would be strong elements of DSM from either the network companies or the ESCOs which are a strong presence here. In addition to significant amounts of large scale centralised generation renewable DG also features strongly in Cm1, as does ESCO provided local CHP schemes in B2. These scenarios both then have similar requirements for transmission and distribution infrastructure.

8.4.3 Distribution System Operators (Lean Transmission)

This scenario comes primarily from scenario Ci1 with some influence from B3. A large amount of generation has moved to the local level and is supplemented by Offshore and Onshore renewables. This reduces the role of the Transmission network which only serves to connect the strategic and economic renewable resources in certain parts of the country.

8.4.4 Microgrids (Small Transmission and Distribution)

Scenarios Ci2 and Cm2 were both considered to display strong tendencies towards the self sufficiency of consumers. Self generation is prevalent via renewables and micro-CHP. The main other source of generation is local CHP schemes or variable renewable DG. The role for Transmission and bulk Distribution is vastly reduced and the local distribution network serves to balance local imbalances only.

8.4.5 Multi Purpose Networks

This scenario comes directly from scenario D where various policies have produced an extremely varied generation portfolio and approaches to demand management. The result is networks that fulfil a broad range of functions and that are to an extent over engineered, with an aspect of redundant capacity and capability.

9 Draft Network Scenarios

Based on the selected network scenario outlines presented in section 8.4, the network scenarios are now developed further.

9.1 'Big Transmission and Distribution'

'Big Transmission and Distribution'

- Transmission and distribution (T&D) infrastructure development and management continues largely as expected from today's patterns while expanding to meet growing energy demand and developing renewable generation deployment.
- Network capability enhancing technologies are deployed to meet the growing demands for network services arising from demand growth. The T&D infrastructure is developed with a focus on enhancing capability for integrating renewables at all levels (larger transmission connected renewable generation and smaller distribution connected renewable generation).
- The geographical reach of the transmission network is expanded to connect offshore and rural on-shore renewables sites and to provide interconnection with European mainland power systems.
- Moderate behaviour change by customers leads to little active demand management. Hence demand growth is unhindered and relatively unmanaged in an operational sense.
- Network companies continue to take the responsibility for providing security and quality of supply.

The key features of this scenario are represented graphically in Figure 10.

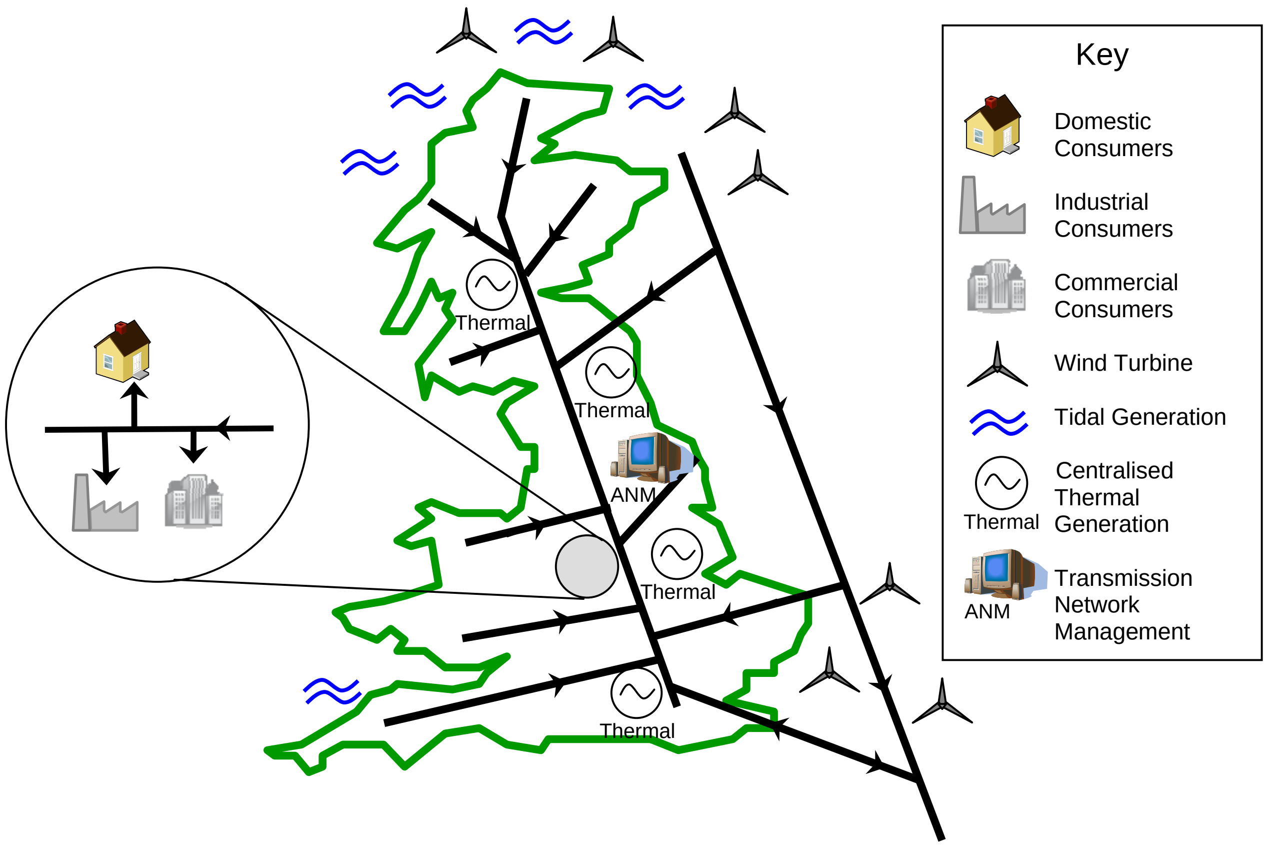


Figure 10: 'Big Transmission and Distribution' network scenario.

Transmission and distribution infrastructure development and management continues much as expected from today's patterns with growing requirement for networks as demand grows unhindered and relatively unmanaged operationally. T&D infrastructure capability development focuses on integrating renewables at all voltage levels (larger transmission connected and smaller distribution connected). It could be argued that this is very much the route down which the industry and much research and development are pointing at present.

Demand grows in line with long term trends (since it is relatively unmanaged) and there is resulting requirement for transmission and distribution systems of greater capability. New circuits and the deployment of technologies for increasing the capability of existing transmission corridors are common (e.g. power flow control devices based on power electronics and HVDC for enhancing transfer capacity on strategic north-south routes). In particular, the requirement for north to south transfer capability increases as renewables are deployed in the rural northern regions of the country and this gives rise to the need for new circuits and system capability enhancing technologies. In addition, offshore renewables developed in the seas around GB and renewable sources of power from northern Europe (particularly Iceland and Norway) use the upgraded transmission networks as a transit route to more southerly European countries. Innovation in transmission networks is geared towards increasing their capability and reliability. The continuing central role in system operations for transmission networks results in the development of extensive offshore grids and international interconnectors to facilitate the integration of large scale renewable generation.

The transmission network extends and increases its capability to more peripheral regions of the country to connect large scale renewable energy developments (e.g. rural Scotland, Wales, Cornwall, offshore). Because of the important role that large scale renewables play in the overall generation portfolio, the security standard continues to be deterministic and high for these connections to large renewable generation developments. These variable output generation sources do not require fully rated connections and advances are made in managing the transmission system capability with the use of better design tools and technologies such as active management and dynamic line rating. A transmission network 'backbone' extends to the north of Scotland and branches to the western and northern isles as well as from offshore grids and rural areas up and down the country (Cornwall, Wales, Cumbria and Dumfries and Galloway). This higher capacity transmission backbone also serves the increased and unmanaged demands. The net result is a geographically expanded and higher capacity transmission network. Offshore grids are developed extensively and the closer ties with the European mainland are established through interconnections for offshore renewables with circuits continuing onwards to the European western seaboard countries. Because of the distances and levels of power transfers these interconnections are made using HVDC technology.

The transmission system operator role is expanded to manage the access of a larger portfolio of variable output renewables. This is achieved through new grid codes where reserve holding on the part of renewables is mandated. Older generation plant plays a reserve and balancing role in the power system. The system reliability standard is maintained through a mixture of reserve sharing across international interconnectors, reserve plant in GB and reserve requirements from the renewable energy generation fleet. One notable development is the emergence of a UK and Ireland system operator where the more closely coupled and similarly structured power systems are operated in tandem for economic and security benefits. The level of cooperation with mainland European power systems on system operations is also much enhanced with joint codes for operations and much more dynamic exchanges of information and coordinated responsibility across borders. This provides the opportunity for securing supplies whilst making the most of the indigenous resources in the European area with exchanges beyond Europe (e.g. Russia and Middle East for gas and Africa for renewables such as solar power).

The main role for distribution networks continues to be as a conduit for bulk power from the transmission system to consumers and this role grows as load demand increases. The secondary role for distribution is in integrating more renewable and distributed generation. This is achieved mainly by increasing the capacity of distribution systems with circuit upgrades and new circuit developments where possible. The level of innovation in distribution networks is relatively low and an approach of capacity expansion planning to meet the requirements of demand customers is prevalent. It is believed that moves away from this approach would risk customer security of supply so tried and tested approaches prevail.

Demand is managed by individual behaviour changes and there is little technological implication for the development of power networks. However there are some advantages from a general restraint in consumption at peak times and this prevents even greater requirement for network capacity. The network companies expend effort in assessing the likely benefits of the effect of behaviour change on demand levels.

System performance is managed by the network companies and the expectation of the relatively passive consumers is that it is the network companies' responsibility to meet their demands for secure and high quality supplies. This responsibility is tackled through the same network capacity and capability investment as is required for the connection of new sources of energy and higher electricity demands. In addition, analytical tools geared towards assessing system security in real time and higher levels of network automation (especially in distribution systems in the lower voltage level network) provide some of the tools for meeting customer demands for service quality.

In this scenario, consumers will still contract with supply companies (more competition though as price becomes a bigger issue). Electricity is still viewed as a commodity where consumers pay per unit of energy as opposed to paying for an energy service. There will be a similar structure as today with DNOs, TNOs and a SO who charge for connection and system use. The SO is responsible for overall system security, quality and reliability (including system balancing) and will be regulated on its performance in this area to ensure consumers' needs are being met. DNOs will also be regulated to ensure they meet security, quality and reliability standards.

The regulator will still be responsible for the "natural" monopolies of transmission and distribution networks. A significant issue will be cost recovery for substantial network infrastructure upgrades due to the large penetration of offshore renewables and overall increased capacity requirements. The current industry structure remains in place with an independent system operator responsible for operating the networks of private, independent, regulated network owners. Due to the complexity of operating a transmission system with higher levels of distribution connected renewable generation the system operator has some obligations for managing the higher voltage distribution systems.

The technology underpinning this vision of future network is evolutionary from that in deployment in previous decades. Power system equipment, control, generation plant and demand side measures have not stretched beyond that in use several decades before.

9.2 'Energy Services Market Facilitation'

'Energy Services Market Facilitation'

- The main role for power networks is to support a vibrant energy services market. The transmission and distribution infrastructure is required to support a super-supplier or energy services company (ESCO) centred world.
- ESCOs do all the work at the customer side and the transmission and distribution networks contract with ESCOs to supply network services, allowing the network companies to operate the networks more actively.
- There are wide ranging developments and vibrant markets in energy services including micro-generation, on-site heat and power, demand side management, telecommunications and electric vehicles.
- The services supplied by the networks include transmission system connection to strategic, large scale renewables and also access to municipal scale CHP and renewables tailored to local demands.
- System management is aided by the degrees of flexibility provided by 'empowered' customers with high capability information and communications technologies (ICT).

The key features of this scenario are represented graphically in Figure 11 where active network management (ANM) at transmission and distribution level is shown alongside other network developments.

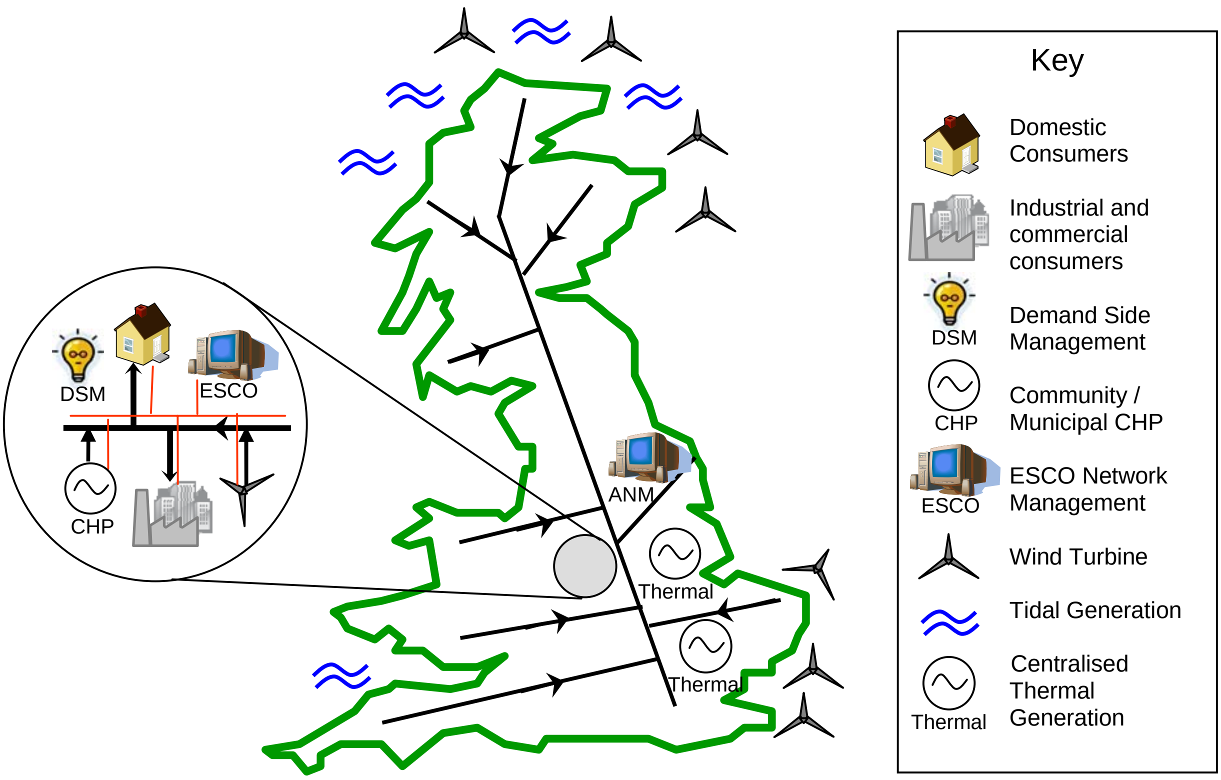


Figure 11: 'Energy Services Market Facilitation' network scenario.

Transmission and distribution infrastructure is required to support a much more vibrant energy services market place with 'super-suppliers' or energy supply companies (ESCOs) taking a central role between the customers and the transmission and distribution network operators (who supply network services that allow the energy supply companies to operate actively and economically). The services supplied by the networks include access to larger scale transmission connected renewables but also to municipal scale CHP and renewables tailored to the local demands served by the ESCOs. Vibrant markets exist for energy services which include imported supply, on-site heat and power, and demand management.

The ESCOs or 'super-suppliers' themselves provide heat, light and power to contracted customers commercial incentives to do this on a cost minimizing basis. This results in ESCO owned generation plant on site, smart meters to manage customer demand, communications links to ESCO customer service and server centres to manage consumption, generation and commercial information. ESCOs also drive a multi-utility offering that incorporates electricity, gas, water and telecoms supplies but also electric vehicle lease (with energy storage charging equipment supplied as part of the deal), security services (alarm and response, CCTVs) and of course on-site generation lease arrangements. ESCOs act as a one stop shop for energy and related services and they have the capability to hedge and substitute across energy supplies (e.g. on-site versus off-site, renewable versus fossil) at a local, national and even international level.

The transmission network continues to play the role of managing the bulk transfer of energy from large scale thermal and renewable generation to exit points at distribution system interfaces. The overall level of bulk transfers is reduced due to the strong developments of generation and energy services embedded within the distribution system. The dynamics of the electricity supply system with so many inter-related energy services being managed dynamically by competing ESCO firms presents major challenges for the power system operators including balancing supplies in real time and securing essential supporting network services. However the general level of exchanges and unexpected energy transfers across the power systems reduce since ESCOs manage customer demand and generation much more dynamically. ESCOs compete strongly to provide commercial services to the system operators such as aggregated demand response, on-site generation capacity and energy contracts, energy storage and electric vehicle charging scheduling.

Transmission upgrades that were developed in the decades from 2010 and 2020 to serve the different need of central generation are now not stressed in capacity terms to meeting the needs of the ESCO focused world. Early transmission investments to meet the initial trajectory of development of large central power stations met the need but are less heavily utilised over the decades as the generation portfolio changes shape. The charges for the use of the transmission system have become relatively high as revenues are charged on a lower volume of transported energy to recover the costs of previous investments. The transmission system balancing role is also generally reduced since a proportion of the balancing is undertaken within the distribution system at the customer level. Maintaining reliability and stability of the system as a whole is a challenging task for the system operator since many independent ESCOs must be contracted and managed to achieve that result. The bulk distribution system plays a similar role to the transmission network in providing the conduit for larger scale generation output. One major challenge for the system operators is to manage the impacts of major energy market events. It would be expected that ESCOs will respond in similar ways to the same market event and take similar actions with customers' generation, storage and demand resulting in infrequent but large swings in behaviour affecting energy flows in the power networks.

In addition, the bulk distribution system also acts as a facilitator of the vibrant supplier/ESCO activity embedded within distribution networks. This is a major change in role for the distribution network operators who adopt functions akin to a Distribution System Operator with more interactive control of connected parties. Distribution network control rooms develop with 'commercial desks' to manage the ESCO interfaces and more sophisticated network management systems to monitor and anticipate emerging operational patterns as information is received from ESCOs and network monitoring installations in real time.

The local generation deployed by ESCOs to serve local demands provides a resource for the distribution network operators with flexibility and clear contractual arrangements to use this generation plant to maintain network performance. Network constraints and performance are managed through this interface with ESCOs, and a symbiotic arrangement is achieved where ESCOs rely on the distribution system to balance their obligations by power exchange across the distribution network and the DNOs tap into this embedded, highly managed resource to assist in network operations.

ESCO contracts with customers cover energy supply from local and on-site generation resources but also electricity demand management in the context of overall energy service provision. Automation of electricity demand is managed by the ESCO so there is an extensive overlay of sophisticated communications and control infrastructure at the distribution level.

The ESCO might not only provide energy services but also telecommunications, water and even an integrated transport option with lease electric vehicle options. The charging of electric vehicles and the use of the home as a work place present a different challenge to energy service providers but meeting these new demands falls to the ESCO who balance all the needs of the consumer and work with local and national resources to meet the demands.

The ESCO would be seen as the provider of consumer supply security and quality demands and would adopt strategies to minimise the cost of providing this level of service to maintain a competitive offering. In some cases this will involve on-site UPS type equipment, in other areas the network will provide the necessary level of performance and the ESCO will manage this in contracts with the DNO. When cost effective, energy storage technology would provide a useful way for the ESCO to provide on-site energy security while at the same time providing a valuable energy balancing and market participation tool.

The hardware deployed at the consumer level will have developed substantially with on-site monitoring, metering, production, storage and control equipment to meet the consumer needs. This customer-side equipment will be linked to sizeable customer service facilities through a substantial telecommunications network. Smart meters (with capability to manage on site generation, demand and storage and services beyond electricity) with extensive external communications and information infrastructures provide excellent capability for network operators to provide highly effective and efficient network access and service levels.

9.3 *'Distribution System Operators (Lean Transmission)'*

'Distribution System Operators (Lean Transmission)'

- Most electricity production facilities are connected to distribution networks thus reducing the role for the transmission network which then only serves to connect the strategic and economic larger scale renewable resources in certain parts of the country.
- Distribution System Operators (DSOs) take much more responsibility for system management including generation and demand management, supply security, supply quality and system reliability.
- Demand side management provides greater options for DSOs in system operations but also leads to a generally reduced demand to service.
- DSOs balance generation and demand in local areas with the aid of system management technologies such as energy storage and demand side management. Dynamic loads and generation sources make local and regional balancing a key activity for DSOs.
- The transmission system acts to provide connections between DSOs and to strategic renewables deployments.

The key features of this scenario are represented graphically in Figure 12.

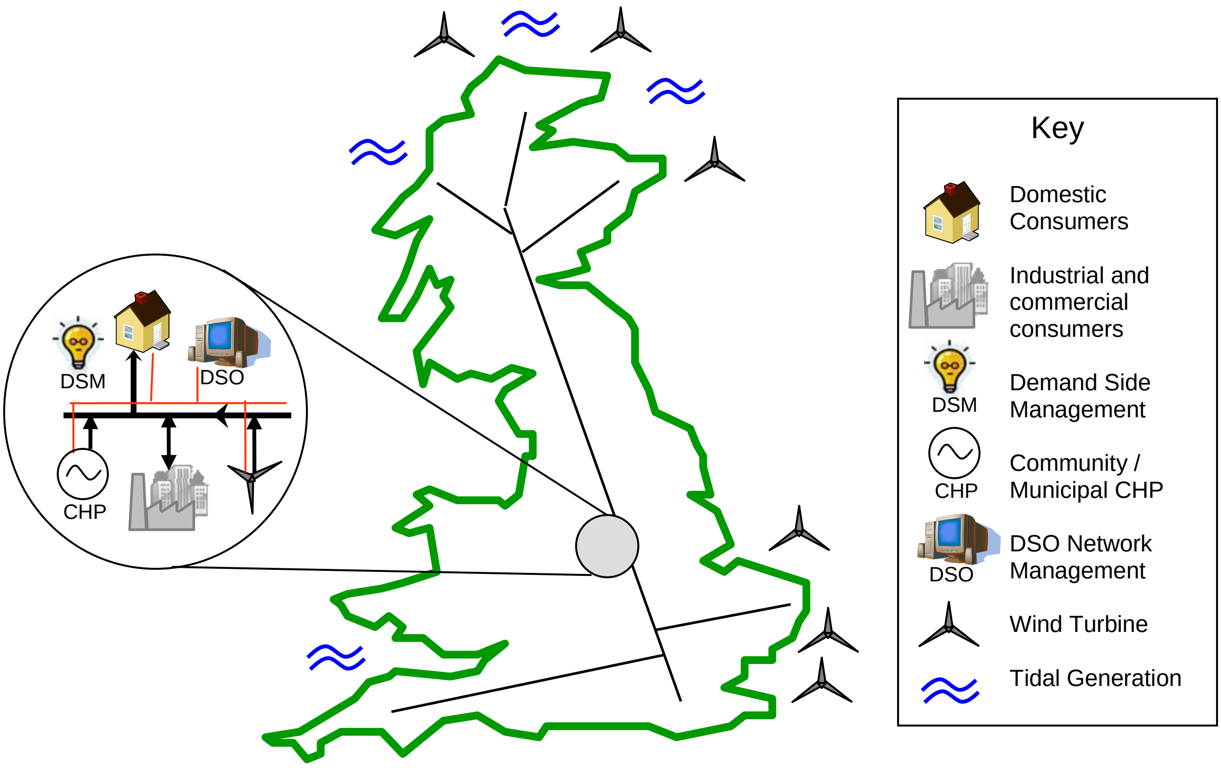


Figure 12: 'Distribution System Operators (Lean Transmission)' network scenario

Most electricity production is connected to distribution networks, thus reducing the role for the transmission network which only serves to connect the strategic and economic renewable resources in certain parts of the country. As a result of the much higher levels of generation and demand activity in distribution networks, the distribution operations function is much more active with local balancing, constraint management and market facilitation being taken on by distribution operators. This leads to the emergence of the Distribution System Operator (DSO) in contrast to the less active Distribution Network Operator (DNO) and this is encouraged by Government as a convenient vehicle to manage the meeting of energy policy objectives of efficiency, emission reductions and municipal and community led energy solutions. Demand side management leads to greater options for the DSO but also a generally reduced demand to serve. Dynamic loads and generation sources make local and regional balancing a key activity for the DSO. The emergence of the DSO is a necessity of the vastly more active situation to be managed within distribution networks.

The role of the transmission network has reduced to be simply the conduit for renewable energy from larger, mainly offshore sources to load centres. The transmission system has changed shape to meet this new challenge with obvious bulk transfer corridors to the coastlines and beyond but these corridors are branched off the existing north-south backbone which continues to meet the needs for transferring renewable energy to demands. Because the proportion of demand met by large scale plant is lower and because the sources of power are renewable and variable output then the transmission system is less heavily utilised in general. However the need for connecting large scale renewables and to enable the level of activity within and between distribution systems does require that the transmission system maintain its geographical reach and the capability to serve a good proportion of the overall energy demand. There is resulting pressure to scale back the size of the transmission system, extend the life of existing assets to defer their replacement against the lower utilisation level. The required capability of the transmission system is not as great as for a fully centralised generation situation.

Technologies enabling the transmission system to operate in a stable manner in the more dynamic environment are deployed such as power electronic based power flow and voltage control devices. The extension of transmission asset lives requires more extensive deployment of condition monitoring technologies and asset management practices. The health (and fitness for duty) of the majority of transmission assets is monitored in real time with operational decisions made around the resulting information feeds.

The accompanying charges made for use of the transmission system also come under pressure as a result of the lower levels of utilisation and the desire for lower asset investment levels.

The higher voltage level distribution systems also act to serve the needs of larger renewable energy development connections and also larger scale natural gas and hydrogen powered CHP plants that have emerged to prominence. This supplements the traditional role for the distribution networks of acting as the conduit for power between the transmission network and connected loads.

The lower voltage level distribution networks provide the connection from local CHP units to loads and also act to marshal demand side response for overall system benefit. This new role requires that ICT technologies are deployed widely to provide an effective communications and control infrastructure for effective system control. Energy storage technology will play a role in managing the wires infrastructure and providing supply security and DSOs will deploy energy storage strategically to manage the distribution network.

The DNOs will have to manage a network with many generation sources and will require much more highly developed control facilities. The idea of distribution system operator emerges and system operations codes develop to recognise the expanded role of the DSO. The DSO is the hub of service provision and takes responsibility to manage supplies from what transmission connected generation exists, local generation facilities and other demand side schemes of control. The DSO develops the network to manage diverse generation and demand side facilities and this includes energy storage devices, responsive reactive control equipment and a substantial network management system capable of delivering high levels of service from the diverse generation portfolio to managed demand customers. In many ways the DSO becomes the centre of the electrical supply system and their role has most bearing on the sources of energy delivered to customers and the other services that customers receive such as balancing, security, reliability, power quality.

The transmission system continues to be operated by a system operator (SO) and the degree of cooperation between DSO and SO is very high as the transmission acts as the conduit from large scale renewables to the DSO. The SO also acts to manage exchanges of power and services (e.g. reserves) between DSOs.

9.4 'Microgrids (Small Transmission and Distribution)'

'Microgrids (Small Transmission and Distribution)'

- The self-sufficiency concept has developed very strongly in power and energy supplies with electricity consumers taking very much more responsibility for managing their own energy supplies and demands. This leads to a greatly reduced role for the bulk power networks.
- Individually and collectively customers actively manage their own energy consumption against their own or locally available supplies and minimise exports to and imports from the local grid.
- Microgrid System Operators (MSO) emerge to provide the system management capability to enable customers to achieve this with the aid of ICT and other network technologies such as energy storage.
- Customers take a lead role in their own energy provision and the security, quality and reliability of the supply with the support of the MSO.

The key features of this scenario are represented graphically in Figure 13.

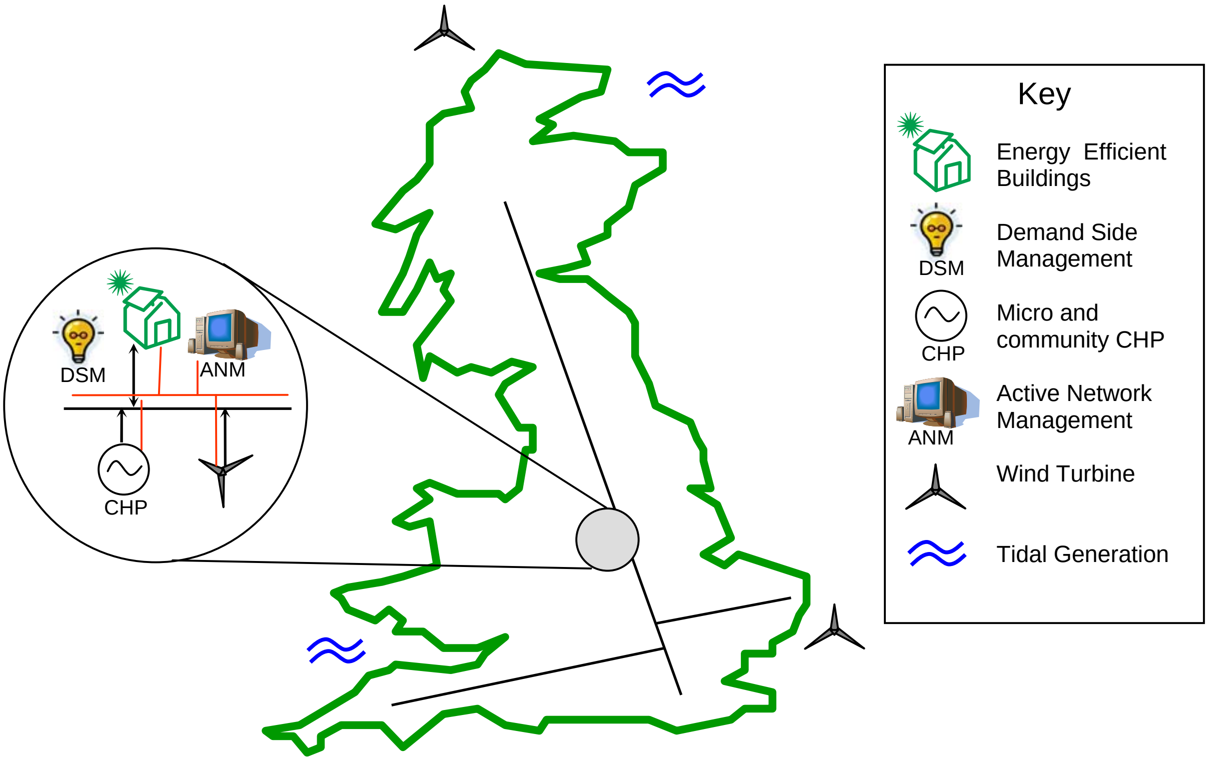


Figure 13: 'Microgrids (Small Transmission and Distribution)' network scenario.

The self-sufficiency (renewables, hydrogen, energy efficiency, demand side management) concept has developed very strongly with electricity consumers so the role for transmission and bulk distribution (through the 132kV sub-transmission network) is substantially reduced. Customers (through some manual intervention but mainly by automatic ICT enabled means) seek to balance their own managed energy consumption with on-site or very local production and to minimise exports to and imports from the electricity system. Local distribution networks provide the balance between local/regional exports and imports.

There may be vibrant local energy markets with small scale merchant generators trading locally but the commercial arrangements for this do not impact highly on networks in an operational sense. The role for the power system is much reduced with alternative energy sources such as hydrogen produced and utilised locally from local energy sources (renewable and other). This provides a degree of separation between local energy systems and the bulk electricity transmission and distribution system with the result of the much reduced role for the bulk power system.

One approach being deployed widely is the microgrid where self-sufficiency among individual and groups of customers has developed to such an extent that demand management, energy storage, power quality as well as energy production are coordinated in well defined customer groups. The role for the distribution network operator might be in operating the microgrids themselves or connecting microgrids to the wider distribution system as virtual or actual private networks. Microgrids provide the capability for isolated operation when circumstances dictate – for example to reduce network access charges or in response to faults or other events in the bulk power system. However, there is often an incentive for microgrids to operate in synchronism with the remainder of the power system for the purposes of selling excess energy or benefiting from the resulting enhanced security and reliability.

Within the microgrid there is exploitation of renewable sources as appropriate to the locality (e.g. solar power, wind, biomass) and a major dependence on natural gas fired combined heat and power systems. CHP (or in many cases tri-generation) is used to provide space, water and process heating as well as cooling). The net effect of this dependence on natural gas is that the wholesale natural gas market is much more important than the electricity market which has as its main function to provide balancing power contracts for local microgrids. The other major implication of the reliance on natural gas for much local energy provision is the major development of the national gas infrastructure while the electricity transmission system comes under pressure to reduce to fit the new role it plays. Gas interconnections to Europe through interconnectors and the rest of the world through liquefied gas transport are developed substantially while there is little requirement for any development of international electricity interconnections.

The distribution network will be characterised by this widespread application of microgrids. The distribution network will play a prominent role in the transfer of power within and between microgrids for system balancing, collecting output from distributed generation and providing back up to local generation. The interface between the microgrid and the regional network will require sophisticated management and will employ power-electronic based solutions as well as much enhanced ICT and automated control capability. Maintaining local system conditions and the integration of the varied generation sources and loads within the microgrid will require advanced, distributed control architectures facilitated by advanced ICT technology.

Consumers (and their energy management systems with external inputs) would make real time decisions on whether to export, locally store power, manage demand, import and various combinations of those actions. There could be a microgrid system operator (MSO) that may be a separate entity or indeed the DSO acting as the MSO in each cognate customer area. The MSO would facilitate these dynamic markets via highly automated intelligent systems.

Consumers and generators would be charged for connection and system use by the MSO.

It is likely that there will be standards of energy consuming/generating behaviour set by the MSO that cover the combined load/generator characteristics of a consumer/generator network connection. These standards will set out the requirements (within clear boundaries) to be met, creating more of a “plug and play” approach. Consumers/generators will connect based on the network access rules and expect the MSO to maintain the security, quality and reliability of supply within the microgrid.

The MSO maintains stability, quality and overall system balancing by a combination of the set patterns of supply/demand behaviour and the MSO balancing services of energy storage, trading and dispatched DSM capability. The MSO also provides incentives for responsive behaviour so that connected parties contribute to system balancing requirements.

Automation would be deployed to allow the MSO to have enough controls to manage generation and demand in the operational timescales required to minimise the dependence on the main power system. Standardisation of systems and standards across all MSOs will automate control of the stability of the overall system.

This new MSO entity would be subject to different forms of regulation and incentives mechanisms for the role they play in energy production, system operation, customer service and energy services management. The issue of energy efficiency is strongly addressed by the advent of the MSO since it has the capability to manage local resources and customer side requirements in a way that reduced overall electricity flows and reduces losses. This might be one aspect of the new regulatory approaches that emerge.

The transmission system role would be to connect a relatively small amount of large scale renewable energy sources that still produce electricity for export through the grid system (rather than producing alternate fuels for transport in non-electricity vectors to points of conversion much closer to eventual end-use). Economies of scale in large scale renewable energy production and strategic drivers for the exploitation of offshore renewable energy sources result in the continued investment in large scale power generation. Some large scale facilities retain the capability to export either hydrogen or electricity to exploit the dynamic markets in both commodity markets. The removal of transmission circuits enabled by the move to microgrids is hailed as a triumph of the ‘local is beautiful’ movement where environmental values are regarded highly. The resulting architecture is a generally much reduced transmission capability but continued geographical coverage. One other important aspect of the higher degree of self-sufficiency within a microgrid and across local groups of microgrids is that supply security can be provided without such heavy reliance on the bulk distribution and transmission systems. One effect of this is that the traditional approaches to the provision of security of supply through network redundancy are challenged through the development of higher reliability single circuit connections.

9.5 *'Multi-Purpose Networks'*

'Multi-Purpose Networks'

- Attempts have been made to exploit many energy technologies over time and there exists a large diversity in electricity production and demand side management initiatives implemented.
- The network is characterised by diversity in network development and management approaches as a result of changing energy policies and company strategies over time.
- Substantial differences exist in network capabilities with excess capability in some areas and constraints in other areas.
- Electricity networks fulfil different roles including bulk transfer, interconnection, backup and security and meeting renewable and demand side objectives.
- Challenges in managing diverse system architectures are accompanied by opportunities from the diversity of generation, network and demand side provision.
- The commercial implications of the lack of consistency in energy policy and the subsequent diverse network infrastructures that emerge means that the stranding of certain power system assets becomes more apparent over time.

The key features of this scenario are represented graphically in Figure 14.

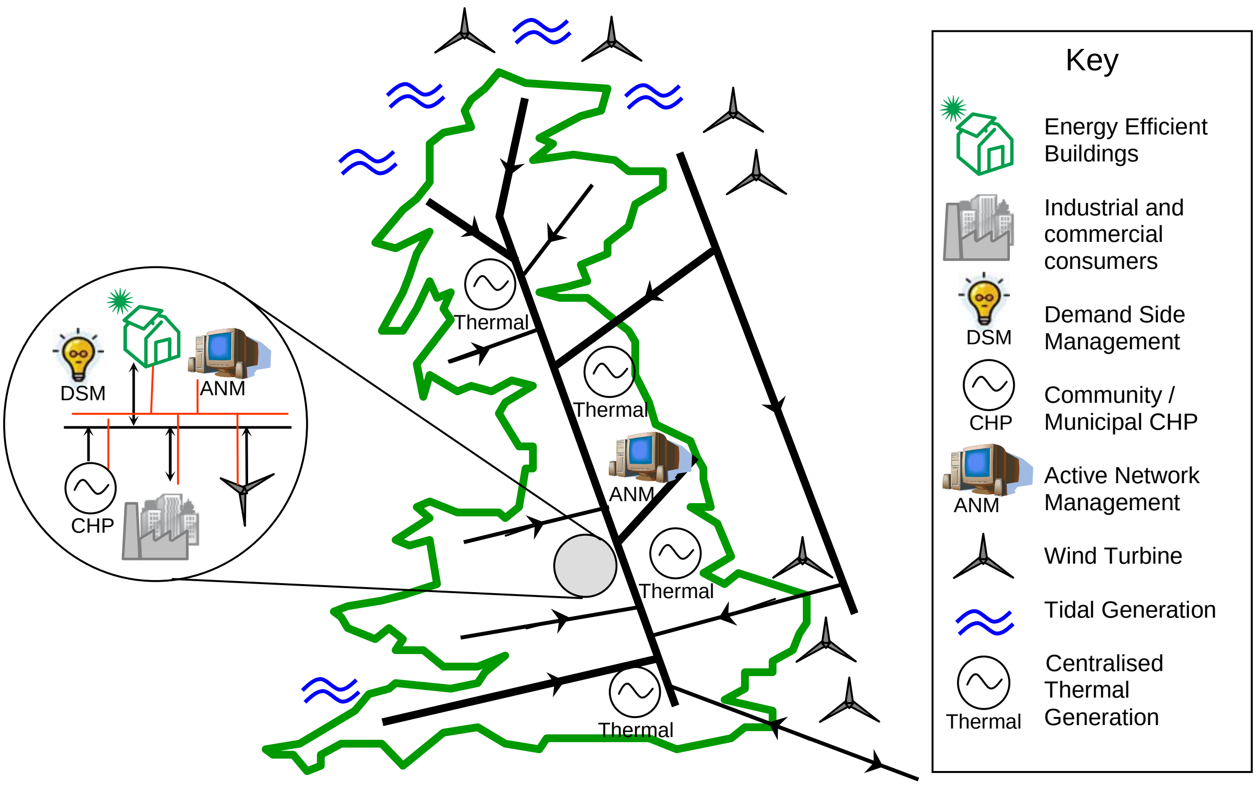


Figure 14: 'Multi-Purpose Networks' network scenario.

Attempts have been made to exploit many energy technologies over time and there exists a very mixed portfolio of large and small scale, renewable and conventional generating units. In addition, different demand side management options have been rolled out over time - some coordinated locally and other at a regional or national level. Networks have developed along several paths to meet the varying objectives over the years and there is a resulting large and diverse (arguably uncoordinated) infrastructure. Managing many technological deployments presents a system operational challenge for the network companies but also several degrees of freedom to meet customer needs.

At times when the national and regional energy policies dictated, large scale renewable energy schemes were heavily developed in regions of the country where this was possible – mainly rural areas and offshore. In addition, a number of new build high efficiency clean coal in addition to carbon capture coal and natural gas fired generation plants are constructed on the sites of existing power stations. New nuclear power plant is also constructed on the sites of existing facilities. At a smaller scale, national initiatives for the exploitation of biomass and smaller scale combined heat and power (linked to community heating) result in large numbers merchant power plants based on these technologies but also a good number of on-site generation facilities.

Individual customers have also developed on-site microgeneration based on solar power, combined heat and power and to a lesser extent wind power. At customer facilities, demand management has been deployed as a result of a number of different initiatives by different administrations. This leads to very good capabilities for demand side management in some areas where pilots and early adoption occurred but no national scale implementation. Coordination of the demand side potential is also lacking partly as a result of the uncertainty in the incentives mechanisms and also because of the unclear responsibilities for overseeing the demand side measures between network operators, system operators, energy suppliers and government bodies.

Customers have also taken several different routes to meet their energy service demands according to the prevailing policies, incentives and market conditions of the day. For example in the area of space heating some customers have followed a trend towards electric heating to reduce their exposure to high natural gas prices. This trend was partly driven by higher building insulation and energy performance requirements. Another example is in the area of transport where some customers made the transition to the use of electric vehicles but again the policy and supporting mechanisms were not consistent over time and although there is a good number of electric vehicles in service the impact on power networks is not as high as some expected if larger numbers of car owners shifted across to electric vehicle technology. In addition, the possibilities for exploiting the system management opportunities from electric vehicles (through charge time scheduling and the use of stored energy at times of system stress) are not fully exploited.

Transmission, extra high-voltage distribution and lower-voltage distribution have each been developed relatively highly since at various times that was what was required to meet the energy policy objectives of the time. The transmission network has been expanded to reach the exploited sources of renewable energy in rural and offshore regions. Additional interconnection to the mainland European power networks has been developed and this provides additional capability for securing electrical supplies and also for balancing the GB system in real time. At the same time some parts of the networks have not been expanded as a result of efficiency and capacity investment deferral initiatives such as demand side management. In addition there have been periods of general under-investment as a result of different energy policies. The result is that in some regions a multi-functional and relatively large power system has developed which is really too big (and over-engineered) for the job it is required to do. In other parts of the country the network is not so highly developed and standing constraints are common. The mix of ‘gold plating’, time expired assets and capacity constraints is challenging from an engineering perspective but also not efficient in economic and customer service terms.

The transmission system operator and DNO/DSOs are required to undertake a fairly challenging task with many different generation source types, network infrastructure types and demand side schemes in place. The plethora of options does provide a high degree of flexibility for network operations in some places and constraints in other places. This result comes with relatively high network access charges because of the high investment levels over time as each different approach was pursued and the costs of managing higher levels of constraints. In addition the costs of managing constraints in other parts of the network lead to higher network access costs for users.

Power networks are expected to fulfil several roles including balancing the very diverse supplies and demands for electricity. The lack of consistency in generation and network capacity investments produced difficulties in fulfilling this role. The networks also are required to fulfil the function of transporting bulk supplies of electrical energy across long distances since the exploitation of energy sources has included large scale remote and more central plant as well as smaller scale energy production facilities. In some periods (daily and seasonal) very little energy is transported but often large quantities of energy are transported and this stretches the network capacity and system operations.

Because of the uncertain and diverse outturn in terms of generation and demand side developments, flexible system technologies play a large role in the power system. For example, power flow control technology (based on transformers and power electronics), energy storage, constraint management schemes, and automation have been deployed substantially by network owners in lieu of capacity investments in uncertain conditions.

10 Next Steps in LENS Scenario Development

This interim report is part of the second phase of the LENS project and provides the initial presentation of energy scenarios and network scenarios developed within the LENS project.

Valuable contributions to the development of these scenarios has been provided by stakeholders in the form of written consultation responses and inputs at workshops in the first two phases of the LENS project.

The scenarios presented in this report will be developed and refined further based on written and workshop contributions as facilitated by Ofgem.

The remaining stages of the project in the third and final phase to be conducted by the LENS project academic team are as follows:

- Consolidation of draft energy scenarios and draft network scenarios into scenarios for draft final report (this work has already commenced).
    - The energy scenarios to network scenarios mapping process and the development of draft network scenarios have highlighted complementarities in energy and network scenario pairs (e.g. the 'Switch me on' energy scenario and the 'Big transmission and distribution' network scenario.
    - Complementary pairs of scenarios will be combined and refined into draft final scenarios that encompass a unique combination of the themes of interest, the scenario context, the energy sector detail and the accompanying network detail.

- 3rd Stakeholder Workshop :
    - Presentation and discussion of draft scenarios and stakeholder responses.
    - Presentation of quantitative modeling approaches using the MARKAL model to provide numerical justification and development of scenarios
    - Discussion of transitional issues within the scenarios
    - Opening discussions on potential implications of scenarios on networks and their regulation.

- MARKAL modeling activities:
    - Initiated from the interim report, draft scenarios and workshop/consultation inputs.
    - MARKAL model development and simulation runs to reflect the content of the energy and networks scenarios presented in this interim report.

- Input parameters to the modeling activity to be presented at the 3rd stakeholder workshop for discussion.
    - Modeling and simulation outputs used to refine draft scenarios

- Draft scenarios report
    - Combined energy and network scenarios refined by stakeholder responses at the 3rd stakeholder workshop and by written response to the Ofgem consultation on the interim report.
    - MARKAL modeling and simulation inputs to scenarios to enable further development and refinement
    - Development of transitional issues towards the 2050 scenarios (i.e. 2025 waymarkers). Exploring transitional issues within scenarios is essential in checking that the pathway towards each scenario is consistent with the end-point and is equally as plausible as the end-point itself. Transitional issues must take into account the present energy sector trends and networks, the evolution and outworking of the themes over time and the development of the networks over time towards 2050.

Further details on next steps are provided in the Ofgem letter accompanying this report.

11 Appendix A: Review and discussion of additional LENS inputs literature

At the time of publication, it was clear from the LENS Inputs Report that studies from specialist areas could help provide deeper understanding of the variations possible within some of the input topics. In addition, several valuable information sources have been highlighted during the stakeholder consultation. The following section identifies the studies that have been reviewed for this purpose and although a full written critical review is not within scope of this report a short note on the most significant points taken from each source is included.

An ongoing BERR consultation [11] provided further information on electricity consumer behaviour. This area was viewed as significant to understanding plausible future electricity usage patterns. This consultation is being conducted in the light of the need to implement, by May 2008, the requirements of Article 13 of the Energy End-Use Efficiency and Energy Services Directive.

Key proposals within this consultation state that, from 2008, the Government will:

- require the provision of comparative historical consumption data on bills for all domestic gas and electricity customers;
- require electricity suppliers to provide (where technically possible) a real-time display unit when an electricity meter is replaced or newly installed in domestic premises;
- require electricity suppliers to provide a real-time display to all electricity consumers who request one for a period of two years;
- require gas and electricity suppliers to install smart meters in those parts of the small and medium-size enterprise (SME) sector, above a certain energy usage threshold, where it has been shown to be cost-effective to do so and where such a meter is not already installed.

The Tyndall world transport scenarios [12] provided a valuable perspective on the factors that influence travel patterns. In particular, the view that travel can influence society and culture and has a fundamental influence on how people live their lives. This was deemed to be an important area to explore in the Energy Scenarios.

The publication “16 pain free ways to help save the planet” explores consumer behaviour in relation to climate change [13] which is a key influence on future energy use. This publication highlights the difference between consumers' claims to be happy to do their bit for the environment and genuine action. The authors claim the basic economic model that has the consumer as a rational economic actor making informed choices after an objective cost-benefit analysis does not work well in the field of sustainable consumption. This is attributed to the fact that in many of our consumer transactions, actual decision-making is based upon a complex interaction of moral, social, symbolic and emotional aspects of behaviour. The challenge for encouraging consumers to be more sustainable is that the change required is often at the more complex end of consumer decision-making processes.

Publications by the Tyndall Centre on the hydrogen economy [14] and fuel cells [15] provide information on the plausibility of alternative energy carriers. Key findings in these publications state that in a sustainable environmentally focussed world a high utilisation of hydrogen could be achieved within the context of a predominantly low carbon transport fleet over a timescale of 50 years (with large scale hydrogen vehicle introductions in the bus and light goods vehicle fleets by 2010 and in the car fleet by 2016, followed by annual new-buy growth rates of 30%). It is also stated that in the absence of major hydrogen production technology innovations, hydrogen for transport would need to be supported by concurrent investment in additional renewable energy (or nuclear) capacity if the anticipated carbon dioxide emissions savings are to be achieved.

This study finds that with regard to fuel cells, both at a technical and non-technical level, there is still a long way to go before fuel cells become an established, mainstream technology. The authors recognise the need to extend the knowledge base for fuel cell technologies, to improve their efficiencies, reliability, lifetime and material performances. A key conclusion was that the Government may not have shown sufficient support for fuel cells to date and that further backing – both in terms of legislative reform and financial assistance – would be necessary to enable fuel cells to reach commercialisation and to establish a sustainable market position for them.

The inputs report identified resources and skills as an important area for future electricity network development. An Energy and Utility Skills publication – Skills Intelligence for Electricity [16] provided additional information in this area. One of the main points to be drawn from this report is that the power industry is experiencing significant skills gaps and recruitment difficulties. 85% of employers report gaps and 46% report gaps that are having a significant impact on business performance. These have arisen for a variety of reasons including changing skills requirements, the loss of experienced staff and skill shortages in the labour market.

The Power Network Sector Structure input can be informed by other industries, such as telecoms, that have seen significant change in recent years [17]. This perspective from the telecoms regulator demonstrates some of the constrictions that can limit competition in certain markets. They note that although competition may be a means to delivering the kinds of outcomes that consumers want, it cannot be effective unless customers are able to make well-informed choices, and to switch easily between suppliers. They also highlight the principle that regulation should promote competition between competing infrastructures, as deep in the network as such competition was likely to be effective and sustainable. In telecoms this leads to the issue that companies who wished to compete on this basis had to rely on BT for access to parts of the network where competition was not sustainable. The conclusion was that in order for competition in fixed telecoms to be effective, access to the network infrastructure needed to be equal for all parties. These aspects of introducing competition to a market with a natural monopoly in the form of network assets bear obvious similarities to the competition in the electricity industry.

A recent report from the WWF presents an 80% emissions challenge [18] and provides an even more extreme view of the climate change issue than the previously reviewed material. In this publication, the future that achieves the 80% target has electricity generation dominated by wind and fossil fuel with carbon capture and storage (CCS) although there is also some domestic CHP penetration. BioFuel and hydrogen are equally common in transport while rail goes fully electric from its current 60% diesel fuelled level – this has an impact on the demands to be met by the electricity networks.

A recent DEFRA analysis of the UK potential for CHP [19] was consulted in light of the focus on efficiency in the reviewed literature and the potential for CHP to feature in the LENS energy scenarios. It is noted in this report that larger industrial or community based CHP schemes hold the greatest immediate potential and micro-CHP is a new technology where the economic benefits and primary energy saving potential are unproven. The largest impact upon the attractiveness of investment in CHP is the relative price of fuel (mainly natural gas), used in CHP, and the financial value of the electricity generated by CHP. If domestic micro-CHP follows a similar build up pattern to that of condensing boilers, it is likely to make a very small contribution to installed CHP capacity by 2010 e.g. around 5MWe by 2010, particularly as early trials in the UK have been unsuccessful. Under the same scenario, installed capacity may rise to around 200MWe by 2020. Government intervention, for example through the building regulations, to require micro-CHP to be installed as a direct replacement for existing and new boilers would, of course, cause the installed capacity to increase at a much faster rate.

The BERR, Heat – Call for Evidence publication [20] highlights the current policies addressing new buildings and relatively low cost abatement options in existing homes. However, it also notes that even by 2050, houses built to the current high-efficiency standards reducing to zero-carbon (the zero carbon homes standard will likely specify high efficiency with any remaining heat load met by zero carbon energy sources) in 2016 will make up only 30% of total housing, and the need for heat in the remaining pre-1990 housing stock will be substantial. This information informs on the impact housing policy could have on the LENS energy scenarios.

A recent Energy Savings Trust [21] publication predicts that by 2010 the consumer electronics sector will be the biggest single user of domestic electricity, overtaking the traditionally high consuming sectors of cold appliances and lighting. Furthermore, by 2020 the combined consumer electronics and information and communications technologies (ICT) sectors are expected to use 49 TWh of electricity, compared with around 110 TWh for domestic appliances as a whole (excluding electric heating). As a result, entertainment, computers and gadgets could account for 45 per cent of electricity used in the home. Should this be the case, there would be a significant influence on the use of electricity in the LENS scenarios.

The UK Fuel Cell Development and Deployment Roadmap [22] promotes the policy of introducing a forward public commitment to buy**.** The reasoning is that forward commitments by public sector procurers offer a powerful mechanism for the market to deliver innovative solutions to meet policy needs. Such commitments also provide supplier companies and their investors with long-term confidence against which to commit resources for manufacturing scale-up. This is potentially in interesting aspect to explore in the LENS scenarios.

The above documents add a valuable level of additional detail to the already comprehensive information gathering process described in the LENS Inputs Report.

12 Appendix B: Summary of themes in relevant scenarios activities

12.1 SuperGen Future Network Technologies Consortium (2005)

The SuperGen consortium produced six overall scenarios influenced by the following themes:

Economic Growth
This parameter influences factors which include increases in energy demand and levels of investment finance. In these scenarios, the following range of values was considered:

- Low growth, whereby economic growth is significantly less than recent levels.
- High growth, in which economic growth is somewhat higher than current levels

Technological Growth
The technological growth parameter governs the appearance and application of new technology to electric power networks. The following range of possibilities was considered:

- Revolutionary development, in which radical new technologies are developed and applied widely.
- Evolutionary development, in which technological advance is restricted to the application and gradual improvement of current and currently foreseen technologies.

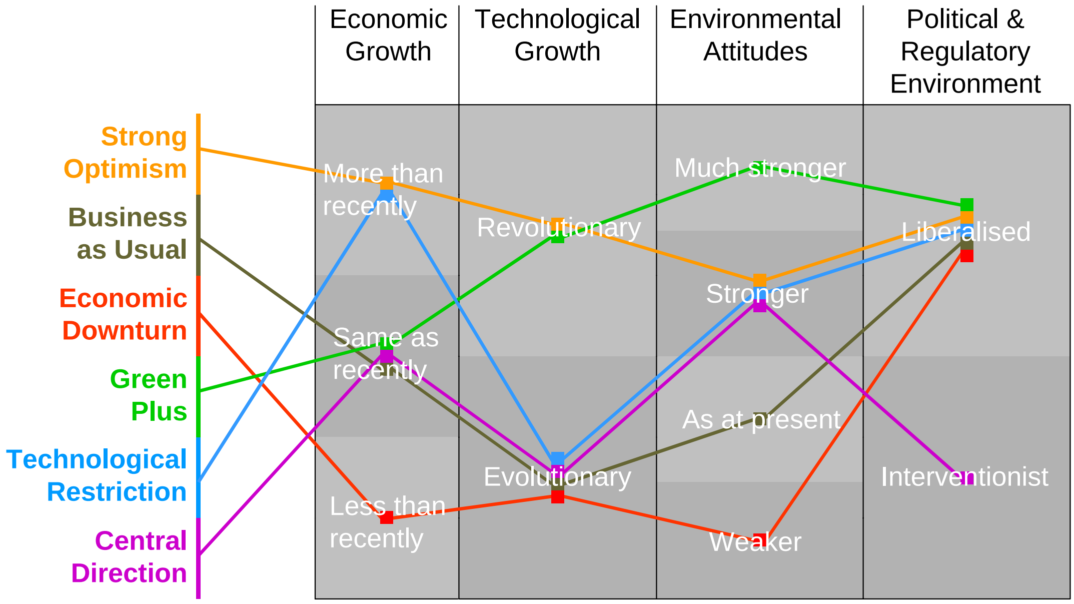
Environmental attitudes
Strength or weakness of prevailing environmental attitude determines factors including emissions constraints and incentives and the acceptability of the power network. In these scenarios, the following range of possibilities was considered:

- Weak environmental attitudes whereby concern reduces in comparison to the current UK atmosphere to a situation similar to that current in the United States
- Strong environmental attitudes whereby popular and Governmental concern for the environment strengthen significantly with respect to the current situation.

Political and regulatory attitudes
This parameter concerns the attitudes of Government and society in general to the management and development of energy industries in general, including

energy use, transportation and electricity generation. Two possibilities were considered:

- Liberal attitudes, in which the current preference for relatively light regulation, together with a market-driven approach continues.
- An interventionist approach, in which a centrally directed model of management and development is adopted, with greater and more prescriptive Government involvement.



12.2 DTI Foresight (2001)

The DTI Energy for Tomorrow study utilised a set of scenarios previously developed by the Foresight programme titled 'Environmental Futures'.

The approach taken was to develop a 2x2 matrix with the axes representing two fundamental dimensions of change: **social values** (horizontal axis) and **governance systems** (vertical axis).

The social values dimension describes patterns of economic activity, consumption and policymaking. Values at the consumerist end of the spectrum are dominated by the pursuit of private consumption and short-termism. The other end of the spectrum, community, is characterised by greater concerns about social equity and long-term sustainability.

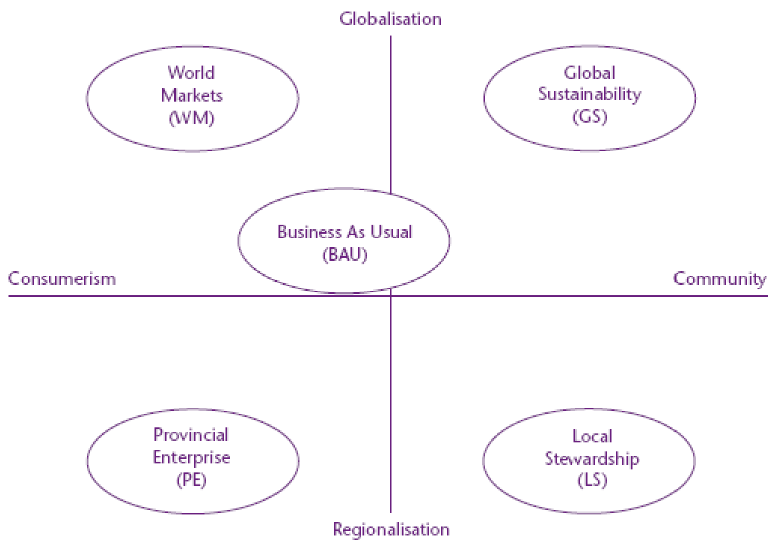
The governance systems dimension describes the structure and scale of political authority. At the globalisation end of the spectrum, political authority is distributed away from nation-states, upwards towards the EU and global organisations. Under regionalisation, national sovereignty is retained or even strengthened.

The scenarios that emerged from the 4 quadrants were:

1. World Markets
2. Provincial Enterprise
3. Global Sustainability
4. Local Stewardship

12.3 The Energy Review (PIU 2002)

The PIU used the 4 scenarios developed by the DTI and added a Business as Usual scenario. See diagram below.



PIU themes and scenarios.

12.4 The Changing Climate (RCEP, June 2000)

The objective for the RCEP scenarios was to achieve a match between energy demand for different end uses and energy supply from different sources while reducing by about 60% UK carbon dioxide emissions from burning fossil fuels.

Themes were not used in this study.

Four scenarios were generated from the starting assumptions below:

- ***scenario 1:*** no increase on 1998 demand, combination of renewables and either nuclear power stations *or* large fossil fuel power stations at which carbon dioxide is recovered and disposed of.
- ***scenario 2:*** demand reductions, renewables (no nuclear power stations or routine use of large fossil fuel power stations)
- ***scenario 3:*** demand reductions, combination of renewables and *either* nuclear power stations or large fossil fuel power stations at which carbon dioxide is recovered and disposed of.
- ***scenario 4:*** very large demand reductions, renewables (no nuclear power stations or routine use of large fossil fuel power stations).

12.5 Decarbonising the UK (Tyndall Centre, Sep 2005)

Again, themes were not used in this study.

The methodology used to generate scenarios was a three stage process employing the ‘back-casting’ technique as follows:

<u>Stage 1:</u> Defining a set of end-points based on a 60% reduction in CO2 emissions.

<u>Stage 2:</u> Back-casting to articulate alternative pathways to the 60% reduction in CO2 emissions.

<u>Stage 3:</u> Multi-criteria assessment exercise exploring the trade-offs which are implicit in alternative means of achieving the target.

12.6 Energy Markets Outlook (BERR/Ofgem Oct 2007)

The recent Energy Markets Outlook (EMO) report is essentially a medium term risk and opportunity analysis for the UK energy market covering the main topics: Electricity, Gas, Coal, Oil, Nuclear, Renewables and Carbon. The scenarios use data on the current and planned generation capacity and are differentiated by **one main driver – the regulatory approach to carbon**. This driver is used to produce 3 scenarios with differing rates of plant closure and build, hence producing a range of possible capacity margins in the medium term.

12.7 Decentralising UK Energy (Greenpeace/WADE Mar 2006)

This report uses scenarios to describe four main alternative futures that can be assigned a capital cost and a CO2 emissions level. The scenarios are differentiated by **centralised or decentralised generation and level of CO2** reduction. This is not an example of scenario planning where high-level qualitative scenarios are used to cover a wide range of eventualities and allow the impact of diverse futures to be explored. The scenarios are used to define two alternative paths and provide detailed analysis to conclude the optimum route.

12.8 The Role of Electricity (Eurelectric Jun 2007)

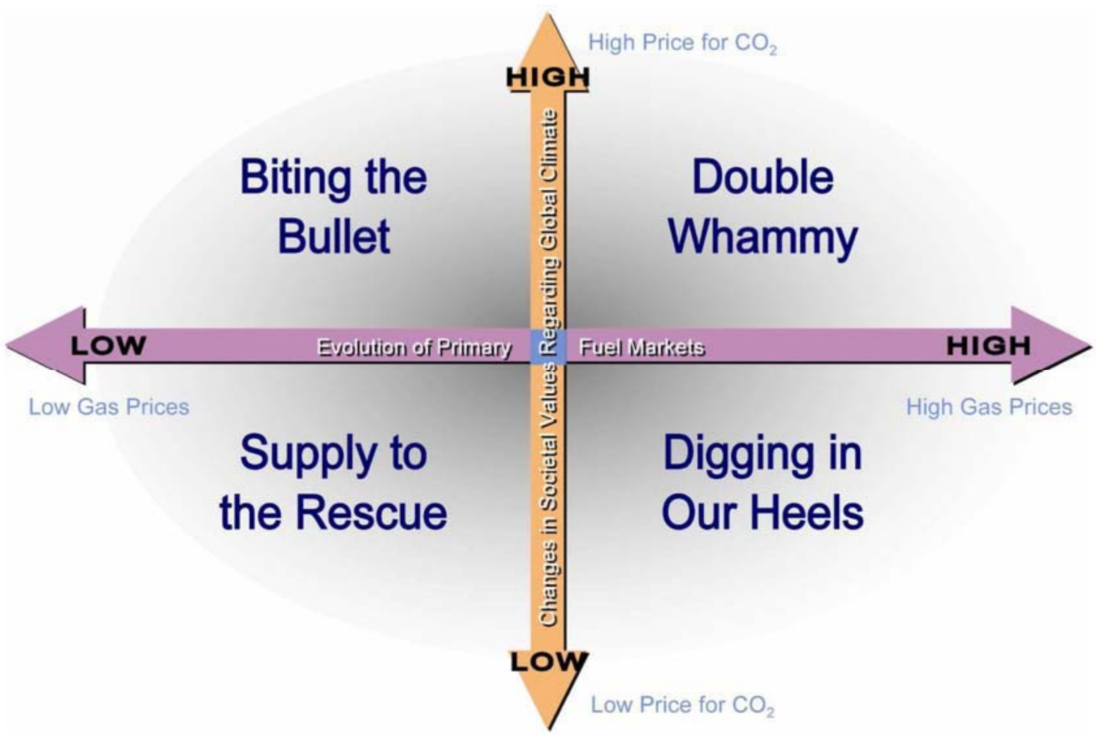
The Eurelectric report on the future role of electricity addressed the triple challenge of making substantial reductions in emissions of greenhouse gases while ensuring a secure supply of energy, all at reasonable cost to the economy.

Four scenarios were developed using the themes **market economics, industry structure, energy/environmental policies and regulation.**

However, these were not scenario themes as per the definition used in the LENS project. The scenarios were developed using two economic modelling tools, PRIMES and Prometheus. In this study a scenario is composed of a set of assumptions and the consequent results of these assumptions worked out through the model. The themes named above are some of the factors considered by the model when generating scenarios.

12.9 Electric Power Industry Technology Reports (EPRI 2005)

This report looks at 2020 scenarios for the US power industry. The scenarios were built on **two key dimensions of change**: the **evolution of primary fuel markets** (in particular the natural gas market that feeds the power sector) and **changes in societal values** (particularly in relation to CO2 emissions). The resulting scenarios were entitled: ‘Digging in our heels’, ‘Supply to the rescue’, ‘Double whammy’ and ‘Biting the bullet’.

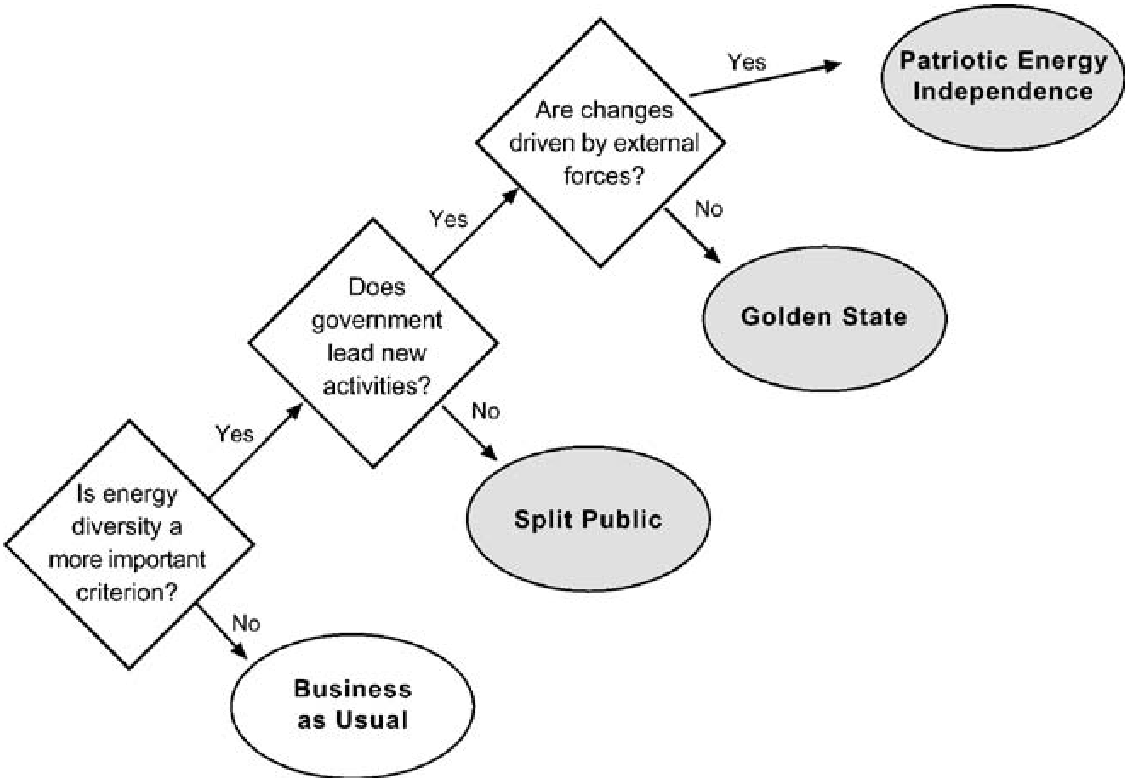


EPRI themes and scenarios.

12.10 Using energy scenarios to explore alternative energy pathways in California

This study considers four exploratory energy scenarios specific to California in light of the 2001 energy crisis. The methodology employed was to develop a logical relationship between the four scenarios that is linked to **three basic questions** about the importance of **energy diversity, the role of Government involvement, and scale of primary influence** in California's future energy pathway.

The relationship between these questions and the resulting scenarios is shown in the diagram below.



California energy scenario pathways.

13 Appendix C: Developing Themes

13.1 Suggested and considered themes from all stages of LENS project

At various stages of the LENS project numerous themes have been proposed, namely:

Methodology report (prospective themes identified prior to and at the 17th August 2007 LENS project workshop):

- DEMAND (high or low growth)
- GENERATION (central or remote)
- UTLISATION
- CUSTOMER (active or passive)

LENS Inputs Report:

- External Landscape
- Consumers
- Network Role

Studies reviewed in Inputs report (as per Table 1):

- Economic Growth.
- Technological Growth.
- Environmental Attitudes.
- Political and Regulatory.
- Social Values.
- Governance Systems.
- Regulatory approach to Carbon.
- Centralised generation.
- De-centralised generation.
- Level of CO2 reduction
- Evolution of fuel markets.
- Is energy diversity important?
- Does Govt lead new activity?
- Are changes driven by external forces?

14th December 2007 Workshop:

- Investment economics:

- Fuel availability:
- Environment:
- Consumers:
- Technology (previously network role)

Consultation responses:

- Consumer and Business Behaviour
- Economic Climate
- Political Landscape
- Global Sustainability
- Technological Advancement
- International/National Culture.

These suggestions contain many similarities and the above lists of suggested themes are summarised as follows:

- Technology – Generation, demand, network technology and rate of advancement
- Economics – General economic situation and rate of growth
- Consumers – Including business. Level of participation.
- Environment – Climate change, CO_2 emissions, overall sustainability.
- Governance – Political/Regulatory landscape
- Fuel – availability, diversity and markets.
- External Landscape – This contains many of the other theme suggestions and was hence deemed unclear and overly complex.
- Social values
- International/National culture

13.2 *Prioritising the critical uncertainties as themes*

13.2.1 High level inputs as critical uncertainties

As defined in Section 3, ***Inputs*** refer to the issues, *prospective* themes and data that are of specific use to the LENS project.

During the workshop of 14th December 2007, participants were split into three groups and after discussing and proposing alternative inputs were asked to rank the inputs in terms of their uncertainty for networks.

The diagram below represents the results of this process and also captures the subsequent discussions and agreed opinion of the academic team.

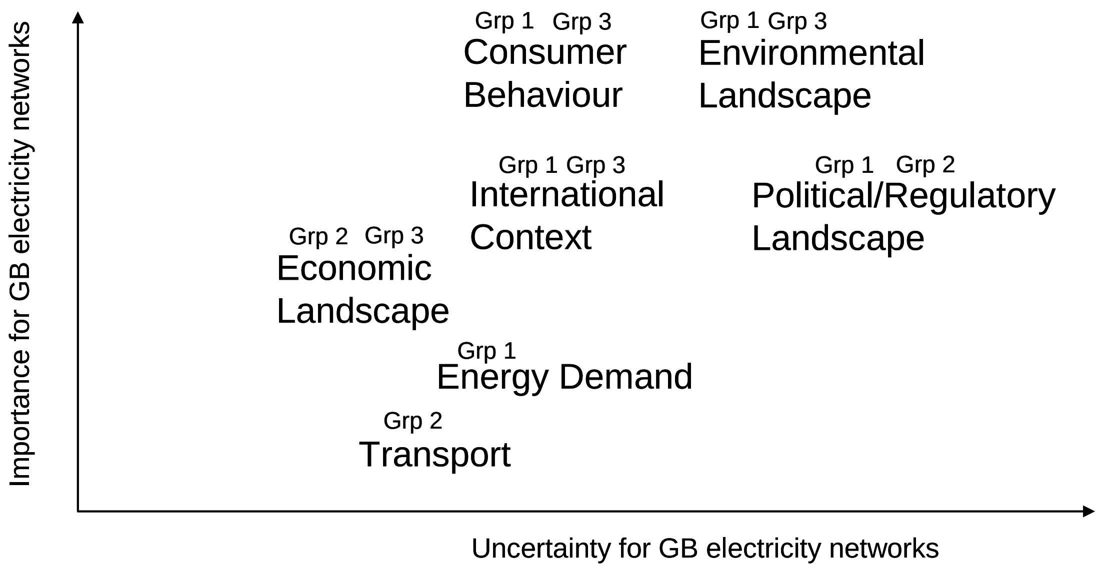


Figure 15: LENS project theme options.

- Group 1 ranked Environmental Landscape, Political/Regulatory Landscape, and Consumer Behaviour/Energy Demand/International Context as its top 3 most important high level inputs.
- Group 2 ranked Political/Regulatory Landscape, Transport, and Economic Landscape as its top 3 most important high level inputs.

- Group 3 ranked Consumer Behaviour, Environmental Landscape/International Context, and Economic Landscape as its top 3 most important high level inputs.

The above diagram is not intended to represent any of these inputs as unimportant or providing no uncertainty for networks. All of the inputs are important and introduce a degree of uncertainty. The intention is to reflect a subjective opinion that some of the inputs are marginally more interesting in terms of their potential influence on future networks.

Three critical uncertainties that could be proposed as themes are therefore: **Consumer Behaviour**, **Environmental Landscape** and **Political/Regulatory Landscape**. These critical uncertainties map clearly to the Consumers, Environment and Governance suggested themes in the list above.

13.2.2 Classification of potential themes in relation to importance and uncertainty for networks

Section 13.1 identified possible themes, each of which has merit and potential as a LENS theme.

Following an iterative process of discussion, the potential themes set out above were loosely ranked in terms of importance and uncertainty to future networks.

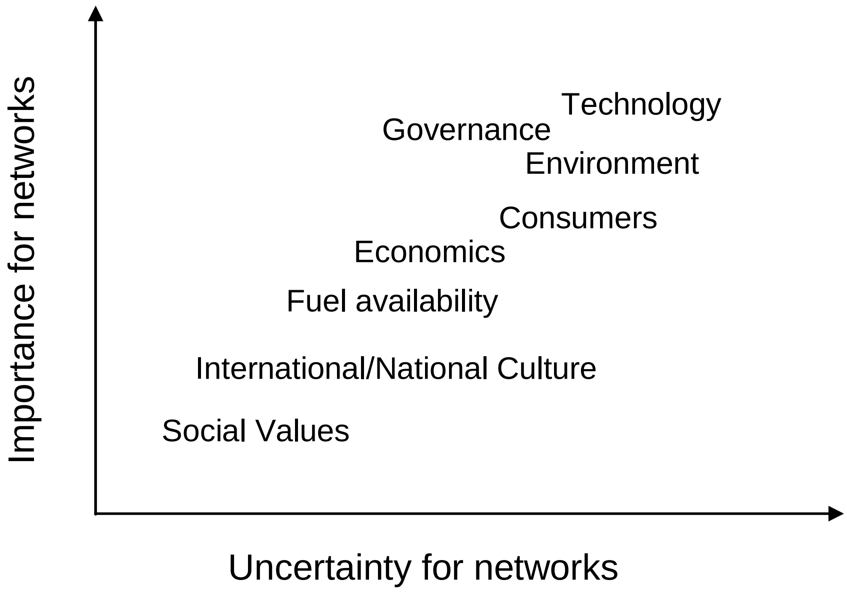


Figure 16: Potential LENS themes uncertainty and importance.

Again, the above diagram is not intended to represent any of these inputs as unimportant or providing no uncertainty for networks. The intention is to reflect the overall opinion of the academic team that some of the potential themes are marginally more interesting in terms of the influence they could have in terms of future networks.

14 Appendix D: Selection of Network Parameters

Workshop discussion 1 network themes/parameters:

- Primary functions of the network (e.g. bulk transfer, backup)
- Size of the network (e.g. heavy versus light, thick versus thin)
- Remote or local generation relative to demands (e.g. long versus short)
- Transmission and distribution roles
- Network reliability and security (actual or desired)
- Level of network redundancy
- Deployment of technology in network
- Active or passive management
- Demand to generation variability/correlation
- Power flow magnitude and direction
- Centre of gravity or demand/generation, spatial differentiation between demand and generation, changes over time
- Network expansion constants

Workshop discussion 2 network themes/parameters:

- Reliability standard
- Degree of innovation in networks
- Manage constraints versus expand network approach adopted
- Electricity/energy weighting – proportion of energy that is delivered in the form of electricity
- Local versus regional versus national energy solutions
- Scale and distribution of generation within networks
- Variability and diversity of generation mix
- Level of utilisation of expected pervasive communications capabilities
- Level of network complexity
- Safety performance desired and delivered
- Reliance on knowledge and skills for operating networks versus automated/software decision making
- Degree of development of integrated solutions

The two independently developed lists of metrics, dimensions and themes were then analysed as follows to identify a consolidated list of network parameters.

Workshop 1	**Workshop 2**	**Consolidated parameter**
Primary functions of the network (bulk transfer, backup)		Primary role of transmission network Primary role of distribution network
Size of the network		Size of transmission network Size of distribution network
Remote or local generation relative to demands	Scale and distribution of generation within networks	Scale and location of generation
Transmission and distribution roles	Local versus regional versus national solutions	Local, regional and national coordination
Network reliability and security	Reliability standard	Network reliability
Level of network redundancy		Network security and redundancy
Deployment of technology in network	Degree of innovation in networks	Technology and innovation in networks
Active or passive management	Manage constraints versus expand network approach adopted	Role of active management
Demand to generation variability/correlation	Variability and diversity of generation mix	Demand and generation variability and correlation
Power flow magnitude and direction		Power flow magnitude and direction
	Electricity/energy weighting – proportion of energy that is delivered in the form of electricity	Size of electricity role in energy sector
	Level of utilisation of expected pervasive communications capabilities	Role of enhanced pervasive communications in network operations
	Level of network complexity	Complexity of network
	Safety performance desired and delivered	Network safety
	Reliance on knowledge and skills for operating networks versus automated/software decision making	Manual or automated operational regime

	Degree of deployment of integrated solutions	

As a result of this exercise a consolidated list of network parameters emerged and these are taken forward in the identification and development of the network scenarios:

- Primary role of transmission network
- Primary role of distribution network
- Size of transmission network
- Size of distribution network
- Scale and location of generation
- Local, regional and national coordination
- Network reliability
- Network security and redundancy
- Technology and innovation in networks
- Role of active management
- Demand and generation variability and correlation
- Power flow magnitude and direction
- Size of electricity role in energy sector
- Role of enhanced pervasive communications in network operations
- Complexity of network
- Network safety
- Manual or automated operational regime

15 References

[1] Long-Term Electricity Network Scenarios (LENS) report on scenario inputs and second consultation. December 07. Ref 287/07. http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=22&refer=Networks/Trans/ElecTransPolicy/lens

[2] Scenarios Development Methodology, Long-Term Electricity Network Scenarios (LENS) Project. November 07. Ref 273/07. http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=18&refer=Networks/Trans/ElecTransPolicy/lens

[3] Long Term Electricity Network Scenarios - initial thoughts and workshop invitation. June 07. Ref 146/07. http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=1&refer=Networks/Trans/ElecTransPolicy/lens

[4] Long Term Electricity Networks Scenarios Workshop Presentation. August 07. http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=14&refer=Networks/Trans/ElecTransPolicy/lens

[5] Long Term Electricity Network Scenarios December Workshop and Consultation summary. http://www.ofgem.gov.uk/Networks/Trans/ElecTransPolicy/lens/Pages/lens.aspx

[6] Scenarios – The Art of the Strategic Conversation. Kees Van Der Heijden. 1996. John Wiley and Sons Ltd.

[7] Elders, I., G. Ault, S. Galloway, J. McDonald, M. Leach, E. Lampaditou and J. Köhler (2006). Electricity network scenarios for the United Kingdom in 2050, in T. Jamasb, W.J. Nuttall and M.G. Pollitt (eds), Future Electricity Technologies and Systems, Cambridge: Cambridge University Press. http://www.supergen-networks.org.uk/publications/publications_softcopies/EPSRC-SGFNT-TR-2005-001-2050-scenarios-report-July2005.PDF

[8] IEE Power Systems and Equipment Professional Network, 'Technical Architecture – A first report', DGCG 3/05, May 2005. http://www.ofgem.gov.uk/NETWORKS/ELECDIST/POLICY/DISTGEN/Documents1/10983-TA.pdf

[9] European Technology Platform Smartgrids, 'Vision and Strategy for Europe's Electricity Networks of the Future', 2006. http://www.smartgrids.eu/documents/vision.pdf

[10] European Technology Platform Smartgrids, 'Strategic Research Agenda for Europe's Electricity Networks of the Future', 2007. http://www.smartgrids.eu/documents/sra/sra_finalversion.pdf

[11] Energy billing and metering: changing consumer behaviour. A consultation on policies presented in the energy white paper – 07/1220. BERR August 2007. http://www.berr.gov.uk/files/file40456.pdf

[12] Tyndall Centre for Climate Change Research 2005. World Transport Scenarios Project. Technical Report 25. http://www.tyndall.ac.uk/research/theme1/final_reports/t3_15.pdf

[13] Hodsworth. M. and Steedman. P. 2007. 16 pain-free ways to help save the planet. http://www.ncc.org.uk/nccpdf/poldocs/NCC081_16_ways.pdf

[14] Dutton, A. G., Bristow, A. L., Page, M. W., Kelly, C. E., Watson, J. and Tetteh, A. (2005) The Hydrogen energy economy: its long term role in greenhouse gas reduction, Tyndall Centre Technical Report 18 http://www.tyndall.ac.uk/research/theme2/final_reports/it1_26.pdf

[15] Peters M., Powell J, (2004) Fuel cells for a sustainable future II: Tyndall Working Paper 64 http://www.tyndall.webapp1.uea.ac.uk/publications/working_papers/wp64.pdf

[16] Energy and Utility Skills. 2001. Employment and Skills Study. Skills Intelligence for Electricity. http://www.euskills.co.uk/download.php?id=68

[17] Final statements on the Strategic Review of Telecommunications, and undertakings in lieu of a reference under the Enterprise Act 2002. Sept 2005. Ofcom http://www.ofcom.org.uk/consult/condocs/statement_tsr/

[18] 80% Challenge: Delivering a low carbon UK. World Wildlife Federation (WWF), Institute for Public Policy Research (ippr), and Royal Society for the Protection of birds (RSPB). Oct 2007. http://www.ippr.org/publicationsandreports/publication.asp?id=573

[19] Analysis of the UK potential for Combined Heat and Power. Department for Environment, Food and Rural Affairs (DEFRA). Oct 2007. http://www.defra.gov.uk/environment/climatechange/uk/energy/chp/pdf/potential-report.pdf

[20] Heat Call for Evidence. Department for Business and Enterprise Regulatory Reform (BERR). Jan 2008. http://www.berr.gov.uk/energy/sources/heat/page43671.html

[21] The ampere strikes back: How consumer electronics are taking over the world. Energy Saving Trust (EST). July 2007. http://www.energysavingtrust.org.uk/uploads/documents/aboutest/TheAmpereStrikesBack%2024thJuly07.pdf

[22] UK Fuel Cell Development and Deployment Roadmap. Fuel cells UK. 2005. http://www.fuelcellsuk.org/_sharedtemplates/Roadmap-Fuel_Cells_UK-final.pdf