Electricity Network Scenarios for Great Britain in 2050

Final Report for Ofgem's LENS Project
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Disclaimer

This report contains forward looking scenarios for electricity networks in Great Britain in 2050. All statements other than statements of historical fact are, or may be deemed to be, forward looking scenarios. Forward looking scenarios are scenarios of future developments that are based on current expectations and assumptions and readers should not place undue reliance on them. There are a number of factors (including risks and uncertainties) that could cause future developments to differ materially from those stated in, implied by or inferred from the forward looking scenarios contained in this document.

The data tables in the report and its appendices have been generated under a range of input assumptions which have been formed as part of a scenario development process which is outlined in detail in the report and its appendices. The data should not be regarded as projections or predictions nor should reliance be placed on the data set out in the data tables. The forward looking scenarios and data are expressly qualified in their entirety by the cautionary statements set out in this disclaimer.

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Ofgem Foreword

Ofgem[1] is pleased to be able to publish the final Long-Term Electricity Network Scenarios (LENS) report. We envisage that this report and the ongoing LENS project and initiative will play an important and continuing role in helping to inform the development of the regulatory framework to protect the interests of present and future consumers, and to deliver future energy networks to meet the Government's challenging renewable and climate change targets. We also hope the document will allow Ofgem, Government, the energy industry and other stakeholders to understand better the issues that these targets raise for the future development of our energy networks and to debate longer term network issues.

This report delivers on our commitment, in response to the Government's Energy Review of May 2006, to play a central role in developing a longer term perspective on the challenges the energy networks will face and how they might need to change, develop and deploy new technologies, for example, to meet the renewable and climate change targets.

Meeting Government renewable and climate change targets will have profound implications for electricity networks in Great Britain as these networks are being asked to rise to new challenges. These challenges mark a radical departure from the way in which networks have been developed and managed during the 20th century when our electricity was primarily delivered by conventional, large-scale thermal generation technologies.

Against this backdrop, stakeholders need a consistent and coherent perspective of the way in which the networks could plausibly evolve. This has been the aim of the LENS project. The project has sought to develop a range of plausible electricity network scenarios for Great Britain for 2050, around which industry participants, Government, Ofgem and other stakeholders can discuss longer term network issues and try to ensure that the regulatory framework will allow companies to make investments with a view to meeting future challenges.

We hope that readers will find the work ground-breaking and innovative. It is the first time that long-term scenarios for Great Britain have been developed with a specific focus on electricity networks. Previous exercises to develop long-term scenarios have looked more at the wider energy or electricity sector or focused on meeting specific targets or on the medium-term.

We have sponsored and led the LENS project with substantive support from our academic partners, who produced this report with guidance and input from us. Our lead partner is the Institute for Energy and Environment (InstEE), University of Strathclyde. Their work has been supported by King's College London, University of London. Peer review has been undertaken by Jim Watson of SPRU (Science and Technology Policy Research Unit) at the University of Sussex and by Michael Pollitt of the Judge Business School, University of Cambridge. Throughout the project, our academic partners have benefited from extensive dialogue and commentary from industry observers and stakeholders.

The LENS project has identified three main drivers of change. First, 'environmental concern', or the level to which the environment affects the decision-making of individuals, communities, private companies, public institutions and the Government (on a UK and global basis). Second, 'institutional governance', or the extent to which institutions will intervene in the energy market and the development of the electricity networks. Finally, 'consumer participation', or the level to which all types of consumers (commercial, industrial, domestic and public) are willing to participate actively in the energy/electricity market and to drive greater energy efficiency.

[1] Ofgem is the Office of Gas and Electricity Markets. Ofgem operates under the direction and governance of the Gas and Electricity Markets Authority (the Authority). The Authority's powers are provided for under different pieces of legislation, the key ones being the Gas Act 1986 (the Gas Act), the Electricity Act 1989 (the Electricity Act) and the Utilities Act 2000. In this document the terms Ofgem and Authority are used interchangeably.

Based on a consideration of the plausible evolution of these drivers, the Final Report sets out five scenarios for the future development of GB electricity networks:

- **Big Transmission and Distribution**, in which transmission system operators (TSOs) are at the centre of networks activity. Network infrastructure development and management continues as expected from today's patterns, while expanding to meet growing demand and the deployment of renewable generation.

- **Energy Service Companies**, in which energy service companies (ESCOs) are at the centre of developments in networks, doing all of the work at the customer side. Networks contract with such companies to supply network services.

- **Distribution System Operators**, in which distribution system operators (DSOs) take on a central role in managing the electricity system. Compared to today, distribution companies take much more responsibility for system management including generation and demand management, quality and security of supply, and system reliability, with much more distributed generation.

- **Microgrids**, in which customers are at the centre of activity in electricity networks. The self-sufficiency concept has developed very strongly in power and energy supplies. Electricity consumers take much more responsibility for managing their own energy supplies and demands. As a consequence, microgrid system operators (MSOs) emerge to provide the system management capability to enable customers to achieve this with the new technologies.

- **Multi Purpose Networks**, in which network companies at all levels respond to emerging policy and market requirements. TSOs still retain the central role in developing and managing networks but distribution companies also have a more significant role to play. The network is characterised by diversity in network development and management approaches.

These scenarios suggest a range of plausible outcomes for GB electricity networks that is perhaps wider than is often acknowledged in recent debates about energy policy and network investment. They imply that radical change for the electricity sector, including networks, and related sectors (such as transport and heat) is both possible and, depending on how key underlying driving forces play out, conceivable.

The breadth of the scenarios suggests that regulatory policy will need to be sufficiently flexible and adaptable to accommodate uncertainty and potentially radical change. For several scenarios, stakeholders may need to develop strategies and act on them in relatively short timeframes. It will be important, particularly for protecting the interests of future consumers, that Ofgem and other policy makers do not inadvertently 'close off' options for the development of the networks and the wider sector they serve.

The publication of the final LENS report marks the culmination of over a year's effort. We remain committed to continuing the LENS initiative over the coming months and years and intend to update the report at regular intervals. Our next step will be to publish our views on the potential implications of the scenarios for the networks and the way we regulate them. This will help inform and guide future (and current) network regulatory price control reviews and our fundamental review of the regulatory framework for the energy networks through our RPI–X@20 project.

Stuart Cook
Director, Transmission

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Executive Summary

Introduction

This report sets out five plausible electricity network scenarios for Great Britain in 2050. It has been prepared by us for Ofgem in the context of their Long-Term Electricity Network Scenarios (LENS) project, and has benefited from several rounds of stakeholder consultation, workshops and peer review.

Ofgem leads the LENS project and has facilitated the development of the scenarios in this report through public consultations and workshops and by providing additional guidance and input for our consideration. Peer review has been undertaken by Jim Watson of SPRU (Science and Technology Policy Research Unit) at the University of Sussex and Michael Pollitt of Cambridge University and the Judge Business School.

Ofgem's main objective for the LENS project has been to facilitate the development of a range of plausible electricity network scenarios for Great Britain for 2050, around which industry participants, Government, Ofgem and other stakeholders can discuss longer term network issues. The project has also set out to: quantify the scenarios through 'energy system' modelling; develop a consistent set of 'way-markers' for 2025 (or staging points on the route towards 2050); and to establish views on the scenarios' implications for networks and their regulation. On this latter aspect, Ofgem intends to publish its own views in due course.

Scenarios are a useful way of grouping and presenting the major drivers and issues that are likely to affect future GB electricity networks, such that valuable insights are gained and 'strategic conversations' can emerge. The scenarios presented in this report have been developed according to a robust methodology, and provide stakeholders of the GB networks with a focus for discussion about longer term issues for networks. The scenarios should not be viewed as either forecasts or blueprints for future networks. Care has been taken to ensure that all major issues for networks have been written into the scenarios, so that between them there is comprehensive coverage of relevant stakeholder concerns.

This report is path-breaking as it presents for the first time a set of long-term scenarios for Great Britain with a specific focus on electricity networks. 'Electricity networks' are the transmission and distribution assets (i.e. the primary current carrying plant and the associated operating systems) that transport electrical energy from generation sources to demand (including consumers, industry, and the service sector). This definition also extends to private networks, offshore networks and interconnectors. Other scenario studies in this area have typically looked at the wider GB or UK energy and electricity sector, or had a more detailed, medium-term focus on networks, with lesser consideration of broader energy system aspects. The LENS project has had to consider relevant aspects of the broader GB energy and electricity sector, including European and global influences, and of the Government's environmental targets, and even the trends *underlying* these aspects.

Such consideration was required before we could develop scenarios for electricity networks, which only have a meaning and purpose within this broader context. Although they provide insights into the Government's targets, the LENS scenarios have not been specifically designed to meet them. Instead, the focus has been more on the driving forces underlying the targets, such as the environmental attitudes and behaviours of society as a whole and the impact these may have.

Scenario development process

An eight-stage process has been followed to develop the LENS scenarios. This methodology was adopted from authoritative publications on scenario development and is a tried and tested approach to scenario development. The eight stages in the LENS project scenario development process are:

1. Define the scenarios' recipient
2. Frame the focal question that the scenarios must address
3. Information gathering to inform the scenario development process
4. Identify themes to focus the scenario development process
5. Sketch possible pathways between now and 2050
6. Write scenario narratives/storylines
7. Model scenarios to test key aspects of the scenarios
8. Identify potential implications of the scenarios on the focal question

It is important to note that the scenario development process is not quite as straightforward (or as linear) as this eight step process suggests. While each of the eight steps formed a major part of the LENS project, the actual process has been more heuristic in nature, as expected.

From the information gathering process, three main themes emerged for the development of scenarios for GB electricity networks in 2050:

- **Environmental concern (moderate or acute):** 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).
- **Consumer participation (passive or active):** 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, motivated by economic or environmental factors.
- **Institutional governance (market led or Government led):** 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.

Five scenarios were developed by considering the interactions between these main themes. The five scenarios encompass a wide range of plausible outcomes for electricity networks in 2050. Scenario narratives were produced and continually refined as the scenario development process progressed.

The five identified scenarios were also modelled in the MARKAL energy system model to inform the scenarios on aspects of plausibility and quantitative detail. In this role, the model provided an additional layer of insight into the causes and effects of changes in the electricity system. Each model run represents just one specific instance of inputs and assumptions for that scenario; therefore, alternative model outcomes would have been possible too for each scenario. The aim of the modelling exercise was not to provide predictions or forecasts of the future, but rather to test the broad plausibility and internal consistency of the individual scenario storylines. This was done by ensuring that the required model input assumptions appeared to be within plausible bounds. The results of the model runs were not made (or intended) to match the scenario storyline exactly.

Finally, way-markers in the year 2025 were produced for each scenario, to illustrate events and developments that might be occurring on the path to 2050. The way-markers provide a tool to assess the emerging pathway along which networks seem to be developing, which allows users of the scenarios to draw conclusions about the emergence of particular scenarios.

Electricity network scenarios for Great Britain in 2050

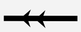
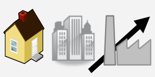
The five network scenarios have been developed to incorporate a rich mix of narrative, illustrations and modelling results. Together, they demonstrate a wide range of plausible outcomes for electricity networks by 2050. A brief summary of each scenario is presented below, alongside a geographical pictogram of the scenario.

KEY TO GEOGRAPHICAL PICTOGRAMS:

A. Each pictogram illustrates key qualitative aspects of the scenario narrative:

- It indicates the main forms of **generation and technology** featuring in the scenario, and where they would be **located geographically and within the system**.
- The picture of Great Britain represents the **transmission system**, while the ‘call out bubble’ represents the **distribution system**.
- The **line thickness** in the picture of Great Britain and the ‘call out bubble’ represents the required **network capability** at the transmission and distribution level, respectively.
- The **size and number of arrows** in the picture of Great Britain and the ‘call out bubble’ represent the **level of utilisation** of the network capacity.
- The ‘call out bubble’ shows details of the network architecture in the **distribution system** with locations of active components, such as generation, demand response and control. It distinguishes between **High Voltage** (HV), **Medium Voltage** (MV) and **Low Voltage** (LV) levels within the distribution system.

B. The symbols used in the pictograms have the following meaning:

	Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation
	Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present
	Renewable electricity generation (including wind, biomass, etc . but excluding marine)
	Renewable marine electricity generation (wave, tidal, etc.)
 CCS	Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation
 ESCO	System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks
-----	Information and communications technology (ICT) infrastructure for network operational management
	Power system transformer between different voltage levels
	Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

'**Big Transmission & Distribution**': Transmission system operators (TSOs) are at the centre of networks activity. The environmental concern of society in general does not grow significantly past today's already heightened 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. Consumers are also satisfied that existing industry structures are best placed to provide a secure and economic electricity supply. A key feature is that fossil fuels for electricity generation, home and commercial energy supplies and transport continue to form a large proportion of the electricity generation portfolio for some time. In addition, a significant amount of large scale renewable and low carbon generation capacity is developed in line with current planned developments and trends. Electricity networks expand to meet the additional energy demands and the requirement to connect large scale renewable generation (both onshore and offshore). Interconnectors to Europe are developed to access additional economic sources of energy and provide additional network security and system operational services. Distribution networks grow in line with energy demands but radical advances in operational management are not required.

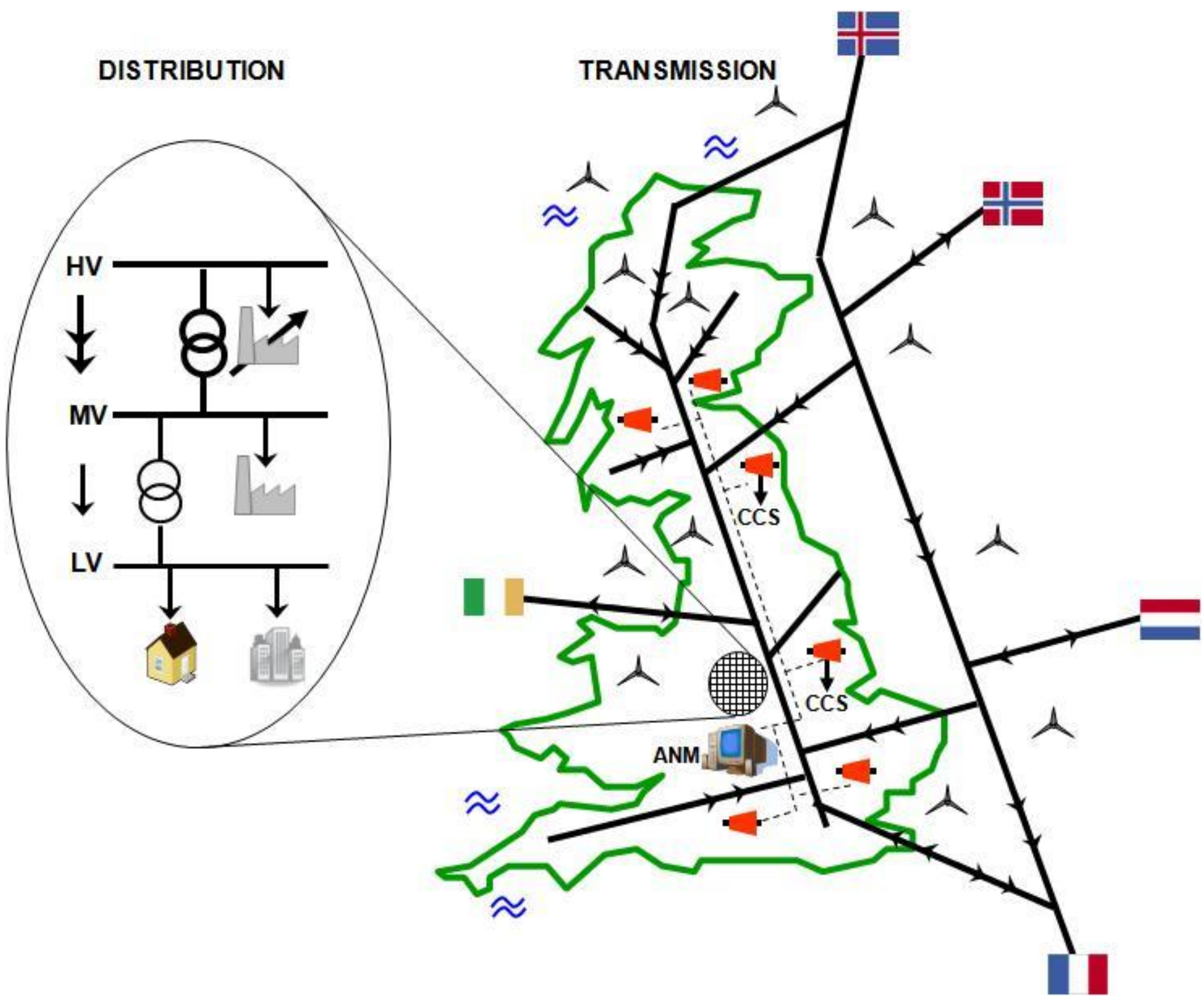


Figure 1: 'Big Transmission and Distribution'

'**Energy Service Companies**': Energy service companies (ESCOs) are at the centre of developments in networks. Consumers remain relatively passive towards their energy supply despite increased levels of environmental concern. Although market solutions are still preferred, strong intervention is not ruled out to address environmental issues. Consumers have a desire to see environmental issues addressed, and strongly feel that this is the responsibility of industry and Government. 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 while firmly believing that it is the duty of others to sort it out. Electricity networks develop to facilitate a vibrant 'energy services' market, that meets the needs of these passive consumers. Much of this development is focused on system operational management approaches to enable effective local energy production and customer services. Distribution networks develop to accommodate the connection of increased levels of distributed generation at a local level, while transmission networks develop to facilitate connection of renewable energy sources.

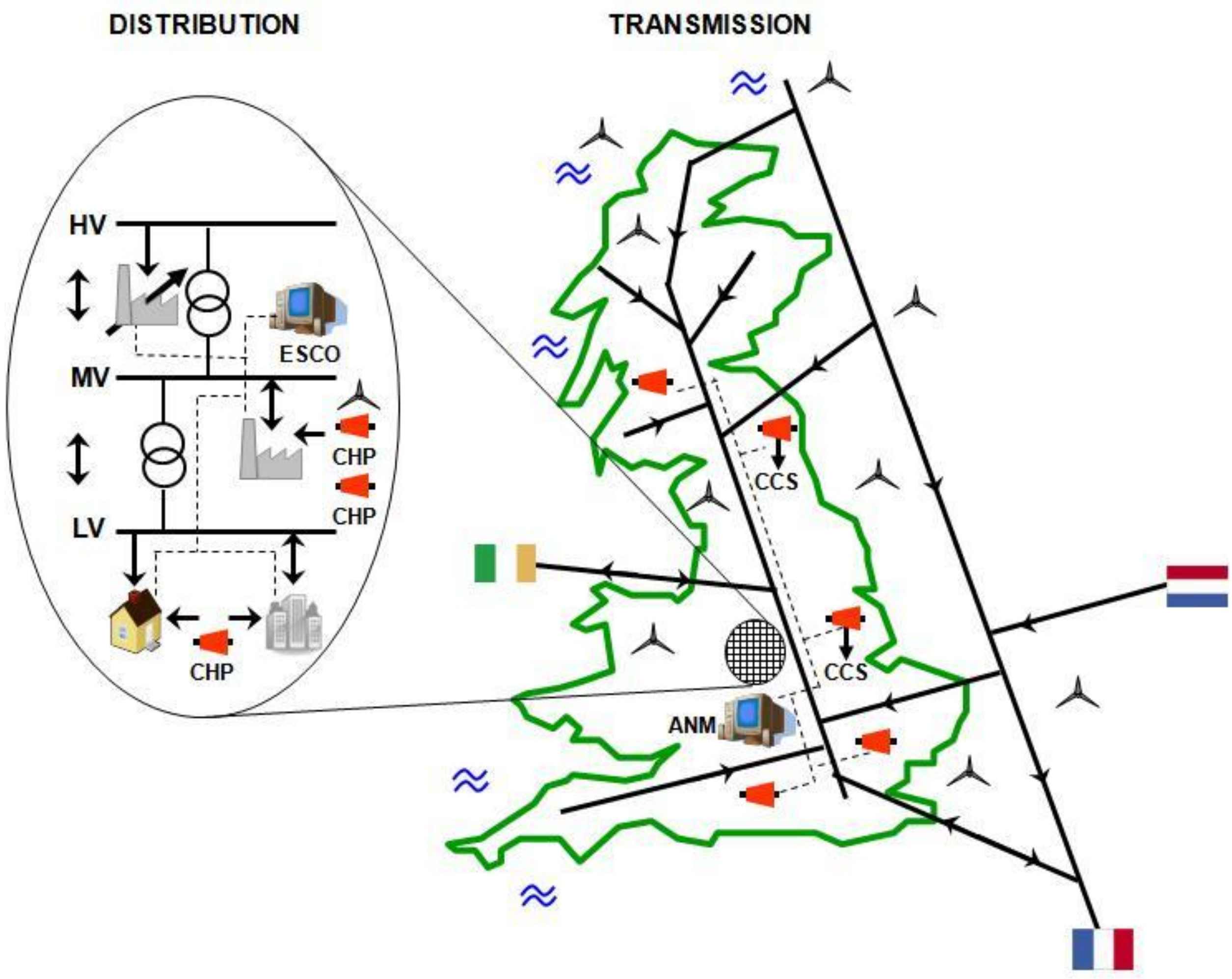


Figure 2: 'Energy Service Companies'

‘**Distribution System Operators**’: Distribution system operators (DSOs) take on a central role in managing the electricity system. 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. Consumers actively participate 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. In electricity networks the largest change is in the development and operation of distribution networks. The networks themselves adapt to accommodate large levels of distributed generation of different technologies and operationally the distribution companies manage the network much more actively. Demand side management grows strongly and this provides a tool for system management at both transmission and distribution levels. The transmission network continues to provide the backbone for bulk power transmission, but the flows are more variable and on average of a lower level.

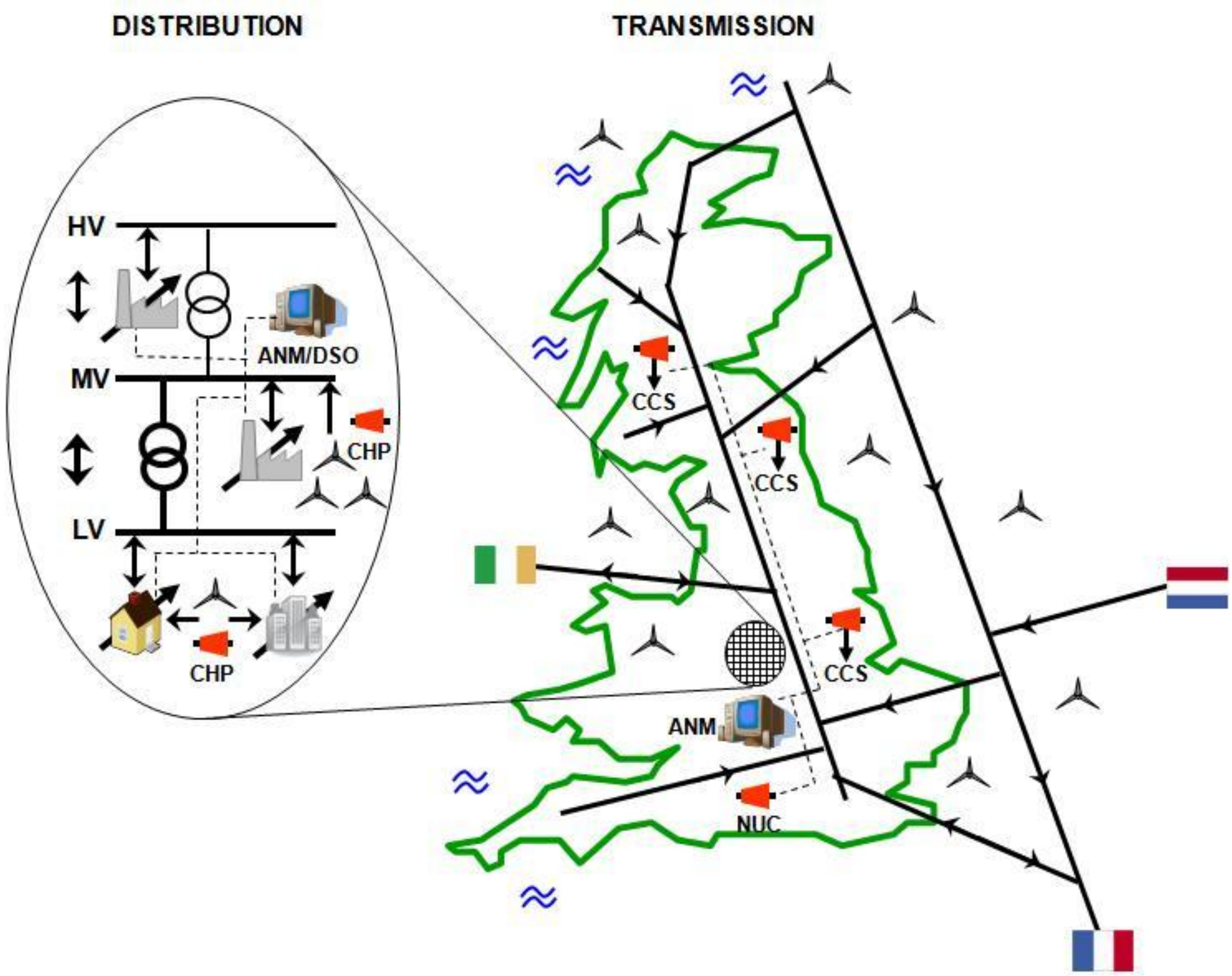


Figure 3: ‘Distribution System Operators’

'**Microgrids**': Consumers are at the centre of activity in electricity networks. They 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 these objectives 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). Electricity networks undergo a radical transformation with very large volumes of generating units and demand response schemes operating at a local level. While the transmission infrastructure still plays a key role in system operations, the utilisation of network capacity is relatively low and the role of centralised generation is reduced. Within distribution networks much more active management is required by the network companies at voltage levels right down to customer supplies. Customer demand management is prevalent and this is often to meet the availability of local sources of energy.

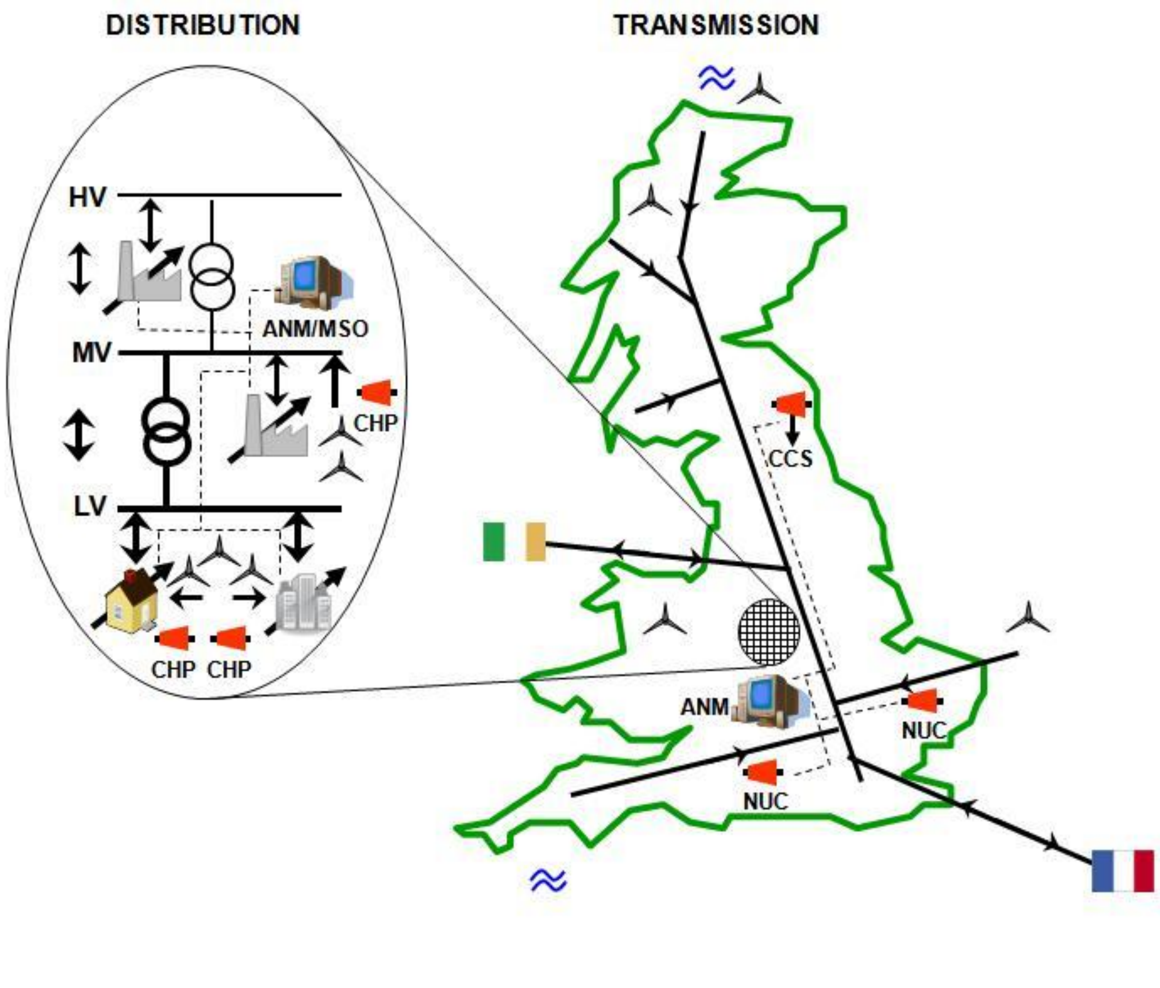


Figure 4: 'Microgrids'

'**Multi Purpose Networks'**: Network companies at all levels respond to emerging policy and market requirements. TSOs still retain the central role in developing and managing networks but distribution companies also have a more significant role to play. The defining feature of this scenario is the pervasive feeling of uncertainty of society towards environmental issues, fossil fuel prices and energy security. 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. Electricity networks are characterised by regional variations in architecture and capability, with the risk of stranded assets in some places and at the same time significant congestion in other places.

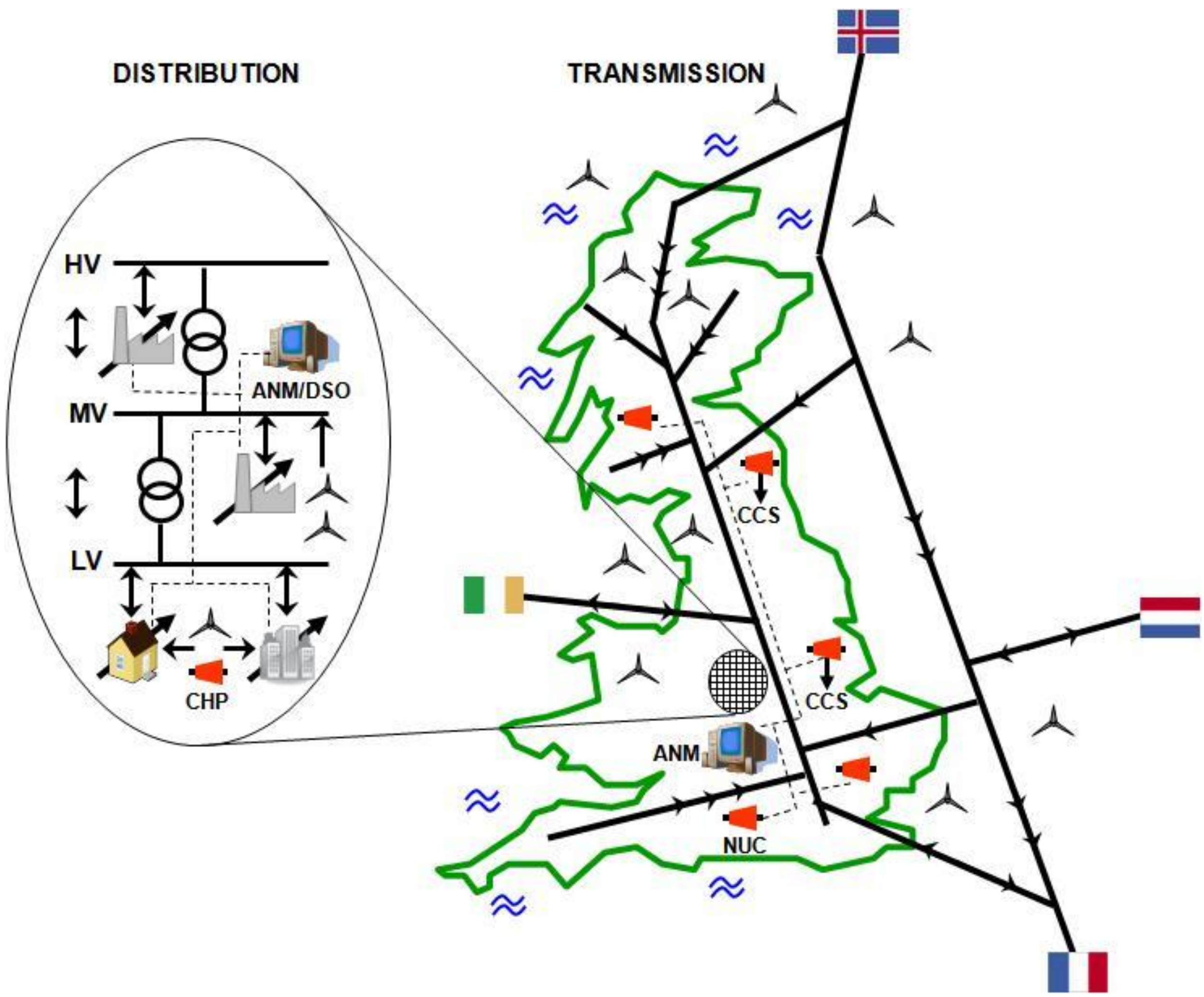


Figure 5: 'Multi Purpose Networks'

Cross-scenario comparisons

This section provides a brief comparison across the scenarios to draw out the main similarities and contrasts.

In terms of the ***transmission networks***:

- ***Network capacity/capability required*** – The 'Big T&D' scenario envisages a major development of the transmission network capacity whilst, at the other end of the spectrum, the 'Microgrids' scenario outlines a situation where there is little or even no need for further transmission capacity (although there may still be a need for maintenance or upgrading).
- ***Utilisation of the network capacity*** – The scenarios where there is more consumer participation and greater production of electricity from within the distribution systems lead to lower levels of utilisation in the transmission system.
- ***Geographical reach of the transmission network*** – Offshore and interconnector development activity is at the 'high end' in the 'Big T&D' scenario and at the 'low end' in the 'Microgrids' scenario.
- ***Type, location and scale of generation*** – The main differences across the scenarios are the relative amounts of offshore generation, the level of generation embedded in the distribution systems, and the balance between intermittent renewables and dispatchable thermal generation.
- ***Operational management approaches*** – The transmission operator takes on the major responsibility for system operation in the 'Big T&D' and 'Multi Purpose Networks' scenarios, but this role is shared with other entities in the 'ESCOs', 'DSOs' and 'Microgrids' scenarios.

In terms of the ***distribution networks***:

- ***Level of consumer activity*** – Several scenarios indicate a high level of consumer activity in generation and demand response, and in the adoption of electric vehicles and energy storage. There are potentially major implications of this for the development, operation and regulation of distribution networks.
- ***New players in distribution networks*** – These appear in some scenarios, for example energy service companies (ESCOs), microgrid system operators (MSOs), and active consumers. All have the potential to change market dynamics and the way in which the networks are used.
- ***More dynamic and even bi-directional power flows*** – Such flows are envisaged in all the scenarios other than 'Big T&D', as a result of new activities in distribution networks.

Table 1 compares key quantitative features of the scenarios, as produced by the Markal modelling exercise. The changes in figures between the model runs illustrate that network development could be affected by both the size and the make-up of the electricity generation mix, changes in different forms of energy demand, and technological developments that stimulate 'new' electricity demands in a variety of sectors, of which perhaps the most significant is transport. The figures in the table are not predictions or forecasts of the future; rather, they add quantitative detail to the scenario narratives.

When figures for certain items (e.g. a particular type of electricity generation) are similar across scenarios, this does not necessarily imply that a particular outcome is more likely; there are other possible outcomes too, that may not be captured by the figures in this table.

	2000	2050				
		Big T&D	ESCO	DSO	MG	MN
Total final energy demand (PJ) [1]	**6,189**	**6,468**	**5,807**	**4,910**	**4,558**	**5,785**
Transport	1,855	2,142	1,542	1,292	1,255	1,538
Residential	1,961	1,920	1,921	1,625	1,431	1,920
Other (Industry, Services & Agriculture)	2,374	2,407	2,345	1,993	1,872	2,327
Total electricity demand (PJ) [2]	**1,176**	**1,522**	**1,623**	**1,243**	**1,044**	**1,662**
Transport	20	85	330	126	263	343
Residential	403	587	473	378	195	531
Other [3]	754	851	819	739	585	788
Total electricity generation capacity (GW)	**84**	**102**	**121**	**105**	**113**	**114**
Large scale generation:						
Fossil (inc. CCS)	59	68	55	27	9	49
Nuclear	12	0	13	19	27	18
Renewables	4	20	24	22	16	24
Interconnectors	2	11	10	10	12	11
CHP	4	2	1	0	0	2
Storage	3	1	1	1	1	1
Sub-total	**84**	**102**	**104**	**81**	**66**	**105**
Small scale generation:						
Micro CHP	0	0	0	0	24	0
Microgen	0	0	17	24	23	9
Sub-total	**0**	**0**	**17**	**24**	**48**	**9**
Total electricity generation output (PJ)	**1,288**	**1,652**	**1,874**	**1,501**	**1,462**	**1,860**
Large scale generation:						
Fossil (inc. CCS)	854	1,173	1,016	457	100	913
Nuclear	282	0	334	502	713	482
Renewables	46	271	300	279	209	279
Interconnectors	52	182	103	103	103	103
CHP	45	27	8	7	7	27
Storage	10	0	0	0	0	0
Sub-total	**1,288**	**1,652**	**1,761**	**1,348**	**1,131**	**1,804**
Small scale generation:						
Micro CHP	0	0	0	0	142	0
Microgen	0	0	113	153	189	56
Sub-total	**0**	**0**	**113**	**153**	**331**	**56**
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%	30%	47%	61%	71%	45%
Electricity sector reduction	0%	67%	88%	95%	99%	79%

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 1 – Comparison across scenarios of modelling results for 2050 (vs. 2000)

Scenario implications and key insights

The scenarios suggest valuable insights for stakeholders in GB electricity networks.

The first and most fundamental insight gained is that there is a ***relatively wide range of plausible outcomes*** for GB electricity networks in the longer term. The five network scenarios paint very different pictures for the architecture of networks, operational arrangements of networks, the main players in developing, operating and using the networks, the different objectives for the regulation of networks, and so on. For this reason, there is a ***relatively high degree of uncertainty*** regarding the future form of electricity networks in GB. Scenarios provide a tool for stakeholders to assess this uncertainty and start the process of considering the most appropriate strategies to position themselves and the GB electricity networks for the long term.

Each of the five scenarios challenges the status quo in electricity networks, although arguably the 'Big T&D' and 'Multi Purpose Networks' scenarios are most like the situation prevailing today. The scenarios show that various driving forces provide the stimulus for a period of substantial change for GB electricity networks and the wider electricity and energy sector in coming years.

Although the development of primary power carrying plant differs across the scenarios, one relatively common element is the development of ***more extensive communications and control infrastructure***. Information and communications technology (ICT) has a major part to play in each of the scenarios – in some cases it serves primarily to facilitate consumer participation in electricity markets and networks, while in other cases it supports the network operators managing more complex networks (at transmission and distribution levels).

More generally, ***technology plays a key role in each of the scenarios.*** The driving forces of electricity generation and demand technologies (including electrical or even hydrogen powered vehicular transport and building technologies) lie behind the changing requirements for the GB electricity networks. New developments in such technologies will determine much of the change that networks must respond to, while new technologies for networks themselves are also important.

The organisational implications differ widely across the scenarios, with new players (e.g. ESCOs, MSOs) and new roles (e.g. managing much more active and complex distribution systems) emerging over time. Changing and diverse organisational arrangements across the scenarios and through time bring with it the ongoing requirement for ***clarity of responsibilities*** for security, control, quality, efficiency and economy of electricity supplies.

Many of the scenarios paint pictures of future electricity networks with ***technical and operational challenges*** in areas such as: system operation in high renewable and high interconnection situations, microgrid-type operation in local areas, the development of DSO functions, and management of demand response. ***Interconnectors to neighbouring countries take on various roles*** in different scenarios such as bulk import; two-way bulk exchanges based on market operation; and pan-European balancing (due to intermittent renewables and/or micro-generation). The arrangements for managing much greater flows in interconnectors and the necessary developments of the GB transmission system to support greater interconnector activity go beyond those in place today in both scale and scope.

Network capacity requirements are relatively similar across scenarios, however there are ***widely varying levels of network utilisation*** across and within the scenarios. For example, intermittent renewable generation may produce a lower average utilisation of transmission network capacity than high load factor thermal generation, but a higher requirement for operational management for system balancing. In distribution networks, the influences of demand side management, distributed electricity generation resources and energy storage are likely to make utilisation variable across the country and through time.

Across most scenarios (to varying degrees), there are more ***active distribution networks***. The technological, commercial, regulatory and organisational arrangements for management of more active networks by the distribution companies is an area where more effort would need to be placed in future.

With different institutional governance arrangements across the scenarios and a spectrum of different approaches from strongly Government led to strongly market led approaches, ***it is likely that the issue of network development will be an area of major debate in future***. Flexible approaches to investment in network and support infrastructures and network regulation are likely to be required.

In reality, elements of different scenarios might evolve in parallel with each other. This is not a deficiency of the scenarios approach, but it does require that users of the scenarios are imaginative with their use of the scenarios. For example, it is entirely possible that while transmission networks follow a path of development as outlined in the 'Big T&D' scenario, distribution networks could emerge with elements of the 'ESCOs', 'DSOs' and 'Microgrids' scenarios.

Recent developments such as the Government's proposed Renewable Energy Strategy, the Crown Estates Round 3 offshore wind letting arrangements, and new offshore transmission arrangements provide ***pointers towards particular network scenarios***. These particular developments point towards stronger growth in renewable electricity which is consistent with several of the scenarios. Although recent announcements may appear to either add to or subtract from the value of certain scenarios, the long term trends that the scenarios are based on encompass these emerging developments. Such trends include, for example, environmental concern (with heightened concern a feature of several of the scenarios), and mixes of market and Government led approaches. Emerging developments reflect variations within these trends.

Network infrastructures (whether gas, electricity, heat, transport or communications) appear to have an 'increasing' effect on each other. This interaction and interdependence has been evident in GB gas and electricity infrastructure for some time. However, the scenarios highlight even greater levels of interaction and interdependence of network infrastructures in future. For example, electric vehicles could have a major impact on electricity demand. Gas networks could start providing a means for decentralised combined heat and power and micro-generation, in which case there will be additional demands on the gas infrastructure. Finally, the prospect of heat networks fed from renewable heat sources could have a significant effect on customer demands for electricity (and gas) and thus on electricity networks.

Network infrastructures are constructed of long life assets and the interactions between the different networks (as noted above) and the uncertainties surrounding the development and use of these assets present a ***risk of stranding of assets in future***. This risk has always existed, but the scenarios present futures in which the demands placed on electricity networks are subject to high levels of uncertainty and very different outcomes.

Concluding comments

Scenarios are a useful tool for promoting strategic thinking about the longer term future. The network scenarios in this report form a valuable resource for GB network stakeholders in developing strategies and plans for future GB electricity networks.

They illustrate the complex dynamics between the background context for electricity networks (e.g. policy, markets, environment, and consumer led requirements) and the future networks that may be required in light of this. They show that there could be a period of more rapid change in electricity networks due to factors such as climate change, fuel security concerns and change in energy consumer attitudes and behaviours. These scenarios are not the only word on the future of GB electricity networks, but they do present a broad view of possible outcomes, taking into account inputs from a wide range of stakeholders and other expert contributors.

Other outcomes for electricity networks are possible. It is unlikely that any one of the five scenarios will emerge in reality precisely as described here. However, as a set of five they span a broad range of plausible outcomes for electricity networks. This breadth of outcomes provides a valuable input to strategic thinking about GB electricity networks.

It is already evident that the LENS scenarios are proving useful as a starting point for further study among academic stakeholders. For example, two major research initiatives funded by the UK research councils, ‘FlexNet’ and ‘Transition Pathways’ are using the LENS scenarios as the basis for their research. Other stakeholders, in industry and Government for example, may choose to assess current development plans, strategies and policies in the light of these scenarios.

1 Introduction and Overview

1.1 Introduction

This document is the final academic report of the LENS project and summarises key stages of the project to date before going on to describe the five network scenarios for electricity networks in Great Britain for 2050.

Ofgem undertook to develop long term scenarios for energy networks in 2006 in response to the Government's Energy Review. This commitment was reaffirmed in the Energy White Paper (HM Gov, 2007) which indicated that Ofgem would take forward an assessment of possible futures for electricity networks. Acknowledging the merits of scenarios for long term planning, the LENS project methodology (Ofgem, 2007a) set out an approach to develop scenarios for the GB electricity networks sector for 2050 with the objective of understanding the implications for the electricity transmission and distribution networks in GB and their regulation.

The LENS draft scenarios report of August 2008 (Ofgem, 2008a) set out the methodology followed by the academic team in developing the network scenarios and presented the five network scenarios for GB in the year 2050. In addition, the draft scenarios report contained an assessment by the academic team of the implications of the scenarios and potential way-markers (or staging points on the route to 2050) for each scenario at the year 2025. The accompanying Ofgem letter put the academic report in its context within the LENS project and set out questions for stakeholders to consider and respond to in relation to the scenarios presented in the report. This final report now presents the outcome of the final stages of the project including consideration of the responses made to the August 2008 consultation.

Analytical (qualitative and quantitative) assessment of the scenarios in the form of cross scenario comparison, implications and conclusions are presented in this report and these constitute the high level outcomes of the academic team's contribution to the LENS project.

1.2 Document Structure

This document is the final academic report following the publication of the May 2008 interim report and the August 2008 draft scenarios report. This report documents the outcomes of the activities in the LENS project that have led to a set of plausible electricity network scenarios for Great Britain for the year 2050.

Section 1 describes the background and document structure.

Section 2 describes the context for the LENS project, the scenario development methodology used, the role of scenarios and the role of the MARKAL modelling activities in the LENS project.

Section 3 presents the five network scenarios developed in the LENS project. This includes illustrations, narratives, modelling results and insights for the scenarios, and way-markers of potential developments at 2025 on pathways towards the 2050 scenarios.

Section 4 provides cross-scenario comparisons which enable the reader to see the distinct differences within both the qualitative and quantitative content of the scenarios.

Section 5 presents the academic team’s thoughts on scenario implications for networks and regulation both within each scenario and also across the scenarios.

Section 6 provides the key insights and conclusions from the development and then assessment of the scenarios.

Appendices provide supporting detailed material on modelling activities, a list of abbreviations, references and a bibliography for the report.

2 Scenario Context

This section provides an overview of the rationale behind key aspects of the LENS scenarios, including the project's objectives, the process adopted to develop scenarios for the long term future of the electricity networks in GB, the role of 'scenarios' in general and for the LENS project in particular, and the role of the modeling in the LENS project.

2.1 Objectives

Electricity network infrastructure is, by the nature of the equipment from which it is constructed, a long life asset for the companies who own and operate this infrastructure and for the customers and wider society who have a stake in the infrastructure. In recognition of this fact and the increased pace of change being experienced in the electricity sector, it is appropriate to focus on the long term future of the GB electricity networks. The LENS project was conceived to facilitate thinking about the way in which GB electricity networks are likely to evolve through the development of a set of scenarios that would capture a suitably wide range of plausible outcomes for GB electricity networks. Because there are so many interconnected, non-linear and dynamic uncertainties regarding the long term, a technique such as scenarios is required to bring any clarity to such a problem.

The LENS scenarios seek to provide a basis for discussion about the evolution of GB electricity systems in the long term and through doing that, shed light on the best approaches towards developing, operating and regulating electricity networks in the coming years. The specific objective for the LENS project is to facilitate the development of a range of plausible electricity network scenarios for Great Britain for 2050, around which industry participants, Government, Ofgem and other stakeholders can discuss longer term network issues. The project has also set out to: quantify the scenarios through 'energy system' modelling; develop a consistent set of 'way-markers' for 2025 (or staging points on the route towards 2050); and to establish views on the scenarios' implications for networks and their regulation.

In addition, the broad question that the scenarios shed light on (i.e. the 'focal question' as set out below) is: What would be the impact of markets, policy, environmental, geopolitical and technology futures on GB electricity networks and their regulation?

The LENS project has sought to meet this objective by following a robust scenarios development methodology, backed up with quantitative modelling and with the input and support of a wide range of GB electricity network stakeholders.

2.2 Overview of Scenario Development Process

An eight-stage process has been followed in the development of the scenarios. This systematic approach was adopted from the experience of the academic team and also from the authoritative publications on scenario development. This is a tried and tested approach to scenario development. The eight stages in the LENS project scenario development process are:

1. Define the scenarios recipient
2. Frame the focal question that the scenarios must address
3. Information gathering to inform the scenario development process
4. Identify themes to focus the scenario development process
5. Sketch possible pathways between now and 2050
6. Write scenario narratives/storylines
7. Model scenarios to test key aspects of the scenarios
8. Identify potential implications of scenarios on the focal question

It is important to note that the scenario development process is not quite as straightforward (or linear) as the eight step process suggests. Account is taken throughout the scenario development process of influences such as feedback obtained from the recipients and trends or important issues identified in the course of the project. This has been the case in the LENS project and, while each of the eight steps formed a major part of the project, the sequencing of the steps, interaction between steps and detailed activity within each step have made the process more heuristic in nature as expected.

The recipients of the LENS scenarios were defined as 'GB power network stakeholders'. The primary stakeholders were deemed to be electricity consumers, however transmission owners, distribution network operators, the GB system operator and the owners of private networks (together, the 'network companies'), power generators, suppliers, Government and Ofgem were also included, since all of these parties arguably have a prominent role in and carry primary responsibility for the actual delivery of services to GB electricity consumers.

Since the GB power network stakeholders are the recipients, the focal question became:

'What would be the impact of markets, policy, environmental, geopolitical and technology futures on GB power networks and their regulation?'

Having set out the recipient and focal question for the scenarios it was possible to start gathering relevant information to feed the scenario development process. The academic team were familiar with and drew on much of the recent publications on scenarios for energy, and more specifically energy in GB. The information used to generate the inputs to the scenario development process was set out in the scenarios inputs report (Ofgem, 2007b).

The inputs included discussions and groupings of the issues identified as important for electricity networks in GB along the path to 2050. Further input was provided through the second project workshop and the consultation responses on the Inputs Report.

From the inputs, three themes emerged for the development of scenarios of electricity networks in GB in 2050:

- **Environmental concern (moderate or acute)**

  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). Acute 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.

- **Consumer participation (passive or active)**

  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.

- **Institutional governance (market led or Government led)**

  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 markets, the approach to network monopolies, network access, planning, and infrastructure investment.

The interactions between these themes were used to identify initial scenarios for the high level energy context, which were then refined and used to identify potential network scenarios through a mapping process. This mapping process revolved around generation, demand and quality characteristics of the initial ‘energy context’ scenarios. This process resulted in two sets of scenarios, namely five high level ‘energy context’ scenarios, and five electricity network scenarios. A single set of network scenarios was subsequently developed by matching and merging the latter scenarios with the former ones, thus producing five final scenarios that have a consistent background energy context and emerging network. This single set of scenarios was then quantified, as explained in more detail below. In this quantification process, it was the scenario narratives that drove the modelling exercise, rather than vice versa. The implications of the quantification exercise for the narratives were then considered, through a process of consolidation and integration, however fundamentally the narratives stood in their own right and were not driven by the scenario quantification exercise. Finally, ‘way-markers’ for the year 2025 were produced for each scenario, to illustrate events and developments that might be occurring in the wider context and within electricity networks on the path to 2050.

Scenario narratives were produced and continually refined as the scenario development process progressed and the five identified scenarios were also modelled in the MARKAL energy system tool to provide insights to aspects of the plausibility and quantitative detail of each scenario.

With the set of five scenarios in place it was possible to analyse them in some detail to establish the implications for the recipients (GB power network stakeholders).

Further details on the scenario development process is provided in the appendices to this report. More information on the role of 'scenarios' in general, and the LENS scenarios in particular, and the quantification through modelling of the scenarios is provided in the subsequent two sections.

2.3 The Role of Scenarios

In recent years scenarios have been used extensively in the energy industry to provide insights into possible outcomes for the sector in the face of a changing agenda mainly influenced by climate change (with a focus on CO2 emissions) and energy security. Since the use of scenarios was pioneered by the likes of Shell (Shell, 2003) and Pierre Wack (Wack, 1985) as a tool to address the unavoidable uncertainty associated with planning for the future, scenarios have been acknowledged as playing an important role and historically have been particularly successful in challenging preconceived assumptions about the nature of future developments. The use of scenarios provides users with the opportunity to plan robustly against a wider range of possible future outcomes.

We expect that the scenarios developed within the LENS project will be used in different ways by different stakeholders in the GB electricity networks sector. In general terms, scenarios provide the opportunity for a 'strategic conversation' within and between stakeholders. This comes about when the scenarios provoke 'outside the box' thinking about the evolution of a complex political, business and technological undertaking such as developing and operating electricity networks to provide secure, economic, efficient and environmentally friendly energy supplies to customers in GB.

The scenarios are not forecasts or blueprints of future electricity systems. The year 2050 is too far away and the uncertainties too great for forecasts to be of any great value in this context. In addition, the role of scenarios in the LENS project is not to propose a blueprint for future electricity network architectures in GB, since system architectures follow the role for future electricity networks that the scenarios seek to illuminate. The scenarios can be used to establish what might be a good path forward in the near term that maximises the chances of success in the long term.

The LENS scenarios have not been explicitly designed to meet the Government's proposed environmental targets. One reason for not constraining the scenario development process in this way is that, depending on future market and policy developments, it is possible (and, under certain circumstances, plausible) that the Government's targets are not met.

So instead the focus has been more on the driving forces underlying the targets such as levels of consumer interest and activity in energy supplies and networks and the environmental attitudes and behaviours of society as a whole. However, a sub-set of the LENS scenarios meets and even exceeds the sorts of levels of carbon reductions implied by Government targets currently under consideration, although it is difficult to draw exact comparisons because there isn't yet sufficient clarity on the definitions that underlie the Government's proposed targets.

2.4 The Role of Scenario Modelling (Using the MARKAL Energy System Model)

The MARKAL (Market Allocation) model is a least cost optimisation model which has been used to inform energy policy-making in a number of countries and is supported by the International Energy Agency (IEA)[2]. It is an energy-economic-environment model, providing a bottom-up technology-rich depiction of a whole energy system, matching resources, energy supply technologies and energy service demands to provide a solution which is optimised on the basis of discounted least energy system cost. Amongst other emissions, the model tracks CO_2 emissions resulting from energy use.

The UK MARKAL model has been developed to generate solutions for the UK energy system over a time frame extending to 2050, particularly with a view to analysing the potential for low carbon energy systems in the UK. It operates with a detailed database of technologies, which is designed both to represent the energy system as it is currently configured, and to offer a range of future technological options from which the model can choose in meeting the system's energy service demands over the whole time period, within any constraints which are imposed upon it. The database includes resources, refining and processing technologies, power generation technologies, infrastructure, and end use technologies. Each technology is defined by capital, operation and maintenance costs, as well as by a number of other operational parameters, including efficiency and availability. It is on the basis of these input data that the model trades off one technology with another to find the overall cost-optimal solution. By changing such input parameters in a systematic fashion, different optimised solutions are generated, and the cross-comparison of these different results permits analysis of the most significant factors and uncertainties that will act on the energy system in the future.

The UK MARKAL database is subjected to continuing updates and peer review through the projects in which UK MARKAL is employed[3]. In its various forms the model has been used to support UK Government Energy White Papers (BERR, 2007), the Draft Climate Change Bill (DEFRA, 2007), reports submitted to the G8 Climate Change process (Strachan et al, 2008a; Strachan et al, 2008b), and has been a key tool employed by the UK Energy Research Centre[4].

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[2] Through the Energy Technology Systems Analysis Programme (ETSAP), an implementing agreement of the IEA.
[3] Documentation on recent UK MARKAL databases, as well as research reports detailing the results they have generated, is available at:
http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM2007/ESM.aspx
[4] See: http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM2007/ESM.aspx

Why use MARKAL in the LENS project?

The key distinctive advantage of the MARKAL model for energy policy analysis is its quantitatively detailed view of the whole energy system, which includes the various energy service demands from all economic sectors, bringing a flexible approach to choosing which technologies and resources can meet these demands.

The five LENS scenarios are focused on the UK electricity networks, but are also located within a wider energy system and social context. The scenarios contain intuitively plausible assumptions about various portfolios of energy technologies and their contribution to reducing carbon emissions within the contexts of the scenarios described. The MARKAL model can add a further dimension to the scenarios by exploring in some quantitative detail the trade-offs between various technology options within the system. MARKAL allows the consideration of whole system interactions and drivers, the competing demands of the various energy using sectors, which raise further implications for the electricity networks. By considering the simultaneous operation of these numerous interactions in a detailed and quantitative way, the model provides insights into the plausibility of the scenarios, and helps to highlight particular challenges or trade-offs which may have not easily been identified through a purely qualitative process.

Through a combination of analysing the results and the assumptions behind them, MARKAL can therefore offer insights in such areas as whole energy system implications, resource trade-offs, physical constraints, policy constraints, technological development, system costs and the effects of demand responses on the system.

The version of MARKAL employed in the LENS project is MARKAL Elastic Demand (MED). This provides the option of exploring the potential for energy demand reduction to be used as a means to achieving the optimal system balance within the constraints imposed. Some more details of this particular model variant are given in the appendices.

Limitations of MARKAL

No model can do everything! It might be said that every model has a particular perspective which gives it a detailed focus on certain kinds of questions, necessarily making it less focussed on others. As discussed above MARKAL's strength is its technologically detailed depiction of the whole energy system over a long time period. As a result of this focus, its key limitations are:

- **Spatial detail**: it is not a geographical model and therefore has a limited ability to account for the spatial aspects of energy use. The model's depiction of technical aspects of network system architectures may be less detailed than in some network specific models; however the benefit of its use in the LENS project is for exploring the implications for networks of wider energy system dynamics.
- **Temporal resolution**: the model's time horizon is 50 years, hence the representation of the dynamics of hour by hour system balancing is somewhat simplified.

- **Economy wide interactions**: it is a *bottom-up energy system* model, hence unlike macro-econometric models or computable general equilibrium models, it does not provide direct outputs relating to trade, competitiveness, growth in other economic sectors, and other macro-economic parameters.
- **Social and behavioural drivers**: the model optimises based on least cost from a system level perspective, though social drivers can be represented to a certain extent through constraints and elasticities, and then expanded within the scenario analysis.
- **Risk and uncertainty**: the model has 'perfect foresight', therefore its solution does not truly account for the uncertainty surrounding future technologies and policies, and how these translate into risks for potential investors.

Readers who are analysing the model runs in the context of the LENS scenarios should bear in mind these limitations. Nonetheless, these limitations which are inherent in the structure of the model can be mitigated through:

- The use of proxies and constraints to create the effect of a particular energy system aspect which the model is not 'seeing'.
- The critical interpretation of the outputs of the model run in the context of detailed off-model scenario analysis.

Are the model runs directly equivalent quantitative versions of the LENS scenarios?

In a word, no. In some cases, this is simply because there are some aspects described in the scenarios - related to the limitations described above - which the model is not suitable for exploring. However, in other cases, the reason is related to a broader question as to what is the most useful way of using the model in conjunction with detailed qualitative scenarios.

The model could have been forced (constrained) into reproducing the scenarios exactly, in terms of which energy technologies become used at which times during the overall period. However, the insights produced from this approach would have been limited- the model would have been an illustrative tool, rather than an interrogative one. Therefore, rather than focussing on defining the final technology mixes to match the scenarios exactly, the approach has been wherever possible to represent key drivers within the model, which the scenario descriptions see as being significant in bringing about the kinds of technology mixes they describe.

The model results in some cases reinforce the scenarios' descriptions; however they sometimes produce different results, which raise questions or challenges to technical and economic aspects of the scenarios. Where modelling results differ they do not necessarily invalidate the scenarios - rather they highlight important issues which should be considered.

Therefore, rather than the model runs being a direct translation of the qualitative scenarios into quantitative terms, the relationship between the two processes may be better described as a critical testing of assumptions.

They are quite different processes, and it is therefore to be expected that they may sometimes produce different outcomes. Each may raise valid questions about the plausibility and assumptions of the other; and often a useful way of doing this is through exploring any differences between their outcomes.

What are the inputs to the model?

The optimised solutions which the model produces are, of course, dependent on the inputs which are put into the model. It is therefore important to consider any analysis of modelling results with some understanding of the kind of input data on which they are based, and perhaps most crucially how this data is changing between, and thus affecting the results, of any model runs which are being compared.

The process of developing input data technologies and energy service demands over the next four decades, inevitably admits considerable uncertainty. Hence it should be clear that no MARKAL model run is in any sense a *prediction*. The process is often described as a 'what-if...?' analysis; in other words, *'what if* the following assumptions about technology, energy demands, and environmental / political drivers are realised- *then* what would be the most economically efficient response of the energy system?' The interest is in sensitivity analysis, and comparing the significance of varying different assumptions on the final model results. *A scenario framework, with its careful development of a consistent and plausible storyline, provides a coherent basis for varying several input parameters simultaneously*.

Table 2 summarises the kinds of parameters which in MARKAL terms are usually considered inputs, and those which are usually outputs.

INPUTS	OUTPUTS
System configuration - potential energy pathways and interactions **Resource supply curves** - imports and domestic production **Energy service demands** - to a detailed sub-sectoral level **Technology characterisation -** capital costs, O&M costs, efficiencies, availabilities etc **Constraints** – physical and policy driven	Primary energy, final energy - by sector and/or by fuel CO_2 - by fuel, sector; marginal emissions prices Electricity generation mix– by fuel and by technology Imports, exports & domestic production of fossil & renewable fuels Energy system costs Transport fuels, transport technology by mode **MED -** Behaviour change in individual demand services

Table 2: MARKAL inputs and outputs

Reference input data

The vast majority of data on which the LENS modelling work depends does not vary between model runs. This 'reference' data derives from the database of technologies which has been developed through systematic literature review and stakeholder validation, through two UK Energy White Papers, and most recently through ongoing work for the UK Energy Research Centre. There is not space within the main report to list this data in detail - more of this data may be found in Appendix B and Strachan et al (2006), Strachan et al (2008) and Kannan (2007). In summary though, it can be said that the data on technologies and policies is calibrated to those in place in 2005. It is important to state that aspirational targets, or those whose implementational or legal status is in any way unclear, are not included in MARKAL reference data.

Variant input data

In order to generate model runs which explore the kinds of societies and energy systems described by the LENS scenarios, variation of a relatively focussed sub set of the data was undertaken. The key 'levers' that were pulled to explore the different dynamics of the LENS scenarios were:

- **Carbon price**: while specific environmental policies were not explicitly represented in the model runs, 'environmental concern', encompassing both the political will and the public tolerance of strong environmental legislation, was represented through varying both the level of the carbon price, and the extent of its application across different sectors.
- **Elastic demand**: in conjunction with the carbon price, allowing the system to respond to higher energy prices through reducing demand, was a distinguishing feature of certain scenarios and thus of model runs too.
- **Technology development**: improved performance and reduced cost of particular technologies in some runs represents the effect of sustained society-wide environmental concern on the investment decisions of private actors, as well as in some cases government led technology-push activities.
- **System constraints**: in scenarios where distribution level networks were increasingly developed, the model was constrained in its ability to use large scale distribution, with the assumption that key decisions would have limited the development of major large scale transmission infrastructure.

The key variant input data are compared across the model runs in Table 3.

Variant input parameter	Big T&D	Energy Service Companies	Distribution System Operators	Microgrids	Multi-purpose networks
Carbon price (£/tCO2)	Rising to £30 by 2050	Rising to £60 by 2050	Rising to £100 by 2050	Rising to £135 by 2050	Fluctuating between £30-£70
Sectors to which carbon price applies	Electricity and industry	Electricity and industry	All	All	Electricity and industry
Demand response	No	No	Yes	Yes	No
Technology development	As reference	Small scale wind Solar PV Micro CHP Energy efficiency	As ESCOs, plus cost reductions in hydrogen generation and end use technologies	As DSOs, plus even more aggressive cost reductions and performance improvements in solar PV and micro CHP	Small scale wind, solar PV, Micro CHP as ESCOs
Reduced use of transmission system	No	No	Yes	Yes	No
Other system constraints	Capacities for electricity interconnectors increased. Barriers to uptake* of electric vehicles, CHP, district heating	Reduced barriers to uptake* of electric vehicles, residential heat technologies, energy efficiency, CHP	Reduced barriers to uptake* of hydrogen vehicles, residential heat technologies, energy efficiency, CHP	Reduced barriers to uptake* of hydrogen *and* electric vehicles, residential heat technologies, energy efficiency, CHP	Broad technology groups (marine, nuclear, gas, wind) forced in at different times to reflect conflicting government led programmes

*Barriers to uptake: in order to reflect societal inertia with regard to new and unfamiliar technologies, the reference data includes barriers to uptake of novel technologies such as electric and hydrogen vehicles, micro-generation and energy efficiency measures in the form of higher discount rates, and market penetration limits. Where these have been relaxed or removed in different runs, this reflects the assumption of action by government or energy companies to promote certain technologies, overcoming this inertia.

Table 3: Key variant input data across model runs

It might be observed that the level of the carbon price appears to move in the same direction as the level of decentralisation of generation. It should be emphasised that this is of course not a necessary relationship - but it is a reflection of the storylines of the LENS scenarios. It is of course possible to imagine Big T&D scenarios with much higher environmental concern than is indicated here; in fact, precisely such scenarios have been explored in other previous and ongoing MARKAL modelling work, and interested readers are referred to BERR (2007), DEFRA (2007), Strachan et al (2008a) and Strachan et al (2008b) for further investigation of the implications of such modelling work.

A more detailed description of the LENS variant input data is available in Appendix B.

3 Electricity Network Scenarios for Great Britain in 2050

This section presents the network scenarios developed over the course of the LENS project. Each scenario has main features highlighted through:

- a summary paragraph and bullet point summary table at the start of each scenario,
- a 'schematic illustration', and
- a 'geographical pictogram'.

Each of these items is designed to convey the key messages from each scenario, using different methods.

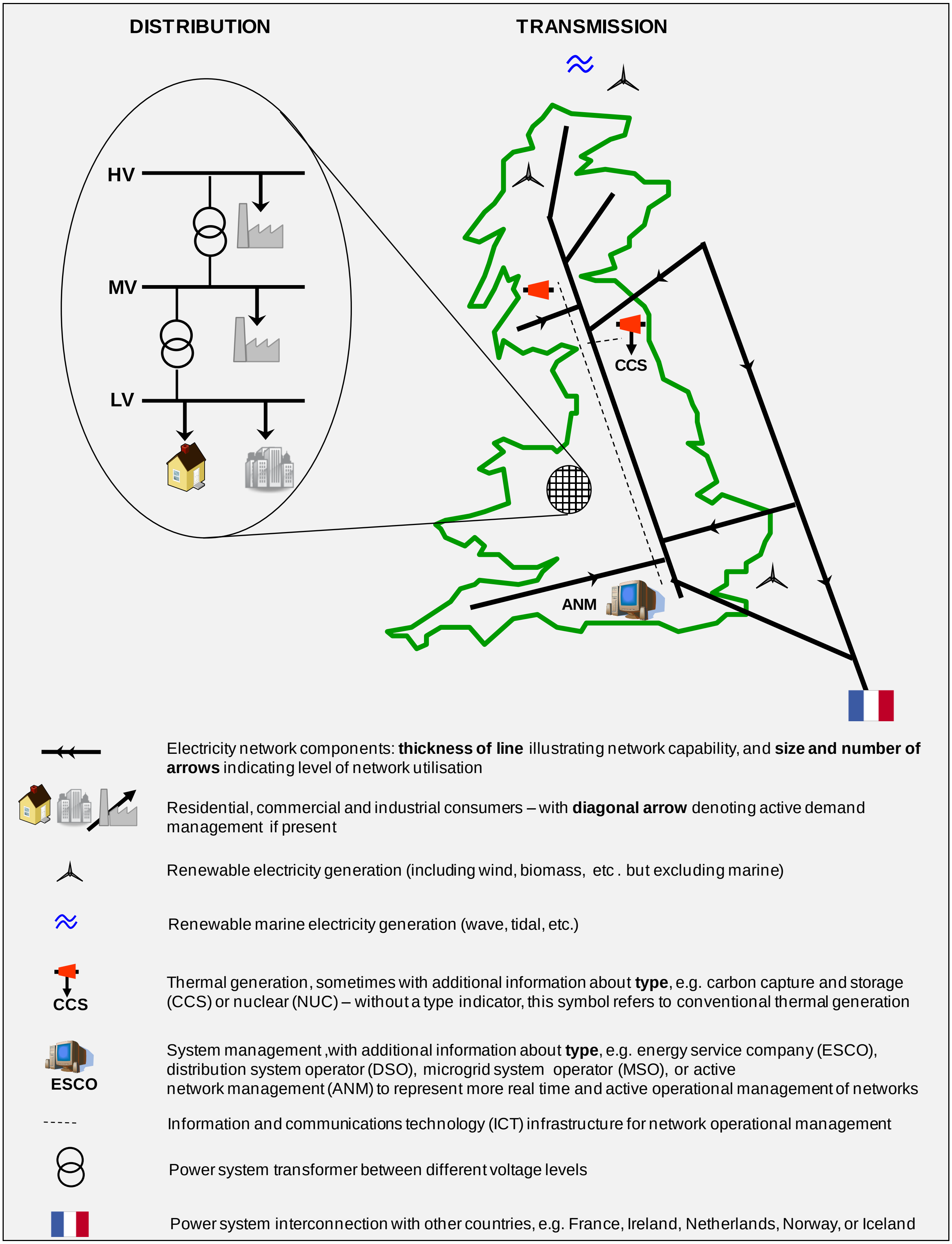
Each scenario is also accompanied by a summary of the outcomes of the quantitative modelling undertaken to inform and plausibility check the scenario. Finally, way-markers for the year 2025 are set out for each scenario.

Key to illustrations:

<u>Geographical pictograms illustrating the key aspects of the scenario narrative:</u>

The geographical pictogram serves several purposes:

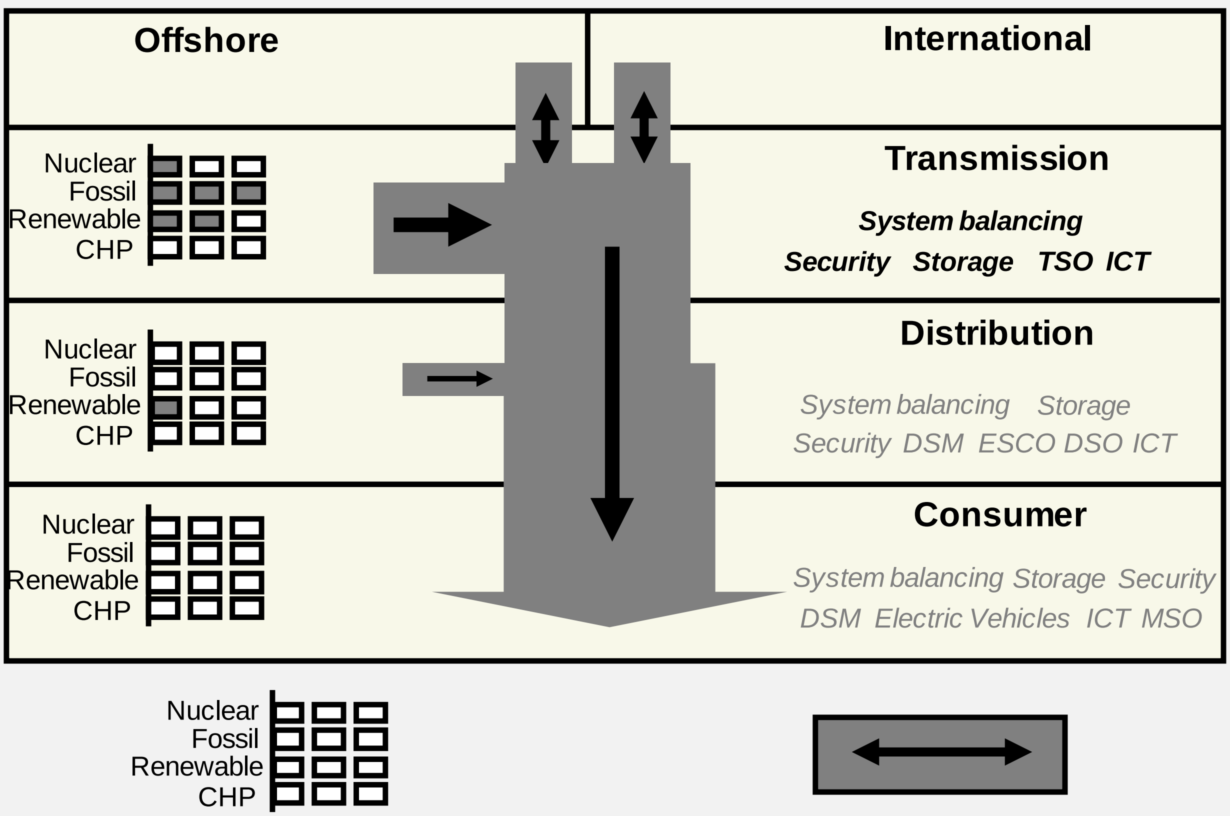
- It indicates the main forms of **generation and technology** featuring in the scenario, and where they would be **located geographically** and within the **system**.
- The picture of Great Britain represents the **transmission system**, while the 'call out bubble' represents the **distribution system**.
- The **line thickness** in the picture of Great Britain and the call out bubble represents the required **network capability** at the transmission and distribution level, respectively.
- The **size and number of arrows** in the picture of Great Britain and the call out bubble represent the **level of utilisation** of the network capacity.
- The call out bubble shows details of the network architecture in the **distribution system** with locations of active components, such as generation, demand response and control. It distinguishes between **High Voltage** (HV), **Medium Voltage** (MV) and **Low Voltage** (LV) levels within the distribution system.


DISTRIBUTION
TRANSMISSION
HV
MV
LV
CCS
ANM
Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation
Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present
Renewable electricity generation (including wind, biomass, etc . but excluding marine)
Renewable marine electricity generation (wave, tidal, etc.)
CCS
Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation
ESCO
System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks
Information and communications technology (ICT) infrastructure for network operational management
Power system transformer between different voltage levels
Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Schematic Illustrations:

The schematic illustration serves several purposes, for non-quantitative comparison with other scenarios:

- The boxes on the **left hand side** indicate the relative amount (high, medium, low) of onshore power generation capacity for each of the main sources of generation connected to that element of the network (i.e. to 'Transmission', 'Distribution', and 'Consumer').
- The width of the flow diagram **in the middle** indicates the relative volume of power flow (or the level of utilisation of the associated network), while the arrows indicate the direction of flow (which can sometimes be bi-directional).
- The items in bold on the **right hand side** indicate the main location for system activities such as balancing and storage. Where they are less likely this is indicated in light grey rather than bold.
- The 'offshore' section on the **top left hand side** denotes offshore electricity generation and networks, while the 'international' section on the **top right hand side** denotes power system interconnection with other countries.



Type and relative amount of onshore power generation capacity (fossil includes CCS)

Relative amount and direction of power flow within areas of the network

3.1 Big Transmission & Distribution

3.1.1 Introduction and summary

In this scenario transmission system operators (TSOs) are at the centre of networks activity.

The environmental concern of society in general does not grow significantly past today's already heightened levels. Consumer attitudes remain relatively passive towards their electricity supply and the belief persists that markets are best placed to service the energy requirements of the nation. Customers are also satisfied that existing industry structures are best placed to provide a security and economic electricity supply. A key feature of this scenario is that fossil fuels for electricity generation, home and commercial energy supplies and transport continue to form a large proportion of the electricity generation portfolio for some time. In addition, a significant amount of large scale renewable and low carbon generation capacity is developed in line with current planned developments and trends. Electricity networks are developed to meet the additional energy demands and the requirement to connect large scale renewable generation both onshore and offshore. Interconnectors to continental Europe are developed to access additional economic sources of energy and provide additional network security and system operational services. Distribution networks grow in line with energy demands but strong advances in operational approach are not required.

Scenario Summary: Big Transmission and Distribution

- 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.
- An early drive for low carbon energy sources sees the development of significant offshore and onshore renewable generation.
- Centralised larger scale power generation (fossil, nuclear and renewable) retains the highest proportion of electricity production capacity.
- 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. 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.

3.1.2 Context

The moderate level of environmental concern reflects Climate Change not developing significantly past the effects we observe 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 average global temperature and weather patterns but they do not accelerate and there is no major social 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, societal concern about it does not. 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 over time. 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.

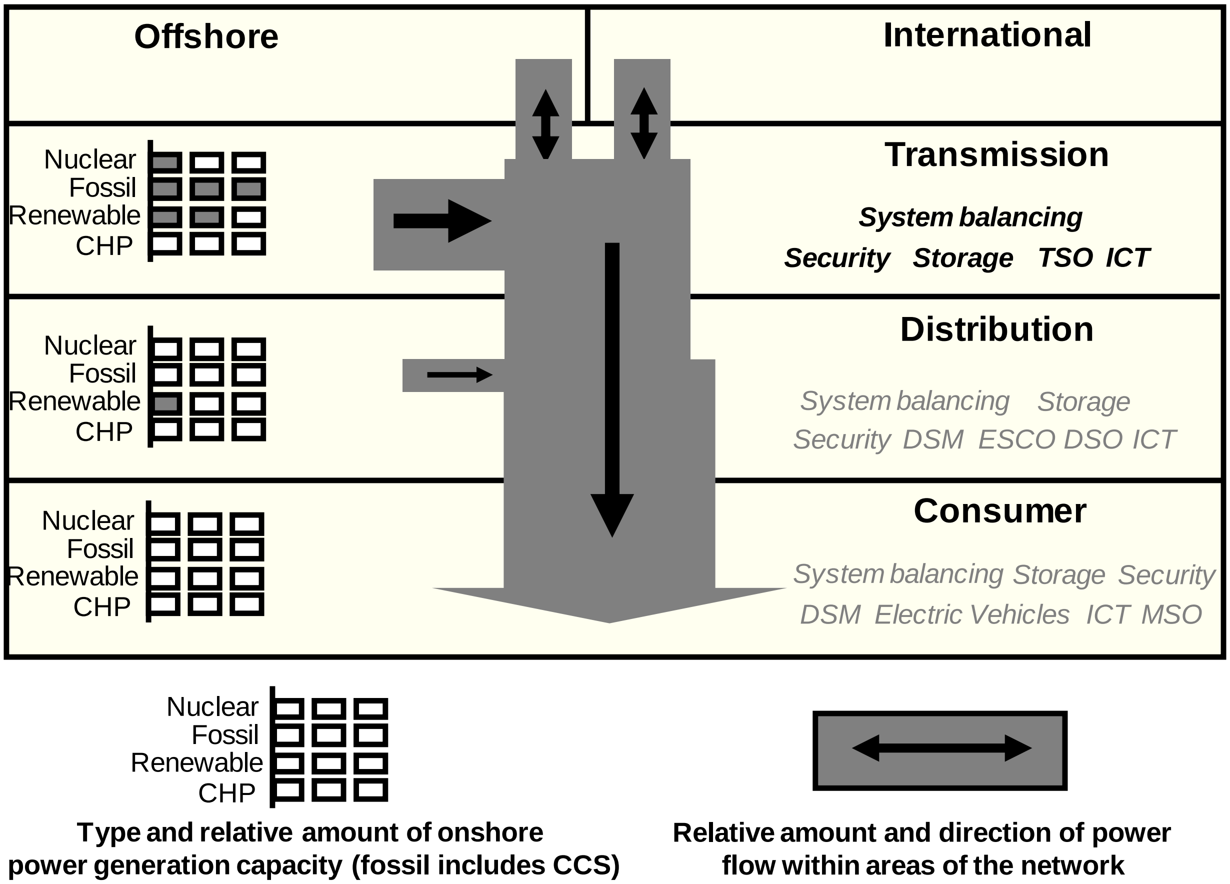


Figure 1: 'Big Transmission and Distribution' scenario schematic illustration.

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 Carbon Capture and Storage (CCS) capability will also be developed. Developed countries also continue to increase renewable and nuclear capability as a long term solution to depleting fossil fuel and in response to rising fossil fuel prices. The momentum to develop offshore and onshore wind capability backed up by strong incentives provide the necessary impetus for a sizeable development of large scale projects. Nuclear fusion and hydrogen are seen as potential future energy sources but remain in developmental stages as the urgency to invest in these technologies does not materialise.

The initial high levels of environmental concern identified above create groups of consumers who take a more proactive approach to their energy requirements, however the majority of consumers will 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.

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. Government involvement 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 such as renewables obligations with banding to incentivise early stage or preferred technologies such as offshore wind and marine technologies and building standards 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 and long-term energy security issues might find their way into markets through price premiums for secure sources of energy.

Carbon trading schemes would continue in a similar form as today but would not develop into sophisticated markets with a stable 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 might be constrained by relatively muted calls regarding environmental goals. Energy generation and use will not undergo a dramatic change in direction in that the focus will remain on centralised solutions but this will include large scale renewables as well as fossil generation. Energy policy will be mainly addressing the demands of the economy and consumer lifestyle. The environment will remain a consideration but will not be sacrificed for the sake of the economy. Energy policy will mainly address security of supply, competition and quality of supply issues.

Moderate economic growth and an only moderate focus on environmental issues will hinder continued investment in low carbon energy technology after an initial surge in response to Government incentives designed to achieve low emission policy targets. 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.

Most types of consumers will be reluctant to significantly change their behaviour and will not be motivated to participate in the electricity market by either economic or environmental factors. 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. 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. 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. People will continue to desire older, spacious, less efficient housing and private car use will remain the main choice for transport. Transport will stay predominately 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. Buses will also begin to electrify by 2050.

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.

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. It is likely in this scenario that there will be a significant development 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. This would be balanced with the continued use of CCGT and coal with and without CCS, leaving the generation portfolio dominated by large scale centralised generation. 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 high 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.

Natural 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. Supply companies will take responsibility and consumers 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.

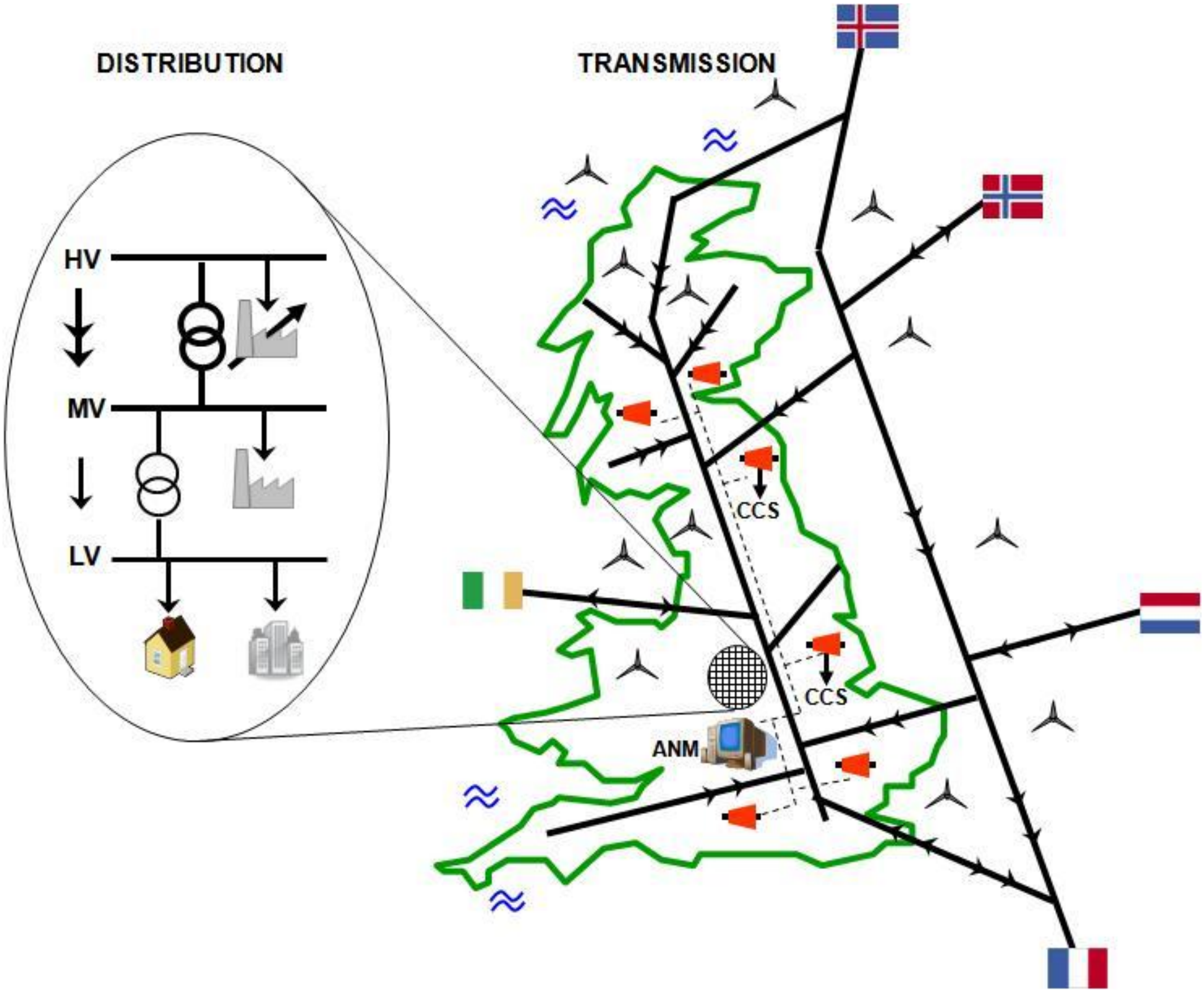
The majority of consumers would be reluctant to interact with their supply and the network. They would have a “switch me on” attitude and be keen for the most economical option without the need for much action on their part. Larger consumers would agree to basic demand management agreements on economic grounds. 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.

3.1.3 Network

Transmission and distribution infrastructure development and management continues much as expected from today’s patterns, with a sustained and growing requirement for network capacity 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) and providing network and generation system security with the increasing demands for electricity. It could be argued that this is very much the route down which the industry and much research and development are pointing at present.

T&D infrastructure capability development focuses on integrating large-scale renewables projects and increased quantities of new large-scale thermal generation to meet the continually growing levels of demand.



Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation

Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present

Renewable electricity generation (including wind, biomass, etc . but excluding marine)

Renewable marine electricity generation (wave, tidal, etc.)

CCS

Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation

ESCO

System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks

Information and communications technology (ICT) infrastructure for network operational management

Power system transformer between different voltage levels

Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Figure 2: 'Big Transmission and Distribution' network pictogram.

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. Objections to network infrastructure developments on environmental grounds increase the use of capability enhancing technology, offshore transmission and under-grounding of overhead circuits.

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. These far-reaching offshore and international connections parallel similar developments in mainland Europe and Scandinavia and as integration progresses, international Super-Grids may develop that aggregate resource in many countries to achieve overall system balancing. This allows individual countries to exploit their existing capabilities within an overall European system (e.g. French nuclear, Danish wind etc).

The transmission system operator role is expanded to manage the access of a larger portfolio of variable output renewables of a wide ranges of capacities. 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 network operators for 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 electricity 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.

3.1.4 Modelling results[5]

Headline results:

The main driver of this run is the moderate carbon price, which encourages the development of coal CCS technology, and a small portfolio of renewables. Imports of electricity increase due to the relaxed capacity constraints. Electricity demands increase in residential and transport sectors, not due to environmental drivers, but rising fossil fuel prices and technological development.

The electricity sector grows strongly from 1,288 PJ generated in 2000 to 1,652 PJ in 2050, due to sectors switching to electricity as certain key resource prices become high towards the end of period. This sector growth is entirely met by large scale generation plants connected to the large T&D network.

For the major baseload capacity the model run overwhelmingly selects coal, finding it cheaper than nuclear or gas plants. The moderately increasing carbon price encourages the selection of coal CCS, installing almost 20 GW between 2025 and 2030. The preference for coal as opposed to gas in electricity generation is due to the fact that the model prioritises the cheapest gas for direct use in the residential, services and industry sectors. This contrasts with the scenario description which indicates a broader range of large generating technologies, including CCGT and nuclear. As it cost optimises, the model is likely to prefer one of these broadly comparable technologies - however it does retain installed capacity of gas generation to meet the reserve margin. The rising carbon price brings in a modest installation of tidal stream power at the end of the period, which generates 38 PJ in 2050.

[5] Discussions of modelling results should be compared with the input assumptions as described in section 2.4, and in Appendix B. More detailed discussions of the results are contained in Appendix B. The figures contained in this section have been summarised in this form using the primary model output data contained in Appendix B.

	2000		2025		2050	
Total final energy demand (PJ) [1]	**6,189**		**6,287**		**6,468**	
Transport	1,855	30%	1,911	30%	2,142	33%
Residential	1,961	32%	2,057	33%	1,920	30%
Other (Industry, Services & Agriculture)	2,374	38%	2,319	37%	2,407	37%
Total electricity demand (PJ) [2]	**1,176**		**1,335**		**1,522**	
Transport	20	2%	33	2%	85	6%
Residential	403	34%	563	42%	587	39%
Other [3]	754	64%	740	55%	851	56%
Total electricity generation capacity (GW)	**84**		**87**		**102**	
Large scale generation:						
Fossil (inc. CCS)	59	71%	44	51%	68	67%
Nuclear	12	14%	3	4%	0	0%
Renewables	4	5%	31	35%	20	19%
Interconnectors	2	2%	5	6%	11	11%
CHP	4	4%	3	3%	2	2%
Storage	3	3%	1	2%	1	1%
Small scale generation:						
Micro CHP	0	0%	0	0%	0	0%
Microgen	0	0%	0	0%	0	0%
Total electricity generation output (PJ)	**1,288**		**1,456**		**1,652**	
Large scale generation:						
Fossil (inc. CCS)	854	66%	953	65%	1,173	71%
Nuclear	282	22%	85	6%	0	0%
Renewables	46	4%	245	17%	271	16%
Interconnectors	52	4%	137	9%	182	11%
CHP	45	3%	31	2%	27	2%
Storage	10	1%	6	0%	0	0%
Small scale generation:						
Micro CHP	0	0%	1	0%	0	0%
Microgen	0	0%	0	0%	0	0%
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%		14%		30%	
Electricity sector reduction	0%		16%		67%	

[1] 1 PJ = 0.278 TWh

[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.

[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 4: Big T&D – Summary of modelling results

Levels of imported electricity show a very significant growth, more than tripling from 2000 levels by the end of the period, the growth in demand for this source of electricity being stimulated by the carbon price as the model considers this electricity as zero carbon. The growth is also related to the relaxing of constraints on the use of imported electricity, which were a distinctive feature of the input assumptions for this scenario.

The strongest growth for electricity demand is found in the residential sector, and the transport sector also begins to electrify by the end of the period. These switches are driven by the rising costs of gas and oil, making electric technologies increasingly favourable - they are not driven by carbon concerns as the carbon price does not directly extend to the residential and transport sectors.

This model run delivers modest decarbonisation achieving a 67% CO2 emissions reduction in 2050 from 2000 levels within the electricity sector, and a 30% CO2 emissions reduction over the same time frame. The majority of the decarbonisation takes place in the electricity generation sector. This is largely because the carbon price only applies to the electricity and industry sectors, and of the two, carbon mitigation options are both more plentiful and more cost effective in the electricity sector.

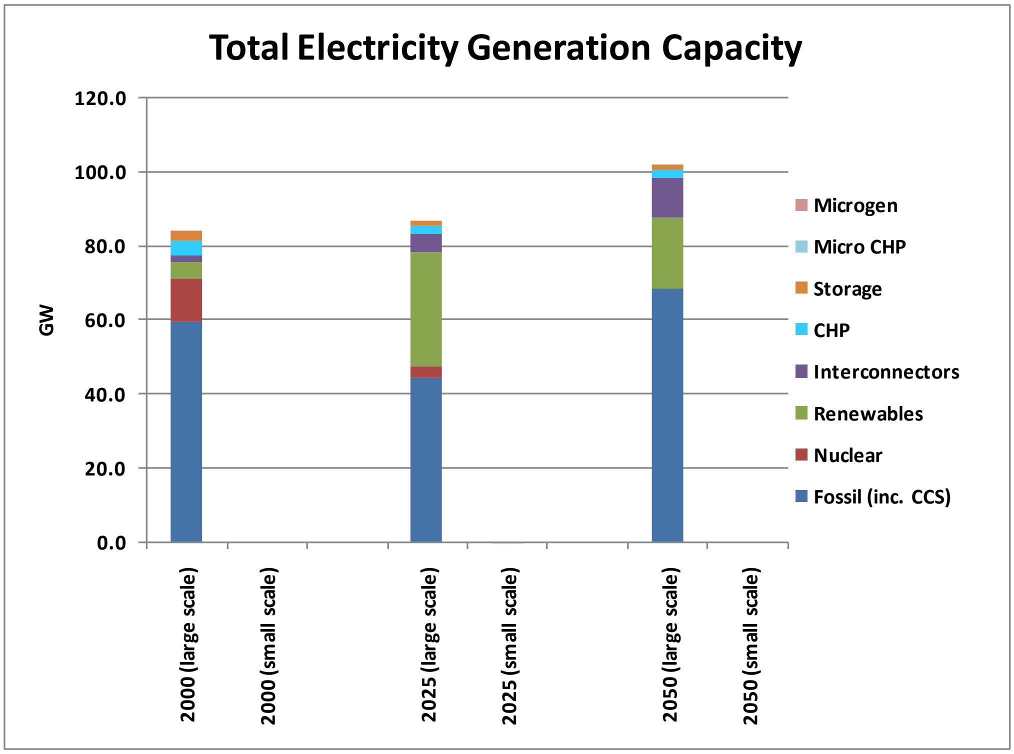


Figure 3: Big T&D – Electricity generation capacity (in GW) (distinguishing large scale vs. small scale generation)

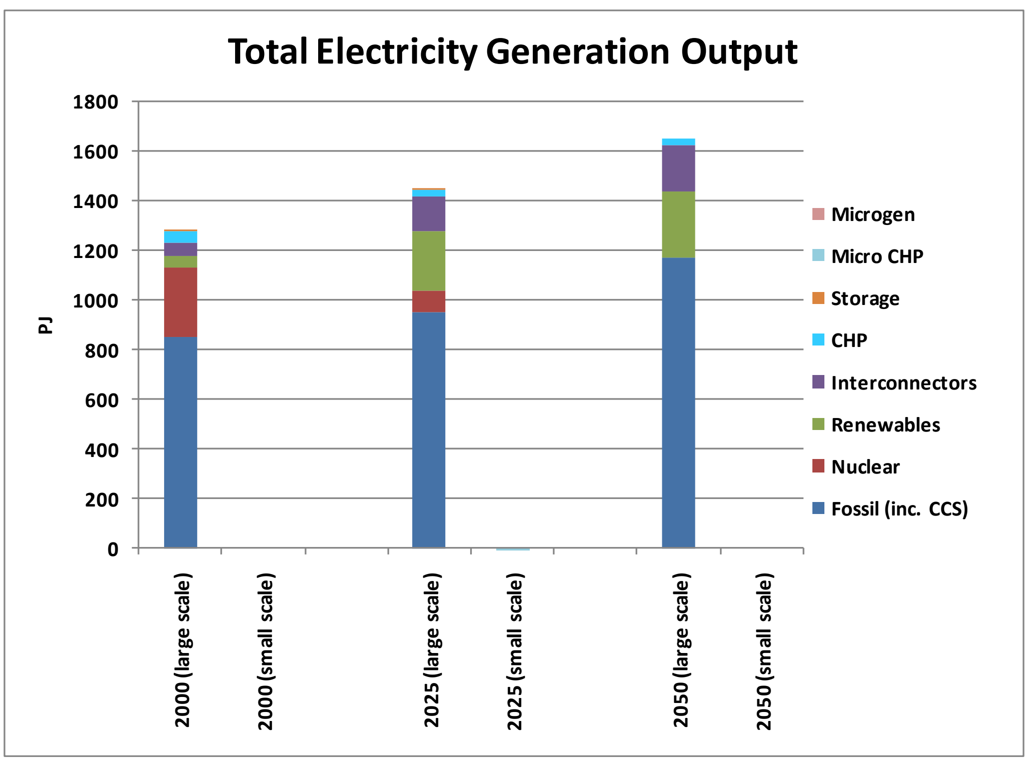


Figure 4: Big T&D – Electricity generation output (in PJ) (distinguishing large scale vs. small scale generation)

Key messages:

- ***A moderate to low carbon price strongly favours coal on the current model input assumptions - however even this low carbon price is sufficient to incentivise the application of CCS.***
- ***The rapid take-up of CCS from 2025 onwards is predicated on the assumption that the technology will be commercially available by then; if this is to be relied on significant and concerted efforts towards demonstration and early deployment of the technology will be required in the next decade.***
- ***Though gas does not feature strongly in the average generation mix, it is installed to meet the reserve margin.***
- ***Gas also remains a strong vector for heat demand.***

A more detailed discussion of these points is contained in Appendix B.

3.1.5 2025 way-markers

The way markers identified for 2025 in this scenario are:

- Strong growth in large scale renewable projects is brought about by a coherent set of incentives for renewable generation of electricity. Large scale renewable developments in line with plans today for both onshore and offshore renewables bring a requirement for several major new network capacity developments, including offshore connections and reinforcement to areas of high onshore renewable energy resource.
- Electricity demand continues to grow along long term trends and weak drive for energy efficiency and demand side management illustrate that consumers remain passive in their approach to their electricity supply and interaction with the network.
- Little adoption of demand management measures as supply companies remain content to supply greater volumes, network operators content to increase asset base and consumers have little incentive to reduce demand.
- Attitudes of the populace remain uncertain or weak towards the environment and evidence of more severe climate change does not appear or is contentious (e.g. ‘El Nina’ effect of cooling).
- Consecutive energy policy targets for renewable energy and energy efficiency are missed, natural gas imports grow and coal (with FGD or SCR) remains in the power generation portfolio.
- Large scale renewables projects emerge including onshore and offshore wind with offshore grids starting to develop (mainly shore to single site configuration in 2025) leading to system expansion with most of the RETS projects completed or underway.
- Microgeneration and distributed generation do not grow strongly (i.e. 2008 trend

growth). DG continues to grow weakly along recent trends with most new build generation being larger scale transmission connected.

- Some new nuclear build is underway on existing sites to replace recently decommissioned plant.
- Fossil fuels continue in their dominant role for electricity generation, heating and transportation despite price rises and scarcity issues arising occasionally.
- Interest in interconnectors to the continent grows and projects are underway to construct new interconnectors.
- DG growth (although moderate) plus demand growth leads to continuation of trends of reinforcement of distribution networks.
- TSOs and DNOs continue on a business as usual approach to network management with the exception of the system operator who takes moderate additional measures to manage the intermittent generation connected to the network.
- The electricity market remains in much the same form as today with only moderate changes to the trading arrangements.
- Retail electricity supply switching remains at moderate levels with some growth due to rising energy prices.
- Transmission system owners continue to invest in reactive power devices to enhance system capability.

3.2 Energy Service Companies

3.2.1 Introduction and summary

In this scenario Energy Service Companies (ESCOs) are at the centre of developments in networks.

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 they strongly feel that 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. Electricity networks develop to facilitate the vibrant energy services market and much of this development is focused on system operational management approaches to enable effective local energy production and customer services. Distribution networks develop to accommodate the connection of increased levels of distributed generation at a local level and transmission networks develop to facilitate connection of renewable energy sources.

Scenario Summary: Energy Services Companies

- 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 realised through the emergence of energy service companies (ESCOs).
- Centralised electricity generation continues to dominate 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.
- The main role for electricity 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).

3.2.2 Context

Environmental concern increases as global average temperature increases and changed weather patterns become apparent and indisputably linked to green house gas (GHG) emissions. 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.

In the UK this results in environmental issues becoming a strong influence on consumer preferences and Government policy. 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 negative environmental impacts. 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.

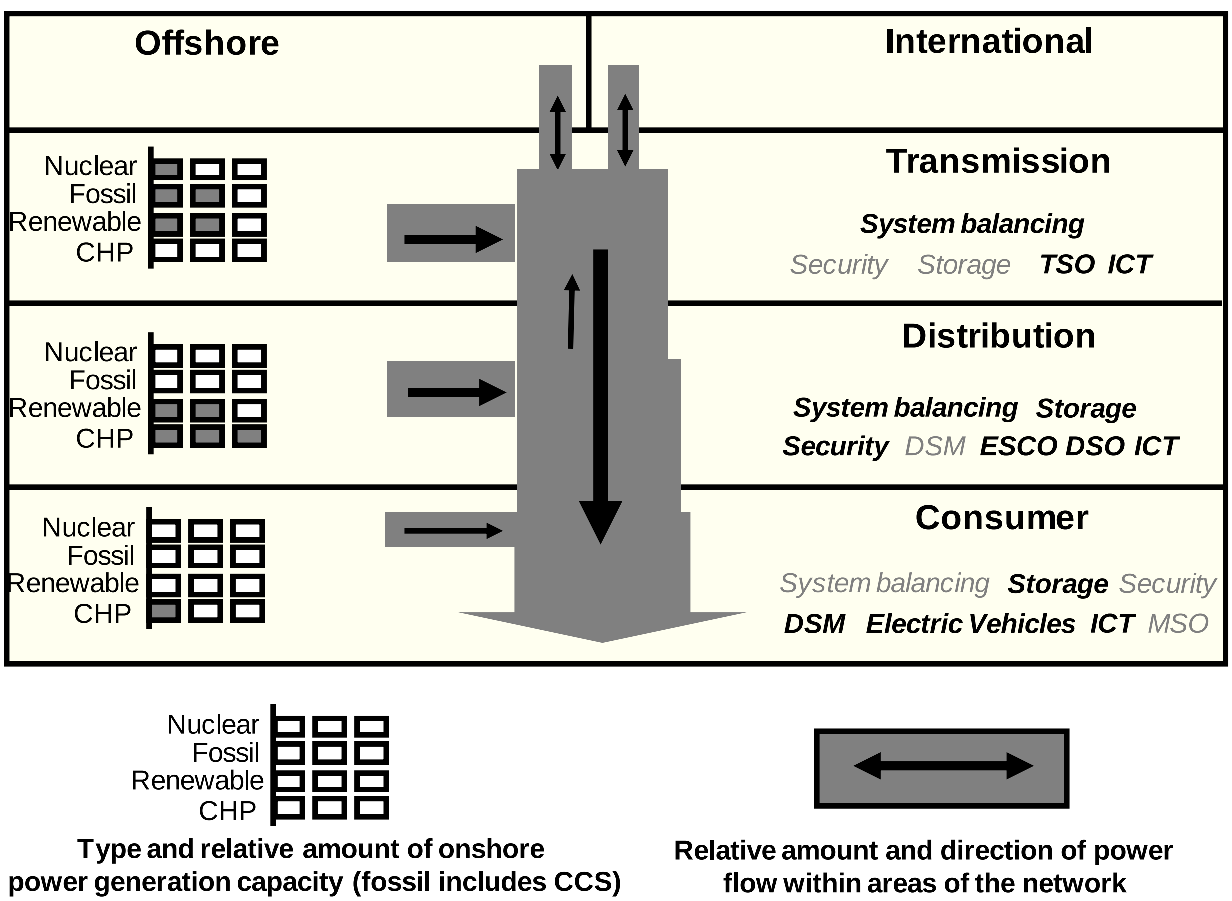


Figure 5: 'Energy Service Companies' scenario schematic illustration.

Government responds to increasingly tough targets for CO2 emissions set in response to strong EU and global mandates. 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 are used to address the environmental issues, promote competition and protect the interests of consumers. The Government identifies 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. Energy efficiency measures would be targeted towards improving the efficiency of products and other electrical loads rather than patterns of use. This would not necessarily be prescriptive and the market could be left to make its own choices within soft boundaries set by the Government. The continued availability of fossil fuels is only marginally affected by increasing prices and energy security of supply policy is to more efficiently use primary fossil fuel resources while gradually diversifying through renewables and nuclear.

A stable carbon price would be established and carbon markets would be developed as firm carbon targets are set and monitored. 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 is 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.

Consumers at all levels will become more conscious of environmental issues but 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 via lifestyle changes 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. People will continue to desire older, spacious, inherently less efficient housing despite Government targets for energy efficiency in housing. Property sector efficiency codes will be on a voluntary basis but the information packs that evolve to contain home energy use information will be seen as the important criteria in house buying decisions. The potential conflict here would be met by energy service companies (ESCOs) that include home energy efficiency in their portfolio.

By 2050, fully electric vehicles are widely used and commonly provided as part of an energy services contract. Biofuels may also play a part in fleet vehicles. Rail will quickly 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. Significant proportions of Bus fleets will be electric by 2050.

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 would 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 but would be willing to participate in local production of electricity through their ESCO.

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. This creates a challenging target for the Government to ensure the market delivers ample supplies of low carbon energy.

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.

The UK generation portfolio will maintain a strong centralised element as CCS for existing fossil fuel thermal generation is developed in conjunction with increased use of nuclear power deployed at large scales to serve the market demand for centralised low carbon electricity.

This scenario will also see some 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 by 2050, ESCOs will have started to deploy solar and wind microgeneration as cost and performance improvements combine with a high carbon price to make these technologies economically viable.

Fossil fuels will still be heavily used in this scenario and Gas 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 either continue with CCS or be replaced by Coal with CCS in the long term. Space and water heating could gradually become an ESCO provided service and could migrate from Gas to network provided electricity as low carbon electricity production increases. Biofuel use may also develop 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 including for electric vehicles provided as part of the ESCO package of services. In the absence of willingly active consumers, demand management is a significant challenge which is addressed by automated DSM schemes provided by the network and managed services from ESCOs to control the growth and high peak nature of demand. The prominence of ESCOs in this scenario could result in quite significant levels of managed DSM but with very little action required from consumers.

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. However, the supply companies will deploy advanced smart metering and charging solutions as part of their overall service provision.

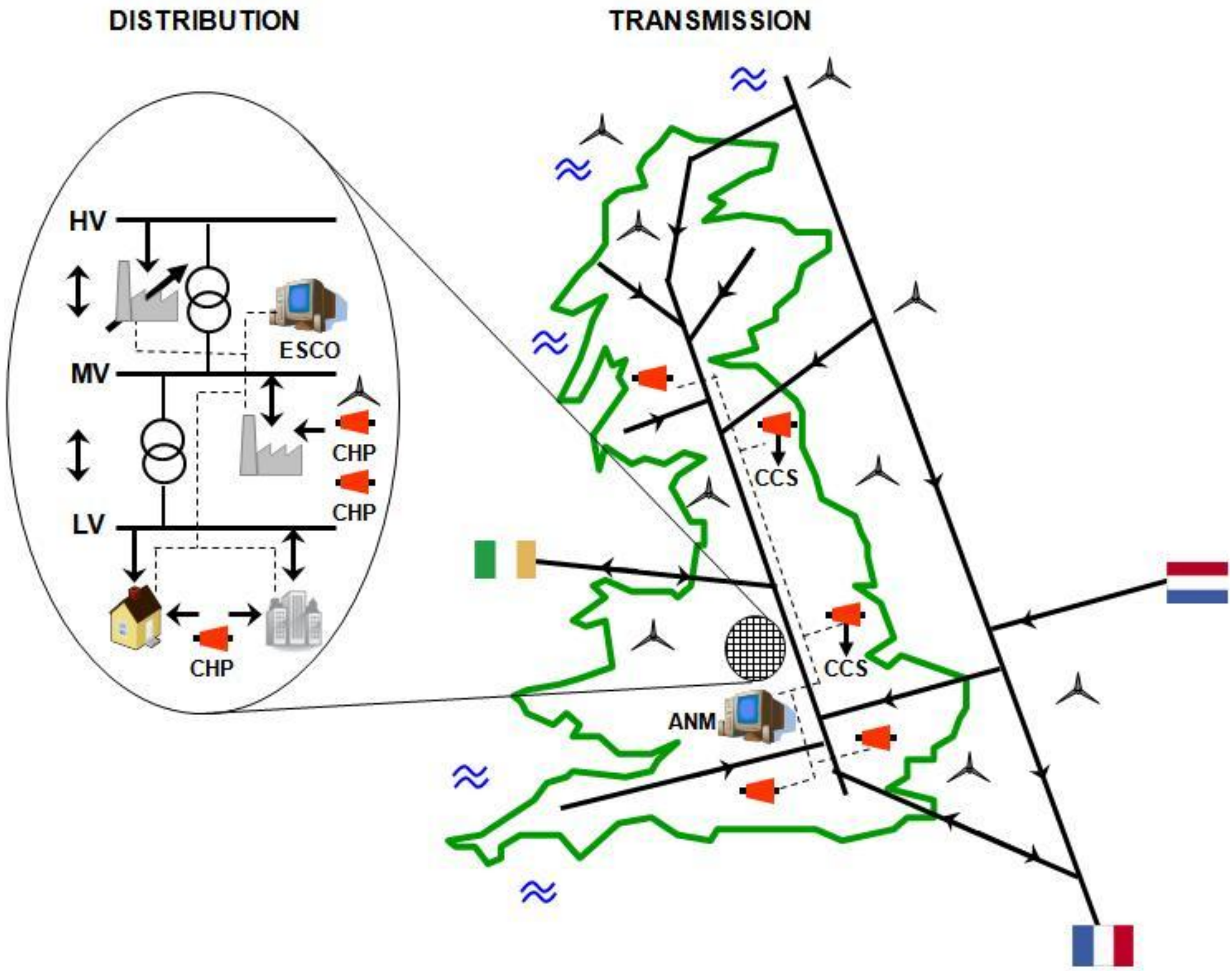
Consumers will be looking for additional services from their supply company to reduce environmental impact. They will expect electricity to be generated in an environmentally friendly manner as the Government shapes the generation industry. Efficiency provisions will emerge as a market develops for third party services through ESCOs who 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. With the combined influence of passive but environmentally concerned consumers and a non-prescriptive but focused Government agenda to significantly alter electricity use and generation, ESCOs become the market for ESCOs develops to be the significant characterizing feature of this scenario.

3.2.3 Network

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 themselves provide heat, light and power (as well as other services such as electric vehicles) to contracted customers and naturally have 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 take advantage of unbundling in other markets to drive a multi-utility offering that incorporates electricity, gas, water and telecoms services 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. Advanced smart meter solutions are a key enabler of the ESCO service provision.

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 somewhat reduced due to the strong developments of generation and energy services embedded within the distribution system, however a large proportion of generation (particularly base load) is still connected at the transmission level. 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.



Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation

Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present

Renewable electricity generation (including wind, biomass, etc . but excluding marine)

Renewable marine electricity generation (wave, tidal, etc.)

Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation

System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks

Information and communications technology (ICT) infrastructure for network operational management

Power system transformer between different voltage levels

Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Figure 6: 'Energy Service Companies' network pictogram.

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 and large-scale renewable developments met the need but are less heavily utilised over the decades as the generation portfolio changes shape. Investment in the development of international connections will create relatively significant interconnection capacity that will be utilised by ESCOs for imports and could facilitate participation in pan-European markets. 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. 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 electricity 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 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 widespread use of electric vehicles is likely to become an important element of on-site energy storage solutions.

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 IP enabled and connected to the home wired/wireless TCP/IP network. Advances in the UK telecoms industry such as BT's 21st century network, network unbundling, fibre to the home, next generation broadband and WiFi and WiMax technologies along with the generic use of TCP/IP for advanced applications and media and content delivery to the home allow ESCOs to build high bandwidth, low latency, Quality of Service enabled virtual private networks overlaying home networks and providing links to sizeable customer service facilities.
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.

3.2.4 Modelling results[6]

Headline results:

Though energy service demands remain high, increased use of efficiency by end use sectors reduces primary energy demand. The higher carbon price compared to Big T&D requires a combination of Coal CCS and Nuclear to meet baseload generation. There is also an important role for large scale renewables, particularly wind, as well as significant use of small scale wind. Reduced barriers to uptake for electric transport options increase their use without improved technology assumptions, and these enable the transport sector to decarbonise somewhat despite not being caught by the carbon price. Plug-in hybrids play a role in system balancing, but CHP for residential use is not selected.

Increased energy efficiency reduces primary energy demand compared to Big T&D, however, the electricity sector as a whole exhibits a growth over the whole period which is greater than that in the Big T&D scenario. This increase is almost entirely the result of a massive increase in electricity demand from the transport sector, rising from 20 PJ in 2000 to 330 PJ in 2050.

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[6] Discussions of modelling results should be compared with the input assumptions as described in section 2.4, and in Appendix B. More detailed discussions of the results are contained in Appendix B. The figures contained in this section have been summarised in this form using the primary model output data contained in Appendix B.

	2000		2025		2050	
Total final energy demand (PJ) [1]	**6,189**		**5,961**		**5,807**	
Transport	1,855	30%	1,635	27%	1,542	27%
Residential	1,961	32%	2,054	34%	1,921	33%
Other (Industry, Services & Agriculture)	2,374	38%	2,272	38%	2,345	40%
Total electricity demand (PJ) [2]	**1,176**		**1,399**		**1,623**	
Transport	20	2%	100	7%	330	20%
Residential	403	34%	563	40%	473	29%
Other [3]	754	64%	736	53%	819	50%
Total electricity generation capacity (GW)	**84**		**88**		**121**	
Large scale generation:						
Fossil (inc. CCS)	59	71%	40	45%	55	45%
Nuclear	12	14%	15	17%	13	11%
Renewables	4	5%	25	28%	24	20%
Interconnectors	2	2%	4	5%	10	9%
CHP	4	4%	3	3%	1	0%
Storage	3	3%	1	2%	1	1%
Small scale generation:						
Micro CHP	0	0%	0	0%	0	0%
Microgen	0	0%	0	0%	17	14%
Total electricity generation output (PJ)	**1,288**		**1,526**		**1,874**	
Large scale generation:						
Fossil (inc. CCS)	854	66%	759	50%	1,016	54%
Nuclear	282	22%	397	26%	334	18%
Renewables	46	4%	256	17%	300	16%
Interconnectors	52	4%	77	5%	103	5%
CHP	45	3%	31	2%	8	0%
Storage	10	1%	6	0%	0	0%
Small scale generation:						
Micro CHP	0	0%	1	0%	0	0%
Microgen	0	0%	0	0%	113	6%
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%		34%		47%	
Electricity sector reduction	0%		60%		88%	

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 5: ESCOs – Summary of modelling results

The carbon price converts all coal power to CCS - however, CCS still hits a ceiling similar to that of Big T&D, 40 GW in 2040. This is due to the increasing costs of storage once the cheaper storage options have been used up, as well as to the fact that residual emissions from CCS are more severely punished by the higher carbon price (CCS being not 100% efficient in removing CO2 emissions). With a reduced capacity for imported electricity compared to Big T&D, the model selects nuclear (which it considers zero carbon) - a technology which had no capacity by the end of the period in the Big T&D run.

The model invests strongly in wind power, including in 9.4 GW of offshore wind by 2040, which generates 110 PJ p.a. By 2045, a total of 247 PJ of electricity is generated from wind, with 27% of the total coming from small scale wind due to the accelerated cost and performance assumptions as part of the ESCO storyline. In contrast to Big T&D the rising carbon price and ESCO accelerated technology assumptions are now bringing on a range of renewable technologies, including from small scale solar PV, marine technologies and biogas driven thermal plant.

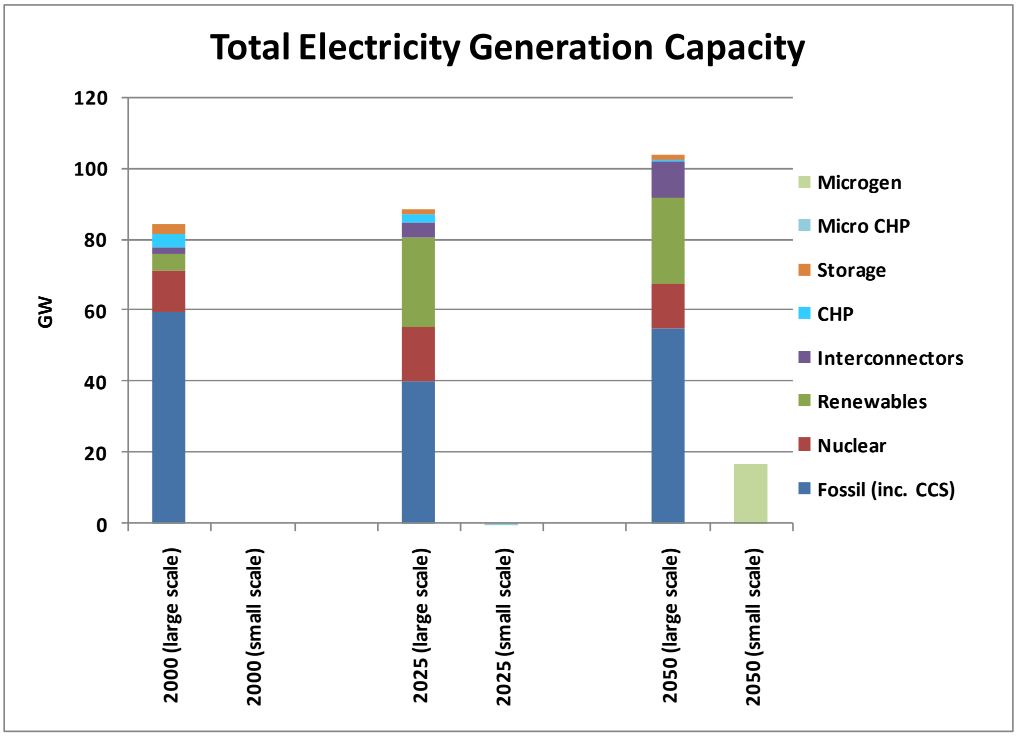


Figure 7: ESCOs – Electricity generation capacity (in GW) (distinguishing large scale vs. small scale generation)

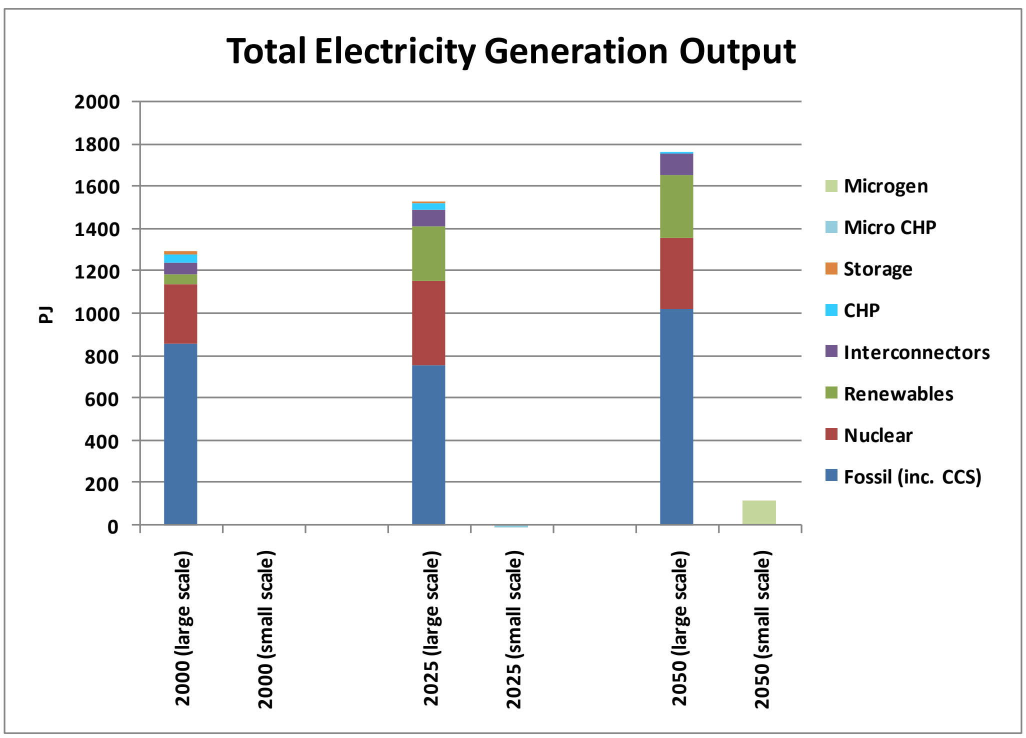


Figure 8: ESCOs – Electricity generation output (in PJ) (distinguishing large scale vs. small scale generation)

The success in the model results of microgeneration technologies as well as electrified transport - driven largely by reduced 'hurdle rates' - highlights the potentially important role identified in the scenario storyline of ESCOs in reducing the financial risk and barriers to market access, as well as driving down costs through economies of scale. The model selects significant levels of microgeneration, assuming some form of aggregation and supply-demand management, such as those described in the scenario as being performed by the ESCOs. The technical and institutional feasibility of such an arrangement is an important area to explore.

The main difference between the model and the scenario description is the almost complete absence of CHP technologies in the model results. Natural gas CHP is not considered a sufficiently low carbon option, and biomass resources are used up in other technologies, including transport and thermal power generation.

All major end use sectors in this scenario achieve significant decarbonisation through their use of electricity. Some sectors, such as transport, increase their use of electricity despite having no direct carbon driver, but rather for reasons of cost and efficiency when new technological options become available. The electricity system reduces its carbon emissions between 2000 and 2050 by 88%, contributing to an overall systems CO_2 mitigation effort of 47%. This run therefore clearly demonstrates that the electricity sector is of major importance in decarbonisation efforts in the UK- however, it is also clear that electricity focused policies alone would not be sufficient to achieve the levels of decarbonisation across the system which are being contemplated at the present time.

Key messages:

- ***Resolving barriers to uptake of novel energy technologies (including public acceptability, mechanisms for spreading up front or replacement cost, capturing financial benefits of efficiency to the consumer) may be more critical to their use then any further cost reductions in the technology per se.***
- ***The assumptions allowing successful penetration of small scale renewables assume some distribution level management to improve their availability and performance- the regulatory requirements to enable this will be important to such a scenario.***
- ***Electricity could be a key means to decarbonisation for the transport sector.***
- ***An important role for system balancing could be played by plug-in hybrid vehicles, or other storage technologies.***
- ***The benefits of CHP were not identified by this run, as existing infrastructures and low carbon electricity were favoured for meeting residential and service sector heat demands.***

A more detailed discussion of these points is contained in Appendix B.

3.2.5 2025 way-markers

The way markers identified for 2025 in this scenario are:

- Plateau reached for transmission transported electricity volumes and peak demand leading to slowing of rate of expansion of the transmission system with the exception of greater reach to larger scale renewable projects.

- System operator adopts new tools and techniques for growth in large scale renewable energy.
- Consumers remain relatively passive towards their electricity supplies and most activity in demand management and energy efficiency are led by supply companies.
- Fledgling development of energy services market through existing major electricity supply companies – some heat services offered in commercial and small industrial markets with trials underway at domestic level.
- Continued growth of natural gas as premium fuel for heat and power with accompanying gas infrastructure development (interconnectors to mainland Europe and from there to gas producing countries, LNG terminals and trade routes, gas storage facilities).
- Increased growth rate in distributed generation projects of various technologies (CHP and renewables) with a substantial minority of this new build DG at the smaller on-site commercial or microgeneration scale.
- Distribution network operators adopt new system operational procedures, tools and technologies to manage DG and supply company led demand and generation activity within distribution networks.
- Roll out of greater communications and control infrastructure within distribution networks and to smaller industrial and commercial customers.
- Hybrid plug-in electric vehicles are prevalent in the automobile market and public transport and supply companies start to trial ‘all-energy’ packages including electric vehicle leasing and fuelling. Full battery electric vehicles are becoming economically attractive.
- DSM takes off as a tool to aid ESCOs manage supply and demand balancing (or at least contract positions balancing) and ESCOs start to trial various packages of cost vs. convenience on electricity supplies.
- Smart meters are recognised as essential to the ESCO business model and significant investment has been made in the roll out of this technology.

3.3 Distribution System Operators

3.3.1 Introduction and summary

In this scenario Distribution System Operators (DSOs) take on a central role in managing the electricity system.

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. 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. In electricity networks the largest change is in the development and operation of distribution networks. The networks themselves adapt to accommodate large levels of distributed generation of different technologies and operationally the distribution companies manage the network much more actively. Demand side management grows strongly and this provides a tool for system management at transmission and distribution. The transmission network continues to provide the backbone for bulk power transmission but the flows are more variable and on average of a lower level.

Scenario Summary: Distribution System Operators

- 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 more electric and more 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.
- Consumers become more active in managing their energy demand and generating electricity in response to their own environmental concern and strong Government measures.
- Significant amounts of electricity production facilities are connected to distribution networks thus reducing the load on the transmission network.
- In addition to its traditional role of connecting centralised thermal generation, the transmission system also now acts to provide connections between DSOs and to strategic renewables deployments.
- 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.

3.3.2 Context

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.

As a result, tackling climate change will be at the forefront of UK energy policy. Other environmental issues such as the impact of network infrastructure will also receive high levels of public 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. Electricity networks may be required to respond to this changing climate in their construction and operation.

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 more strongly steering 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.

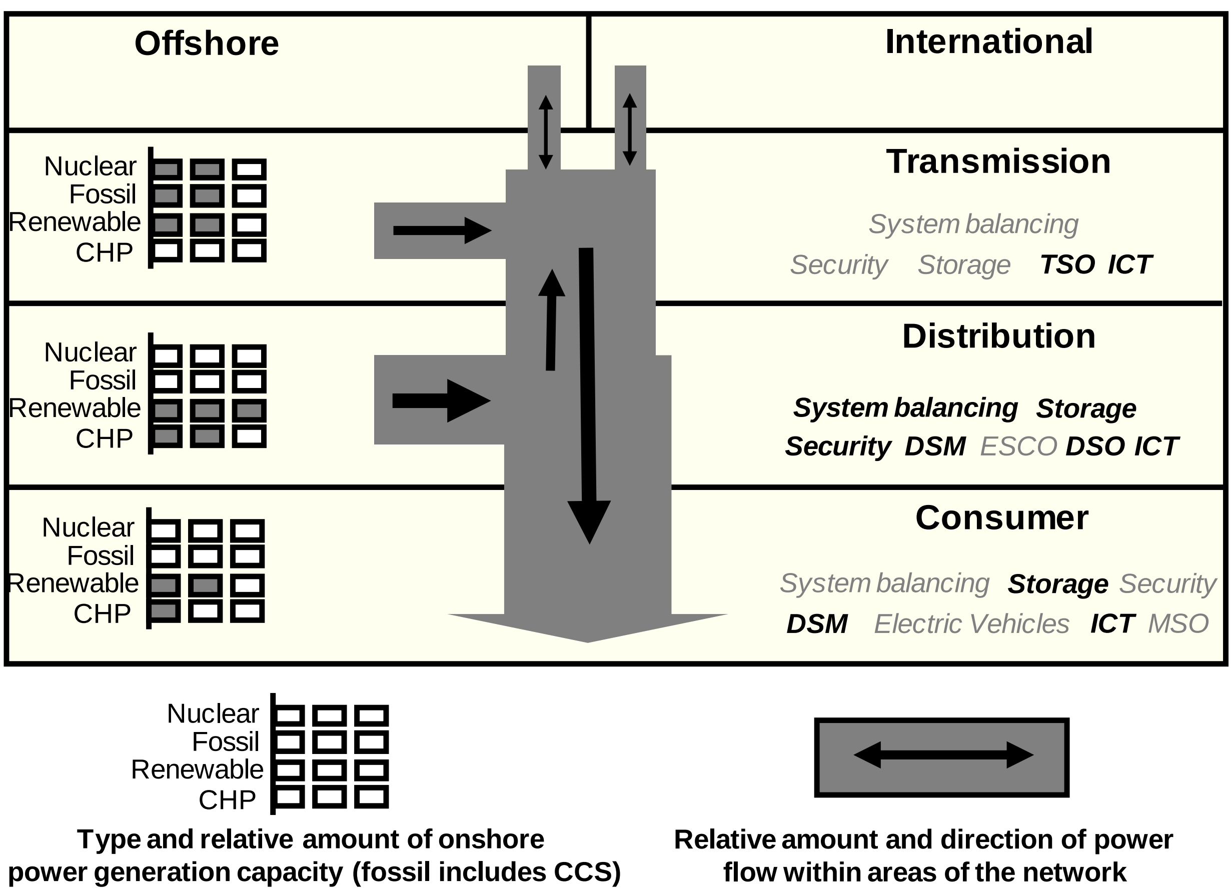


Figure 9: 'Distribution System Operators' scenario schematic illustration.

The electricity market would be a tightly controlled mechanism for achieving the generation, supply and transmission of power in line with the environmental and economic requirements of society. A centrally planned market would set incentives and rewards to encourage strong investment in renewable generation and decarbonised large-scale thermal generation. The desire for competition is demoted by the urgent need to address CO2 emissions and the market is arranged and controlled to deliver these targets. In the absence of healthy competition, the task of ensuring suppliers, generators and network companies are fairly rewarded while consumers receive value for money is a significant feature of this scenario. Although the market reverts to a centrally planned model, the operation and control of the network becomes more de-centralised as discussed below.

Emission capping and carbon taxation will be applied. The governing institutions would tend to “pick winners” and use subsidies and taxes to aid the development of particular technological solutions such as under-grounding and offshore transmission links.

A hydrogen economy develops due to strong Government lead and EU wide initiatives on R&D and infrastructure development. The primary use of hydrogen as an energy carrier is in the decarbonisation of the transport sector alongside the much more widespread use of electricity as a clean energy vector for transport. Publicly funded demonstrations and feasibility studies are swiftly followed by strong policy support in the form of tax incentives and public-private partnerships. There is partnership with the major petroleum suppliers and vehicle manufacturers as these industries gradually diversify their business to include hydrogen. As the market develops, Government intervention becomes less necessary and hydrogen production, storage and transportation becomes a huge industry to satisfy primarily transport and also some fuel cell demands. The majority of hydrogen produced for the transport sector will be via small scale steam methane reforming with the remainder coming from small scale electrolysis. This is primarily dictated by the economic advantage of using existing gas and electricity infrastructure to avoid the requirement for large scale hydrogen transportation. The use of electricity from clean sources for transport brings a substantial rise in the electricity demand which is offset only by the same environmental drive bringing strong action on energy conservation and by the use of hydrogen for vehicular transport.

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 and new transport methods.

Investment will either be public funded or prompted by Government policy. Decision making here would be more focused on public benefit and achieving Government targets. 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.

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. 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 electric vehicle or 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.

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 CHP. 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 widespread development of sustainable power parks.

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 localized planning and rapid deployments may result in clashes with public opinion and local pressure groups on renewable developments and geographic reach of the transmission network. This could prompt Government mandates for renewable developments and public funding of undergrounding.

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 will be met by a generation mix that maximises the potential of localized renewably generated electricity, CHP (possibly Hydrogen) and latterly, offshore wind and tidal generation. Significant quantities of base load generation in the form of Nuclear and Fossil fuel with CCS are also still required to supplement the renewable resources.

Variable renewable generation becomes a major part of the electricity generation portfolio as Government subsidies and emission taxing make this an attractive 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 CHP and possibly wind and solar renewable sources that provide a localized 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 could also extend in a small way 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 and will continue to be the preferred fuel source for domestic space and water heating.

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 will be welcomed especially where 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.

Within the domestic consumer sector, population growth, increased affluence and associated growth in dwellings would seem to indicate increasing levels of demand. However, the concurrent strong action on energy efficiency and the hydrogen economy would reduce the demand for network supplied electricity from traditional sources but increased demand from transport results in a flattening or modest decrease.

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 CHP and renewable generation become an economical energy source due to carbon taxation and other Government mandates, these larger consumers will have a significant generation potential 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. Prices for exported electricity are likely to be set centrally.

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.

3.3.3 Network

Large quantities of electricity production is connected to distribution networks, somewhat reducing the load on the transmission network which serves to connect base load centralised generation and 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. The operation and construction of the distribution network may also have to account for increased quantities of faults due to changed weather conditions. 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 downward pressure on demand to service offset on the upside by greater demand from electric vehicles. 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.

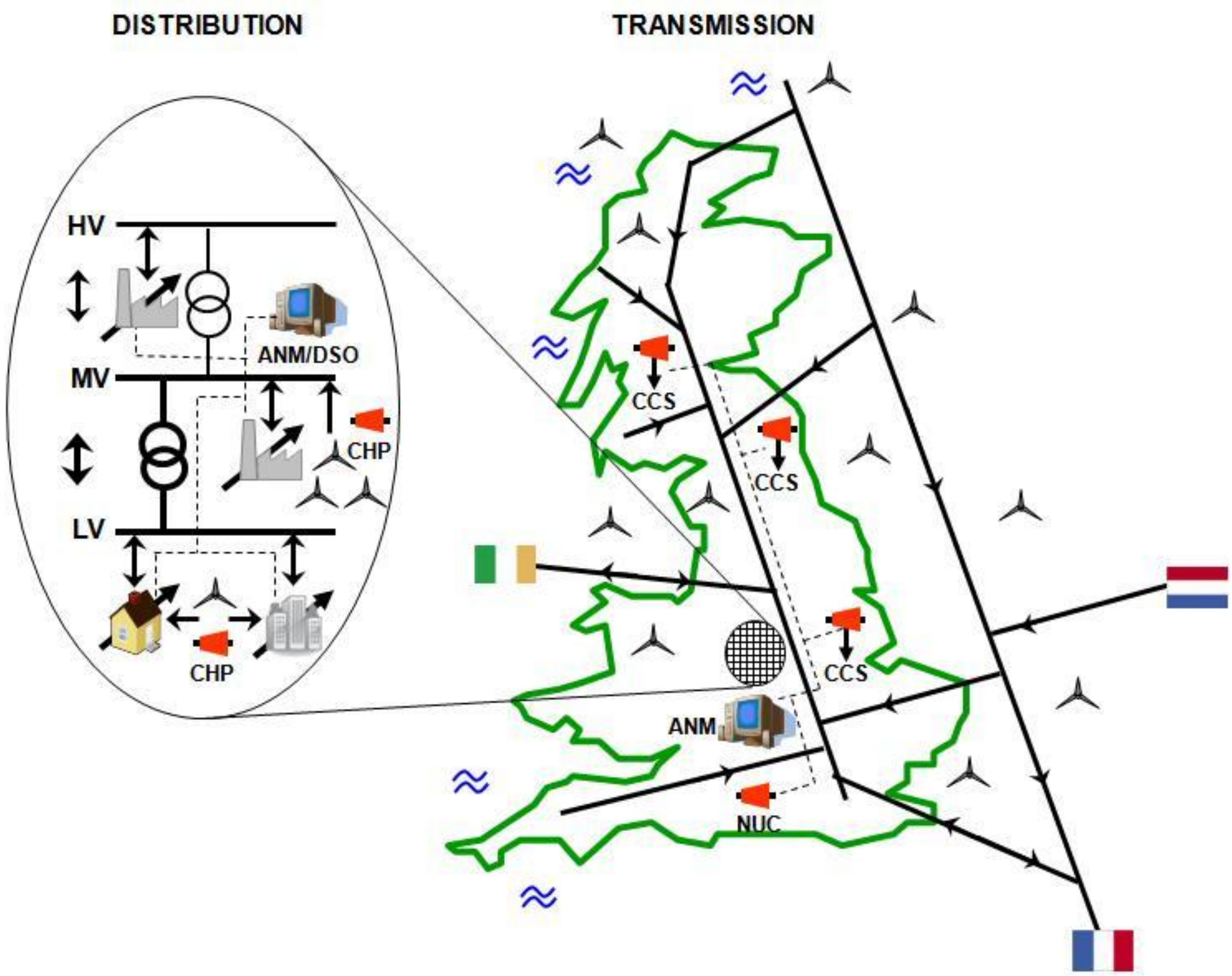
Because the proportion of demand met by large scale plant is lower and because the sources of power are renewable and variable output, then the transmission system is less heavily utilised in general. However, in addition to a continuing role facilitating the connection of base load generation, the need 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 no pressure to increase the size of the transmission system or 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.



Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation

Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present

Renewable electricity generation (including wind, biomass, etc . but excluding marine)

Renewable marine electricity generation (wave, tidal, etc.)

CCS

Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation

ESCO

System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks

Information and communications technology (ICT) infrastructure for network operational management

Power system transformer between different voltage levels

Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Figure 10: 'Distribution System Operators' network scenario

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. The DSO relies heavily on the functionality provided by networked smart meter technology. 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 generation to the DSO. The SO also acts to manage exchanges of power and services (e.g. reserves) between DSOs.

3.3.4 Modelling results[7]

Headline results:

The higher carbon price in this scenario begins to favour nuclear over CCS, due to the residual carbon emissions of the latter. Renewables are strongly favoured, in particular onshore wind, both large and small scale; however the limits on the transmission system drastically reduce access to offshore wind and marine technologies. Hydrogen technologies develop strongly, particularly in transport, having a significant on demand for both electricity and natural gas. CHP is once again eschewed as a long term option. CCGT plant is installed but largely kept in reserve for system balancing.

[7] Discussions of modelling results should be compared with the input assumptions as described in section 2.4, and in Appendix B. More detailed discussions of the results are contained in Appendix B. The figures contained in this section have been summarised in this form using the primary model output data contained in Appendix B.

	2000		2025		2050	
Total final energy demand (PJ) [1]	**6,188**		**5,775**		**4,910**	
Transport	1,855	30%	1,853	32%	1,292	26%
Residential	1,961	32%	1,807	31%	1,625	33%
Other (Industry, Services & Agriculture)	2,373	38%	2,115	37%	1,993	41%
Total electricity demand (PJ) [2]	**1,176**		**1,102**		**1,243**	
Transport	20	2%	33	3%	126	10%
Residential	403	34%	418	38%	378	30%
Other [3]	754	64%	652	59%	739	59%
Total electricity generation capacity (GW)	**84**		**83**		**105**	
Large scale generation:						
Fossil (inc. CCS)	59	71%	24	29%	27	26%
Nuclear	12	14%	19	22%	19	18%
Renewables	4	5%	21	25%	22	21%
Interconnectors	2	2%	4	5%	10	10%
CHP	4	4%	2	3%	0	0%
Storage	3	3%	1	2%	1	1%
Small scale generation:						
Micro CHP	0	0%	0	0%	0	0%
Microgen	0	0%	12	14%	24	23%
Total electricity generation output (PJ)	**1,288**		**1,287**		**1,501**	
Large scale generation:						
Fossil (inc. CCS)	854	66%	417	32%	457	30%
Nuclear	282	22%	488	38%	502	33%
Renewables	46	4%	191	15%	279	19%
Interconnectors	52	4%	77	6%	103	7%
CHP	45	3%	24	2%	7	0%
Storage	10	1%	6	0%	0	0%
Small scale generation:						
Micro CHP	0	0%	1	0%	0	0%
Microgen	0	0%	85	7%	153	10%
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%		37%		61%	
Electricity sector reduction	0%		74%		95%	

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 6: DSOs – Summary of modelling results

All sectors reduce their energy service demand levels in response to the carbon price, and the constraint on the use of the transmission system. These demand reductions imply end use efficiency, but also some significant cultural and lifestyle changes in perceived energy service 'comfort' levels.

The DSO model run shows very significant levels of large scale centralised low carbon generation becoming and then remaining the backbone of the electricity system. A notable outcome of the further increased carbon price is the improvement of economic prospects for nuclear compared to CCS - the latter being increasingly ‘punished’ for its residual carbon emissions, as described in the previous section.

The onshore wind resource is fully utilised, however the offshore resource remains relatively underdeveloped for most of the period, achieving a constant generation of only around 10 PJ p.a. until 2040. This is a result of the reduced capacity for transmission of large scale electricity. This changes suddenly in 2040 with the growth of new electricity demands which can be met through the transmission network, and offshore wind jumps to 70 PJ p.a. with the investment in an additional 5 GW.

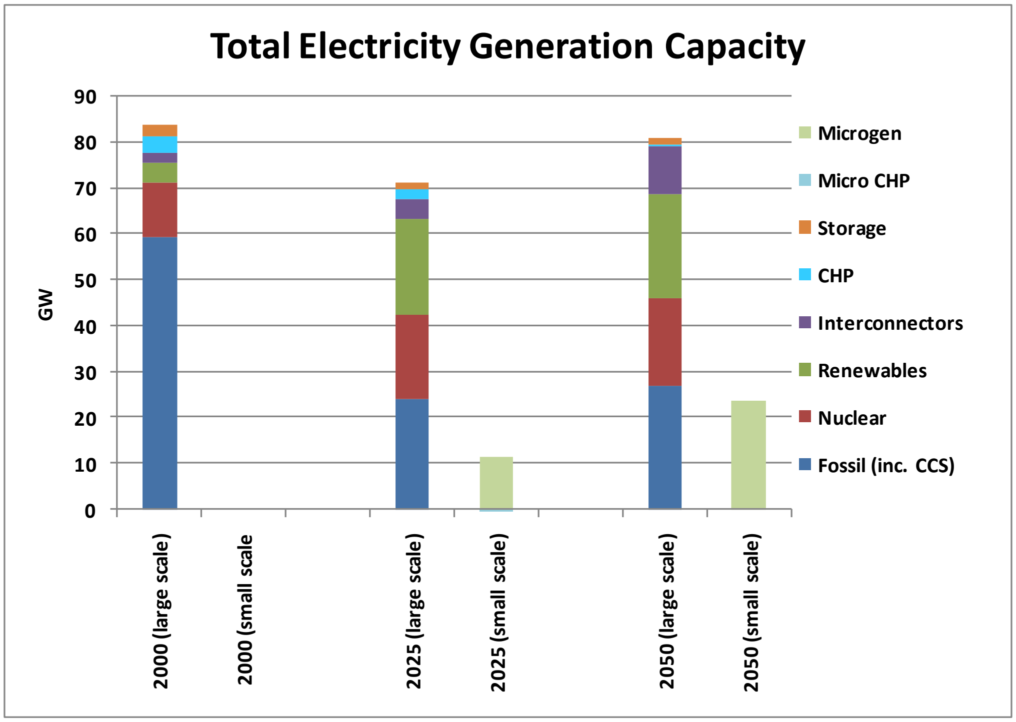


Figure 11: DSOs – Electricity generation capacity (in GW) (distinguishing large scale vs. small scale generation)

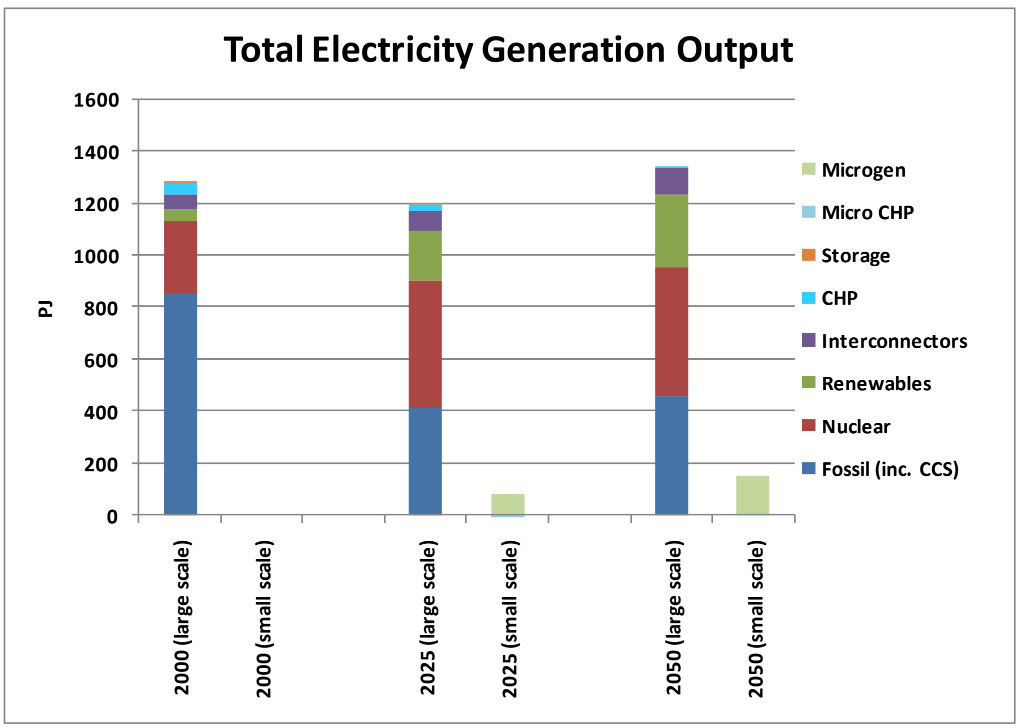


Figure 12: DSOs – Electricity generation output (in PJ) (distinguishing large scale vs. small scale generation)

The higher carbon price and the constraints on transmission mean that small scale wind (which avoids the transmission network) is an attractive option much earlier in the period, receiving its first major investment in 2015, and generating 66 PJ in 2020. Similarly, small scale solar PV, reaches a substantial 57 PJ p.a. by 2050, with 9 GW of installed capacity. A small amount of residential CHP running on natural gas also contributes to residential electricity demand in the middle of the period, but by the end of the period the increasing carbon price means that as this is not a zero carbon option it is no longer cost effective, and access to low carbon biomass is limited. The lack of uptake of CHP is again a major contrast to the scenario narrative.

The development of hydrogen technologies has a significant impact on the electricity and gas networks. The use of electricity for hydrogen production from electrolysis is constrained to 100 PJ per year; this is an intuitive outcome of the scenario description, that a system which over several decades had not developed the capacity to expand its transmission network would not be able to have the flexibility to respond to very large additional demands at a future point. This constraint is the reason why the model also selects small scale SMR, despite the high carbon costs. In a sensitivity analysis the constraint on electricity for hydrogen production was removed. The model produced all the hydrogen from electrolysis, with the result that total electricity generation in 2050 increased by a third - from 1,501 PJ to 2,071 PJ.

All sectors contribute to decarbonisation, though once again, the electricity sector plays a major role in this. Transport achieves quite considerable emissions reductions through technology switching to electricity and hydrogen. The residential sector on the other hand decarbonises through significant demand reductions. The electricity sector reduces its carbon emissions by 95% compared to the year 2000 base. This is driven by the higher carbon price, as well as the fact that this price is also applied to transport, residential and service sectors, and the electricity sector takes the responsibility of 'finding' low carbon energy for these other sectors. The overall system decarbonisation is 61% by 2050.

Key messages:

- ***Limited development of the transmission capability could reduce availability of stranded renewable resources, increasing the burden on more conventional connected sources.***
- ***Developments in other technologies such as hydrogen vehicles, could have major effects on overall electricity demand and hence on the networks.***
- ***Again, the model's use of small scale generation options assume management at the distribution level, and possibly demand side management.***
- ***Load spreading technologies, such as plug-in hybrid vehicles, could be crucial in allowing a low carbon electricity portfolio.***
- ***CHP faces challenges in high-carbon price scenarios, particularly if biomass is limited, or is preferred for use in the transport sector.***

A more detailed discussion of these points is contained in Appendix B.

3.3.5 **2025 way-markers**

The way markers identified for 2025 in this scenario are:

- Growing interventions of government in setting the pace for climate change and energy security action.
- Primary energy demand is showing a steady downward trend.
- Hydrogen technology trials and demonstrations grow in number with a larger volume public transportation fuel cell powered and hydrogen infrastructure emerging (e.g. refueling, hydrogen production facilities).
- Significant growth in DG connected directly to distribution networks (Renewables in general and wind in particular).
- Economic breakthrough for micro generation and small but significant growth in numbers of households fitting microgeneration (solar and micro-wind feature prominently). Micro-generation is now standard for new build housing developments (as a natural progression of the zero carbon housing standards set by government. Retrofit microgeneration market grows.
- Transmission system volume flows start to decrease marginally with the result that some previously planned network expansions are deemed not necessary and removed from investment plans.
- Greater diversity in imports into grid supply points is experienced with a small number of grid supply points exporting at some points in the year.
- Distribution network infrastructure growth rate increases to keep pace with higher levels of activity in distribution networks. Consecutive price control periods see increased capital expenditure plans.
- DNOs start to adopt new network and enabling technology more aggressively to deal with the growing demands for network capacity and the necessity to manage more active networks. ICT infrastructure development becomes a more central issue in network expansion.
- DSM takes off as a tool for the DNO to manage a complex system balancing situation within their area. Incentives for efficiency in distribution system management are mooted. Smart meters are an integral part of this development.

3.4 Microgrids

3.4.1 Introduction and summary

In this scenario customers are at the centre of activity in electricity networks.

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 these objectives 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. Electricity networks undergo a radical transformation with the centre of activity with very large volumes of generating units and demand response schemes operating at a local level. While the transmission infrastructure still plays a key role in system operations, the utilisation of network capacity is relatively low and the role of central generation is reduced. Within distribution networks much more active management is required by the network companies at voltage levels right down to customer supplies. Customer demand management is prevalent and this is often to meet the availability of local sources of energy.

Scenario Summary: Microgrids

- 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.
- 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.
- Individually and collectively customers actively manage their own energy consumption against their own or locally available supplies, aiming to 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.

3.4.2 Context

Environmental concern grows strongly as climate change develops to a serious degree and is indisputably linked to GHG emissions. Global initiatives will be slow to gain traction and widespread support 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 firmly established carbon markets will help incentivise low carbon energy in developing countries.

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 on the environment 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 that energy efficiency is essential and a matter of national strategic importance. This will be delivered through markets with appropriate frameworks and bounds.

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.

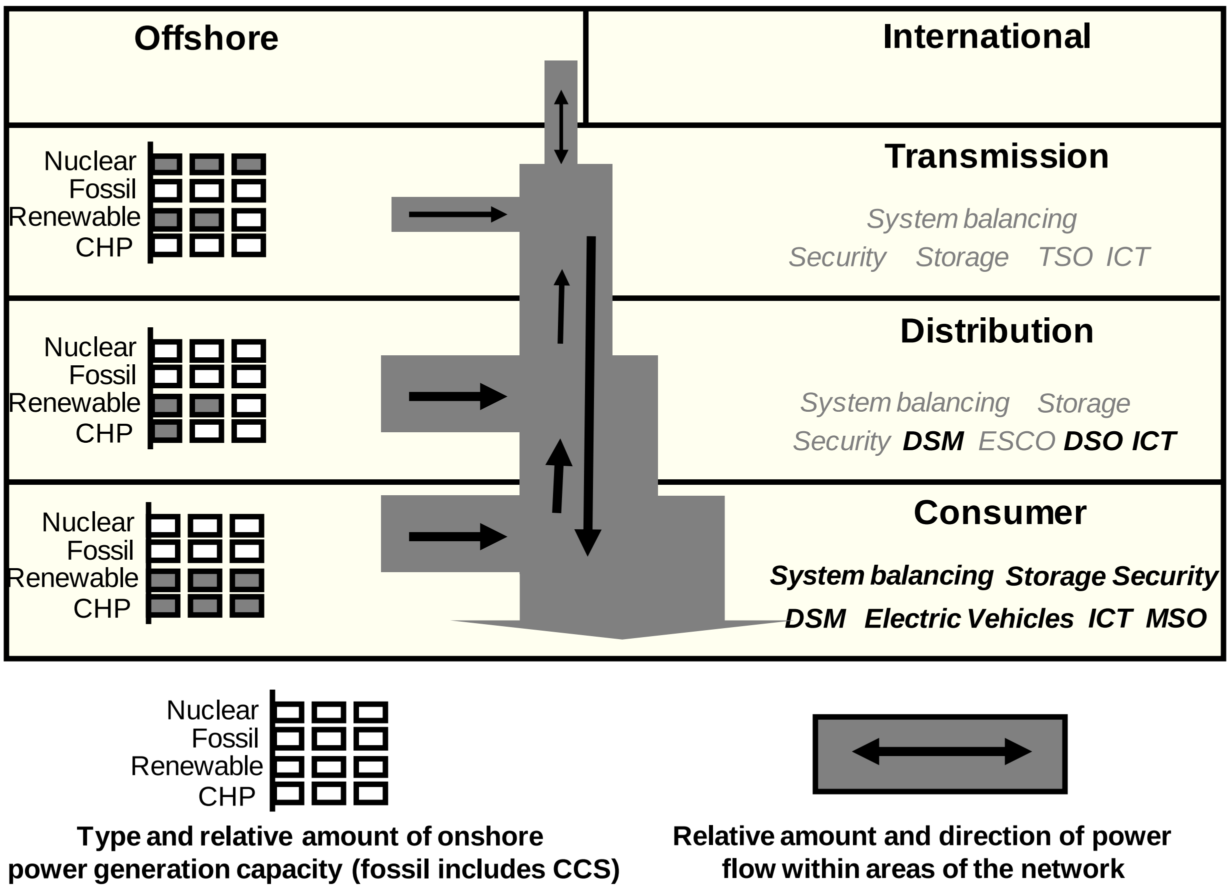


Figure 13: 'Microgrids' scenario schematic illustration.

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 be a strong focus on the benefits of decentralised energy and energy efficiency, not only to meet environmental objectives but to reduce reliance on centralised fossil fuel in a world of decreasing supply and increasing prices.

There will still be regulation to oversee the operation of and to promote competition in the energy markets. Government will 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. Emissions trading will develop and the resulting market price of carbon will reflect the perceived high cost and consequence of not hitting emissions targets. 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 permission for micro generation projects will become a standardised, fast-track process, removing barriers to uptake. 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 economic environment will be healthy enough to provide investors with the confidence necessary for new markets to develop amid innovation and entrepreneurialism. There will 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. 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.

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. Government strongly encourages this trend with reform of building regulations setting zero carbon objectives in the new build and public sectors. This is only one of many policy measures introduced to promote energy saving and remove barriers to micro-generation. With the benefits of reduced energy consumption and renewable generation in regard to CO2 emissions clear, the Government will initially act to remove economic and social barriers and encourage consumers to be active in these areas as part of an overall strategy for decarbonisation. The shift in consumer attitudes results in a strong response to these measures stimulating a growing market in the provision of diverse microgeneration technology. One other factor influencing customer decision making is the perception that micro-generation puts energy security into the hands of the consumer with a degree of independence from larger scale generation and the bulk electricity transport networks. However, with a growth in natural gas fired micro-generation and the use of the electricity networks to provide residual power import and backup for customers with micro-generation, such independence is only partly realised.

Attitudes to transport change. Longer journeys and commuting are avoided where possible and use of public transport becomes more popular. Private car use will still be widespread, mainly used for shorter leisure journeys. Transport migrates towards low carbon options in this scenario. Hybrid electric vehicles will be the initial preferred choice moving to fully electrified vehicles by 2050. Hydrogen fuel cell cars are also likely to feature as competition develops between low carbon options. This is driven by a consumer desire for clean transport and market provision but is also supported by government led frameworks for the introduction of low carbon vehicles such as R&D support, low carbon transport incentives and mandated obligations. Home charging of electric vehicles could become common creating a new source of electricity demand with the potential for under-sizing of micro-generation installed on a self sufficiency objective in comparison with the growing demand for electric vehicle charging. 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 hydrogen. The market will lead these developments by responding to consumer demand and Government prompting.

Flexible working will become more common as people actively try to avoid unnecessary commuting and a growing preference for living in smaller more rural communities develops. Advances in ICT and the capabilities of telecommunications networks enable the rise of a digital networked economy and the emergence of virtual office working practices makes highly distributed workforces a common business model. In industry, policy on estate and working practices will be heavily influenced by energy considerations. Voluntary Corporate and Social Responsibility (CSR) policy would aim for energy efficiency.

The majority of consumers actively look 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 that are assisted by Government promotion of energy efficiency and the introduction of strong environmentally targeted supply and demand side targets and incentives.

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

Generation is almost exclusively low carbon due to the above influences with low carbon 'certification' available for the high overall energy utilization achievable in gas fired micro-CHP. The market pressures will create a strong focus on the deployment of renewable generation which is often distributed and/or micro in nature. Centralised generation will be sized to supplement the distributed and micro generation deployed in local areas and to meet growing demand from new sectors such as transport. Nuclear and fossil fuel with CCS are likely to be prominent as stable high carbon prices incentivise investment in these technologies.

Within the domestic sector there could be widespread deployment of micro CHP and renewable micro generation. As a result of government strategy, public bodies (schools, hospitals, council offices) may have developed CHP, storage and renewable energy sources that reduce these organisations reliance on their grid connection and centralised 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[8]. Many companies would service consumer demands for a variety of self generation technologies and products.

As described above, active consumers will be motivated to develop their own supply of energy and the ability to minimise energy purchased from non-renewable sources. Their motivation is partly due to a general shift in attitudes and also to demand reduction measures such as DSM schemes and possible carbon market penalties for unconstrained energy demand growth. Consumers will also be using energy storage technology to promote self sufficiency with the option of generating their own power or using stored energy. These moves are supported and encouraged by overall Government strategy supporting distributed energy and energy efficiency. Mechanisms similar to the RO are used to promote micro-generation, as are feed-in tariffs at the domestic level. The potential to export low carbon energy and be rewarded fairly by the market provides additional motivation to develop self generation technology. These measures have a similar impact as ROCs have had on onshore wind in recent years and result in the widespread adoption of micro-generation. As this trend develops and innovative markets emerge and mature, initial economic and social barriers are overcome and distributed energy plays an important part in decarbonising the GB energy system.

Gas is likely to remain an important fuel in the short to medium term and would be used

[8] 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.

for space and water heating, increasingly in the form of CHP. Biomass could gradually penetrate as a CHP fuel due to environmental and security of supply reasons but there continue to be serious issues of sustainability for large scale biofuel exploitation and this limits the overall penetration of this fuel source. The reliance on gas is an important issue for energy security of supply and long term alternatives for space and water heating are deemed essential. Generation from waste and synthetic organisms is the most plausible development. 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.

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

Public bodies and Industrial consumers will initially participate in DSM in the form of existing commercial agreements with the 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 or a decline in energy consumption.

Characterising features of the domestic consumer sector will be population growth, a preference for rural living and increased affluence and associated growth in numbers of dwellings and electronic consumables. The advent of home charged Electric Vehicles will create a new demand source as well as a storage capability. These features indicate a significant growth in demand, however the stringent energy efficiency measures of this scenario (within building regulations and electrical products etc) control and reduce the net growth in demand. The majority of space and water heating at present uses gas. It is likely this would migrate to CHP, utilizing existing heat networks where present (high rise building, power parks, old peoples' homes, university campus etc) or micro CHP in the domestic setting. Other technology such as heat pumps and solar heating would also be deployed. The overall result is that many energy consumers reduce their reliance on grid supplied electricity, using distributed and micro energy sources to meet a significant amount of a demand already reduced by energy efficiency measures.

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. 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.

3.4.3 Network

The self-sufficiency concept (renewables, CHP, energy efficiency, demand side management) has developed strongly with electricity consumers, so the role for transmission and bulk distribution (through the 132kV sub-transmission network) has 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 local production and to minimise exports to and imports from the electricity system. The success of this objective is varied depending on local resources and circumstances meaning grid connection and centralised generation still have an important role to play. Local distribution networks provide the balance between local/regional exports and imports.

This scenario will require the balancing of flows within and between different regions. This may need to remain a responsibility of the Transmission and/or Distribution System Operators. While there will undoubtedly be a significant reduction in average utilisation of the bulk power transport networks a significant amount of capacity will be required both to meet the demand in periods when locally produced energy is short and to provide the essential link to larger scale nuclear, renewable and fossil generation as well as to continental interconnectors.

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 reduced with alternative energy sources 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 reduced but still significant role for the bulk power system.

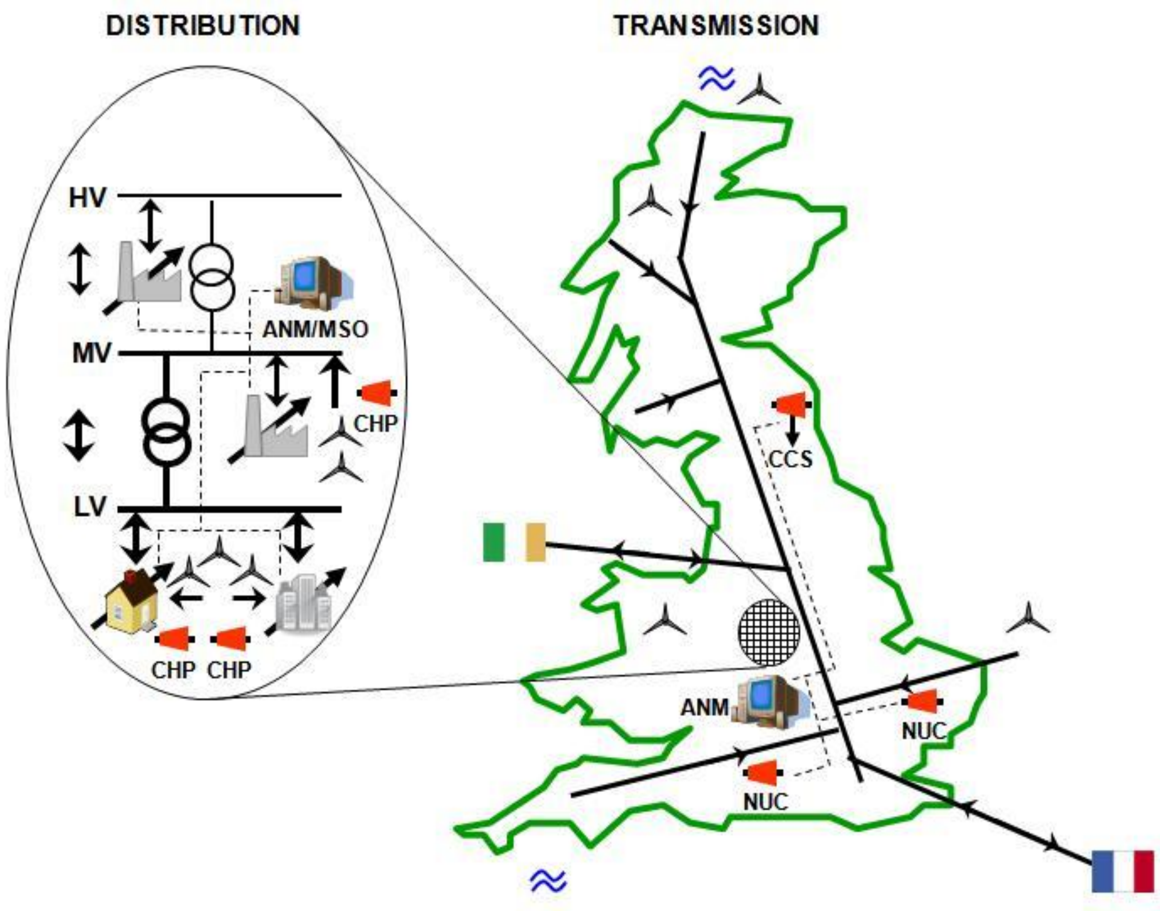
One approach being deployed widely is the microgrid where self-sufficiency among individual and groups of customers has developed to such an extent that demand management, energy storage, power quality as well as energy production are coordinated in well defined customer groups. The role for the distribution network operator might be in operating the microgrids themselves or connecting microgrids to the wider distribution system as virtual or actual private networks. Microgrids will sometimes 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. Although the attitudes within society and the thrust of government policy promote the self-sufficiency and local generation trend, this is not a universal solution and the grid connection is still an essential part of microgrid operation.

Within the microgrid, there is exploitation of renewable sources as appropriate to the locality (e.g. solar power, wind, biomass) and the current high dependence on natural gas fired boilers for space and water heating migrates to the use of combined heat and power systems. Other renewable technologies such as heat pumps and solar water heating combined with improved energy efficiency of buildings helps reduce the reliance on gas. However, the net effect is that the wholesale natural gas market is possibly more important than the electricity market. The other major implication of the reliance on natural gas for much local energy provision is the continued development of the national gas infrastructure while the electricity transmission system faces reduced load in the new role it plays. Gas imports from 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 the 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 from transmission connected central 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. Hardware to provide on-site monitoring, metering, production, storage and control equipment will be deployed. The widespread use of electric vehicles will be a key component of demand management and storage solutions.

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.



Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation

Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present

Renewable electricity generation (including wind, biomass, etc . but excluding marine)

Renewable marine electricity generation (wave, tidal, etc.)

CCS

Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation

ESCO

System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks

Information and communications technology (ICT) infrastructure for network operational management

Power system transformer between different voltage levels

Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Figure 14: 'Microgrids' network scenario.

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 control flexibility to manage generation and demand in operational timescales and this will be required to reduce the dependence on the main power system to meet one of the customer objectives. 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 strategic 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 will result in the continued investment in large scale power generation. Centralised thermal generation (especially nuclear) will also continue to play a role in supplementing the increased levels of localised generation. Some large scale facilities retain the capability to export either hydrogen or electricity to exploit the dynamic markets in both commodity markets. The resulting architecture is a generally reduced transmission requirement 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.

3.4.4 Modelling results[9]

Headline results:

With a very high carbon price and an even stronger constraint on the use of the transmission system than in DSO's, this run sees major demand reductions, particularly in the middle of the period. In the latter half of the period however, increased availability of distributed generation, and a growing electrical demand from the transport sector, in part through hydrogen, increases electricity generation again. Small scale CHP is prominent in this scenario as a means of providing decentralised energy services - it is fired on natural gas due to limited access to biomass. Small scale wind and solar PV make a major contribution to meeting electricity demand. Nuclear plays a strong role in the generation portfolio, as the high carbon price favours it over CCS, and transport provides an additional load for baseload generation.

The high carbon price demand reduction mean that total primary energy demand ends up at the lowest level of all the runs (5,148 PJ in 2050). Transport demand reductions are in general slightly less great. In fact, the demand for car transport shows a late increase, due to the availability of cost effective low carbon alternatives late on in the period.

Small scale gas fired CHP, at the residential and commercial scale, now has an important role in meeting distributed residential and service electricity demand as the constraint on transmission becomes more and more pressing. Total CO2 emissions from the residential sector remain virtually the same in this run as in DSO, despite the higher carbon price and greater demand reductions. Despite the extremely optimistic input assumptions on hydrogen fuel cell CHP, this technology is still not chosen, as hydrogen is prioritised for the transport sector. Biomass is not chosen due to its limited availability and due to the fact that it is prioritised for conversion to biodiesel for HGVs, and for thermal power generation.

[9] Discussions of modelling results should be compared with the input assumptions as described in section 2.4, and in Appendix B. More detailed discussions of the results are contained in Appendix B. The figures contained in this section have been summarised in this form using the primary model output data contained in Appendix B.

	2000		2025		2050	
Total final energy demand (PJ) [1]	**6,188**		**5,641**		**4,558**	
Transport	1,855	30%	1,842	33%	1,255	28%
Residential	1,961	32%	1,780	32%	1,431	31%
Other (Industry, Services & Agriculture)	2,373	38%	2,020	36%	1,872	41%
Total electricity demand (PJ) [2]	**1,176**		**864**		**1,044**	
Transport	20	2%	33	4%	263	25%
Residential	403	34%	271	31%	195	19%
Other [3]	754	64%	560	65%	585	56%
Total electricity generation capacity (GW)	**84**		**83**		**113**	
Large scale generation:						
Fossil (inc. CCS)	59	71%	25	30%	9	8%
Nuclear	12	14%	10	12%	27	24%
Renewables	4	5%	11	13%	16	14%
Interconnectors	2	2%	4	5%	12	11%
CHP	4	4%	2	2%	0	0%
Storage	3	3%	1	2%	1	1%
Small scale generation:						
Micro CHP	0	0%	8	10%	24	22%
Microgen	0	0%	22	26%	23	20%
Total electricity generation output (PJ)	**1,288**		**1,203**		**1,462**	
Large scale generation:						
Fossil (inc. CCS)	854	66%	423	35%	100	7%
Nuclear	282	22%	267	22%	713	49%
Renewables	46	4%	151	13%	209	14%
Interconnectors	52	4%	77	6%	103	7%
CHP	45	3%	19	2%	7	0%
Storage	10	1%	6	0%	0	0%
Small scale generation:						
Micro CHP	0	0%	83	7%	142	10%
Microgen	0	0%	177	15%	189	13%
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%		36%		71%	
Electricity sector reduction	0%		74%		99%	

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 7: Microgrids – Summary of modelling results

This run also deploys greater quantities of small scale generation, and at an earlier time than in DSO. The small scale wind resource is once again fully deployed by 2020, and small scale solar PV is already generating significant amounts of electricity by 2015, rising quickly to generate 142 PJ by 2025. The reduced transmission capacity sees a much reduced role for large scale renewables, including offshore wind and marine technologies, whose combined contribution in 2050 is now less than a third what it was under ESCO, despite the higher carbon price.

The transport sector again undergoes major transformation, with implications for the electricity sector. In this run hydrogen and electric technologies share the majority of the transport fleets. The model retains a preference for small scale hydrogen production methods which avoid the problems of distribution infrastructure. The same quantity as in DSO comes from small scale electrolysis (85 PJ), again reflecting the constraint on transmission electricity for electrolysis which is still in place. However, the quantity produced from small scale SMR is significantly reduced from DSO, at 55 PJ in 2050 compared to 356 PJ previously. Now the greater use of natural gas in electricity generation and CHP makes less gas available for hydrogen production. This means that the model resorts to importing significant amounts of liquid hydrogen (150 PJ).

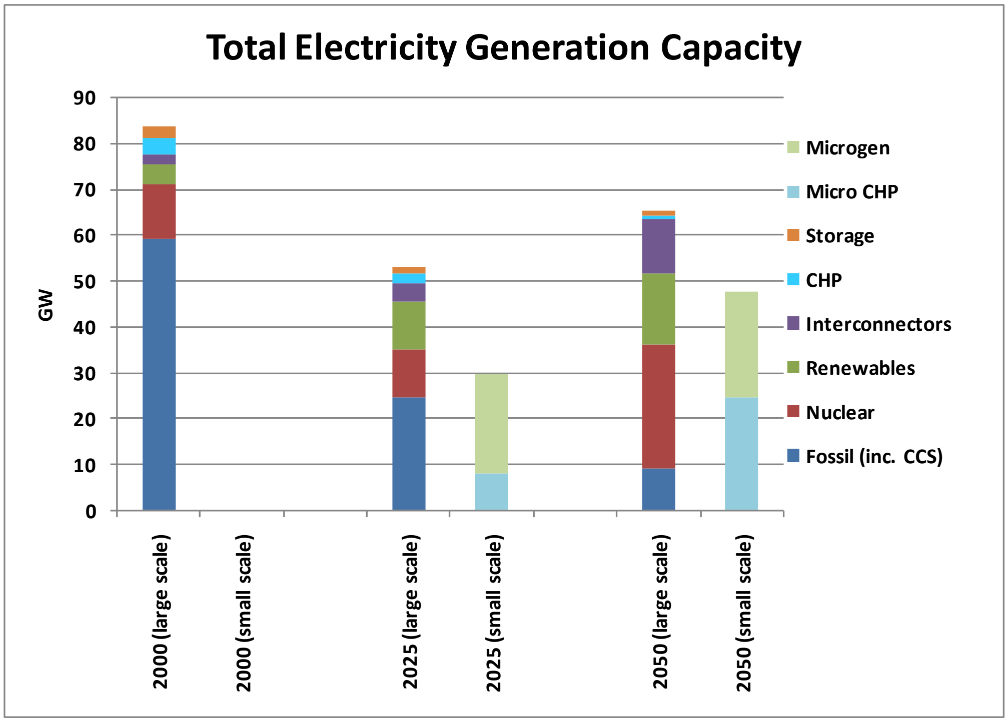


Figure 15: Microgrids – Electricity generation capacity (in GW) (distinguishing large scale vs. small scale generation)

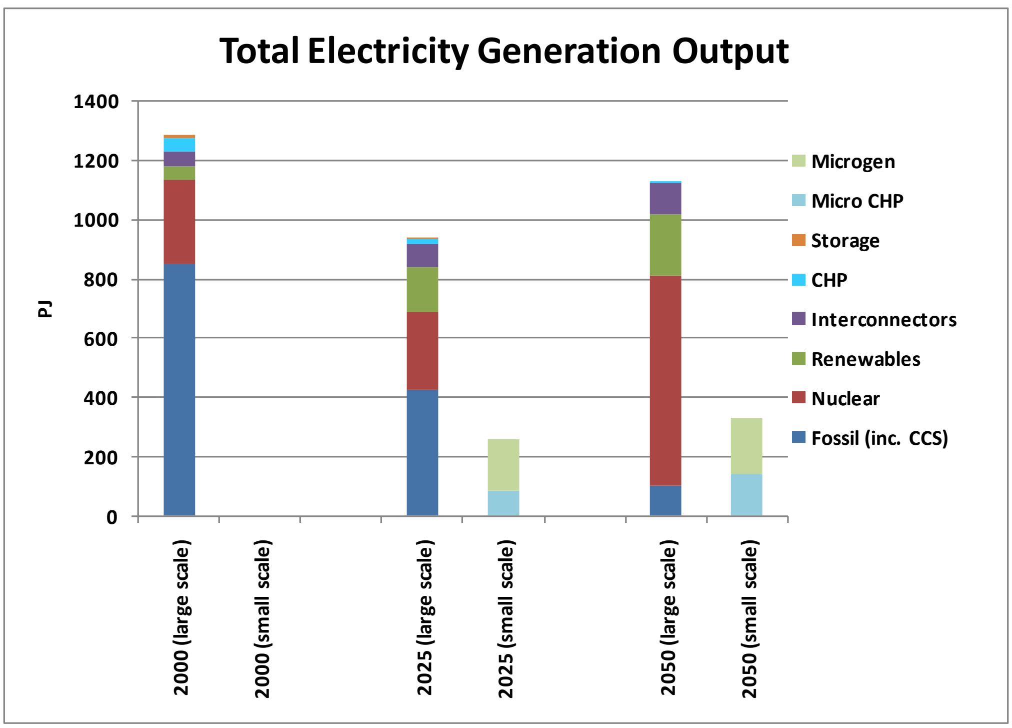


Figure 16: Microgrids – Electricity generation output (in PJ) (distinguishing large scale vs. small scale generation)

Electricity emissions are reduced by 99%, though this does not include emissions associated with small scale CHP plants. Overall this scenario achieves a system wide decarbonisation of 71% compared to 2000.

Key messages:

- ***Demand reductions could provide a means of decarbonisation in a high carbon price world where access to major low carbon sources was constrained, however, this would entail significant behaviour change and arguably loss of welfare.***
- ***The assumptions of the technical viability of integrating high levels of distributed generation need further investigation then detailed in the model runs.***
- ***This run assumes significant technological development in a number of areas, including small scale renewables, dynamic system management, and novel transport technologies.***
- ***When CHP is forced in due to transmission constraints, it does not generate low carbon energy- further investigation of the potential for low carbon fuels for CHP is needed.***
- ***Transport again has a significant impact on electricity demand, and the use of dynamic load management allows more baseload generation.***

A more detailed discussion of these points is contained in Appendix B.

3.4.5 2025 way-markers

The way markers identified for 2025 in this scenario are:

- Measurable and widely accepted global environmental change.
- Stronger international agreements, targets and deployments against climate change agenda.
- Significant decline in primary energy demand and a corresponding decrease in total electricity generation.
- Substantial growth in renewable generation (all scales).
- Consumer activity increasing tangibly (e.g. supplier switching, adoption of microgeneration, self-initiated energy conservation measures, early demand side activity).
- Growing but still relatively small number of consumers (in new build but also in the retrofit housing market) adopting a self sufficiency approach to their energy supplies and early adopting technologies (generation, storage, demand control, communications) to achieve this.
- Electric vehicles become prominent and hydrogen fuel cell vehicles start to enter the market.
- Microgrid technology and concept trials and demonstrations.

- Growth in DG penetration (renewable and CHP) into distribution networks.
- ICT infrastructure deployment to consumer premises for energy management purposes.
- Distribution system operator functions adopted by DNOs to manage complex situations emerging in parts of their networks.

3.5 Multi Purpose Networks

3.5.1 Introduction and summary

In this scenario network companies at all levels respond to emerging policy and market requirements. Transmission system operators (TSOs) still retain the central role in developing and managing networks, but distribution network operators (DNOs) also have a more significant role to play.

The defining feature of this scenario is the pervasive feeling of uncertainty of society towards environmental issues, fossil fuel prices and energy security. 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. The networks are characterised by regional variations in architecture and capability.

Scenario Summary: Multi Purpose Networks

- 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 power 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 where there exists a favourable 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 electricity sector (generation and networks).
- Attempts have been made to develop and exploit many different 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 architectures and management approaches as a result of changing energy policies and network company strategies over time.
- Substantial differences exist in network capabilities with excess capability in some areas and constraints in other areas.
- Electricity networks fulfil a variety of 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.

3.5.2 Context

The international situation will be an underlying cause of Great Britain'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, general agreements with soft targets will be adopted but a coherent EU wide policy will fail to materialise. 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 is acknowledgement that the environment is important and should be protected, however opinions on how this can best be achieved are 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.

In Great Britain, the Government responds in a reactive manner to changing international influences and this will affect the clarity of long term policy. Periods of high fossil fuel prices and concerns over depleting supplies will intermittently push security of supply to the front of the political agenda. Successive administrations will place varying importance on 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 on low carbon electricity generation and energy efficiency. Although these stand alone initiatives and interventions will achieve their specific goals; without a long term strategic approach there will be no revolution in electricity generation and fossil fuel will continue to be a significant primary energy source. These instances of intervention create 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.

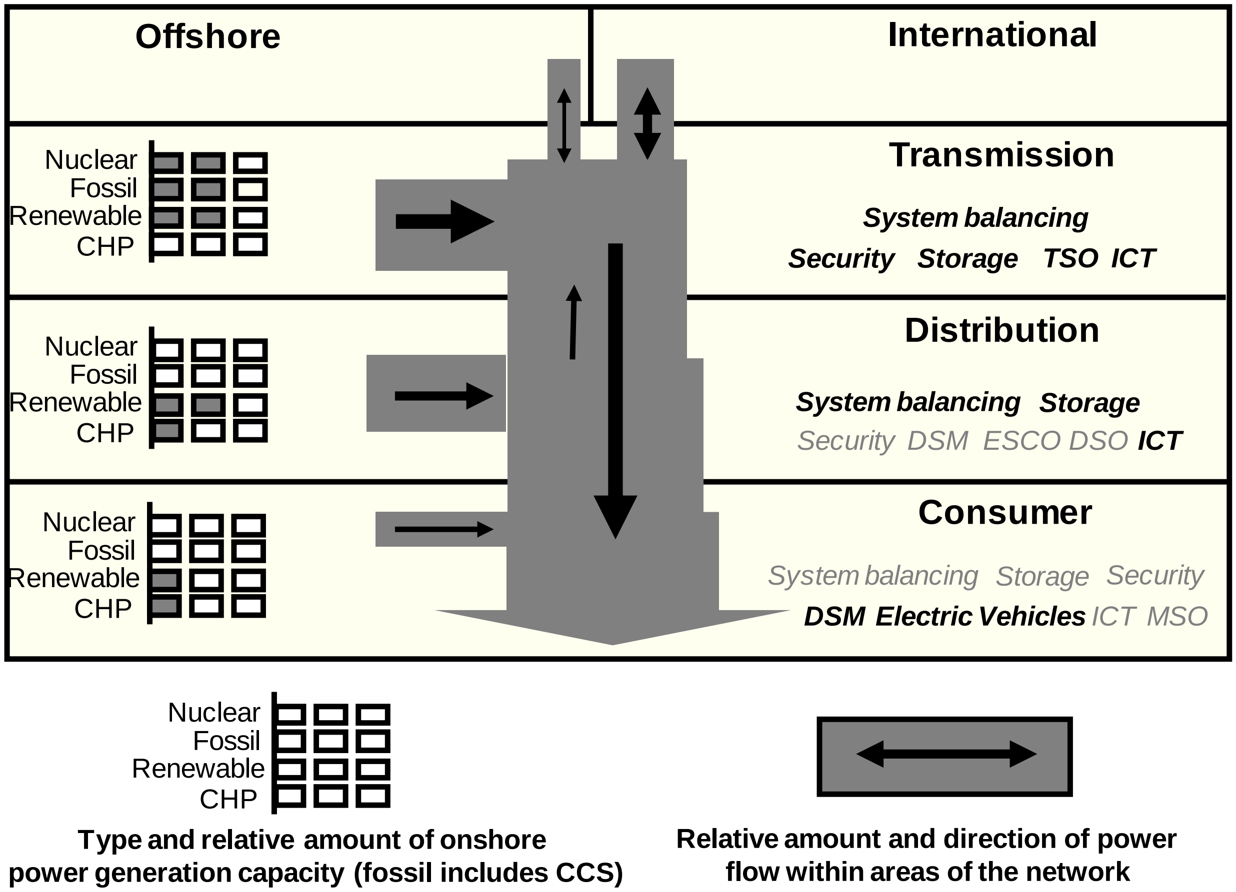


Figure 17: 'Multi-Purpose Networks' scenario schematic illustration.

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. These factors will prevent 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 in place but as a succession of different approaches have limited impact and are subsequently replaced, concern over reaching targets will increase. This results in increasingly serious and ambitious measures as 2050 approaches. These include carbon limits for participants in different sectors with high penalties for breaching limits and even rationing of energy use.

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 as projected returns would be difficult to predict in the uncertain and changeable political environment.

In this scenario, investment is increasingly public sourced as the level of uncertainty discourages private investors. 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 in the absence of a coherent strategy that prioritises specific goals and addresses local concern. 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. These issues will create uncertainty in the private sector that sometimes stifles investment in network infrastructure and new generation plant. Infrastructure development will primarily be in response to the periods of strong government intervention that promote the deployment of specific generation technology and provide reassurance on investment cost recovery. This leads to disjointed infrastructure with various different technologies preferred at different times and regional differences in capability.

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". 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. There will be varied attitudes towards housing and home energy efficiency. New housing will have greatly improved efficiency as once improved standards have been implemented they will stay part of accepted practice. Modifications to older housing will be limited, as a prolonged and effective policy of standards and incentives does not materialise.

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 predominantly remain fossil fuelled although efficiency will be improved and hybrid electric vehicles will slowly penetrate the market providing much improved vehicle emissions levels. 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.

A lack of strong focused driving influences results in little change to social demographic patterns. Population centers are primarily urban and there is little change to employment patterns. 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 variety of policies and approaches towards energy supply will result in extremely varied generation mix. Initial environmental concern and rising fossil fuel prices result in support for nuclear and wind technology. A replacement fleet for the existing nuclear plant is commissioned and current trends in onshore and offshore wind continue. Subsequent periods of revised policy that respond to the economic availability of fossil fuel and reduced environmental concern see large scale renewable development curtailed and periods of new build to maintain levels of coal and gas thermal generation. There will also be periods of considerable incentive support for demand reduction through energy efficiency and microgeneration. A conceivable eventuality is that by 2050 a significant amount of wind farms have been built, a nuclear fleet is available, fossil fuel powered thermal generation plants are also still available and a small but not negligible amount of microgeneration is present. A proportion of this generation would therefore become redundant or suboptimal as the total generation capacity exceeds requirements and the economics of current carbon policy and primary fuel prices dictate the preferred technology.

The location of generating plant will be distributed across 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.

As mentioned above, 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 by public bodies and in new housing developments. Other regional areas may have considerable quantities of renewable DG with the potential to 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. The mix of strategies and technologies in these specific areas will lead to more complex management and trading issues.

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 and 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). 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[10]. 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 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.

3.5.3 Network

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. Network development reacting to events is not viewed wholly negatively since it is

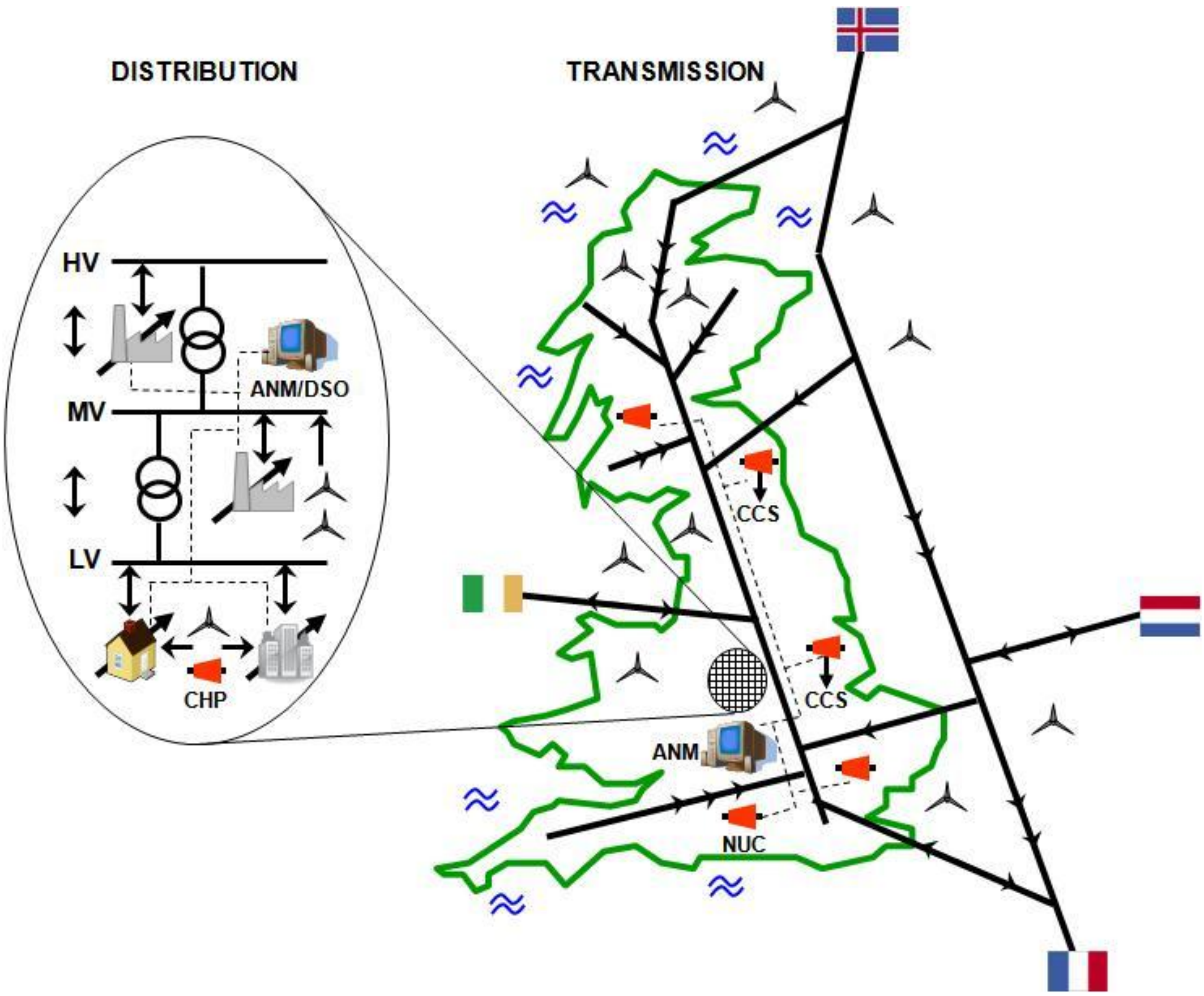
[10] There is good evidence that continued DSM participation requires continued marketing and management by the DSM operator.

believed that network responding to need is an efficient approach leaving less underutilised 'speculative' developments.

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 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 significant numbers of merchant power plants based on these technologies.

Individual customers have also developed on-site micro-generation 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; although there is a good number of electric vehicles in service, the impact on electricity 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.



Electricity network components: **thickness of line** illustrating network capability, and **size and number of arrows** indicating level of network utilisation

Residential, commercial and industrial consumers – with **diagonal arrow** denoting active demand management if present

Renewable electricity generation (including wind, biomass, etc . but excluding marine)

Renewable marine electricity generation (wave, tidal, etc.)

CCS — Thermal generation, sometimes with additional information about **type**, e.g. carbon capture and storage (CCS) or nuclear (NUC) – without a type indicator, this symbol refers to conventional thermal generation

ESCO — System management ,with additional information about **type**, e.g. energy service company (ESCO), distribution system operator (DSO), microgrid system operator (MSO), or active network management (ANM) to represent more real time and active operational management of networks

---- Information and communications technology (ICT) infrastructure for network operational management

Power system transformer between different voltage levels

Power system interconnection with other countries, e.g. France, Ireland, Netherlands, Norway, or Iceland

Figure 18: 'Multi-Purpose Networks' network scenario.

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 electricity 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 and uncertainty regarding cost recovery. 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 widely viewed as 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.

Electricity 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 produces 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.

3.5.4 Modelling results[11]

Headline results:

This run is characterised by high levels of energy demand, and limited efficiency measures. An approach of government drives to meet this high demand through concerted, technology-directed policies is reflected by the 'forcing in' of key technologies at different points in the time period. This leaves the system over-capacity, but with a number of options ready to meet different generation needs. Offshore wind sees limited development however, due to the availability of other options. Growth in electricity demand from the transport sector is again significant, with load management and energy storage again an important function.

	2000		2025		2050	
Total final energy demand (PJ) [1]	**6,188**		**5,939**		**5,785**	
Transport	1,855	30%	1,635	28%	1,538	27%
Residential	1,961	32%	2,054	35%	1,920	33%
Other (Industry, Services & Agriculture)	2,373	38%	2,250	38%	2,327	40%
Total electricity demand (PJ) [2]	**1,176**		**1,343**		**1,662**	
Transport	20	2%	100	7%	343	21%
Residential	403	34%	539	40%	531	32%
Other [3]	754	64%	704	52%	788	47%
Total electricity generation capacity (GW)	**84**		**88**		**114**	
Large scale generation:						
Fossil (inc. CCS)	59	71%	29	33%	49	43%
Nuclear	12	14%	22	24%	18	16%
Renewables	4	5%	27	30%	24	21%
Interconnectors	2	2%	4	5%	11	9%
CHP	4	4%	2	3%	2	2%
Storage	3	3%	1	2%	1	1%
Small scale generation:						
Micro CHP	0	0%	0	0%	0	0%
Microgen	0	0%	3	3%	9	8%
Total electricity generation output (PJ)	**1,288**		**1,488**		**1,860**	
Large scale generation:						
Fossil (inc. CCS)	854	66%	537	36%	913	49%
Nuclear	282	22%	567	38%	482	26%
Renewables	46	4%	254	17%	279	15%
Interconnectors	52	4%	77	5%	103	6%
CHP	45	3%	23	2%	27	1%
Storage	10	1%	6	0%	0	0%
Small scale generation:						
Micro CHP	0	0%	1	0%	0	0%
Microgen	0	0%	24	2%	56	3%
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%		37%		45%	
Electricity sector reduction	0%		72%		79%	

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 8: Multi Purpose Networks – Summary of modelling results

[11] Discussions of modelling results should be compared with the input assumptions as described in section 2.4, and in Appendix B. More detailed discussions of the results are contained in Appendix B. The figures contained in this section have been summarised in this form using the primary model output data contained in Appendix B.

This run shows high levels of primary energy demand and a large electricity system, encouraged both by the lack of elastic demand response within the model, and by the large scale deployment programmes in particular technology areas, represented in the model through 'forcings' of technologies into the mix at different points in the time period.

The deployment of CCS is delayed in this run in response to the forcing in of nuclear which culminates in 2025. However, from this time on the mid-range carbon price stimulates CCS sufficiently, without punishing it excessively for its residual emissions.

Wind capacity remains high in response to a forcing which culminates in 2030. This year sees small scale wind installed at around 40% of its available capacity, a level which it subsequently does not exceed. Large scale onshore wind is operating at full available capacity for most of the period, however there is a comparatively small contribution from offshore wind, which does not exceed 11PJ p.a. at any point. This is due to the fact that given the number of other electricity generation technologies which the model has been forced to build, as well as the declining carbon price towards the end of the period, the model simply has no need for this slightly more expensive wind capacity.

Accelerated technology assumptions for small scale generation technologies also see small scale solar PV making a small contribution towards the end of the period.

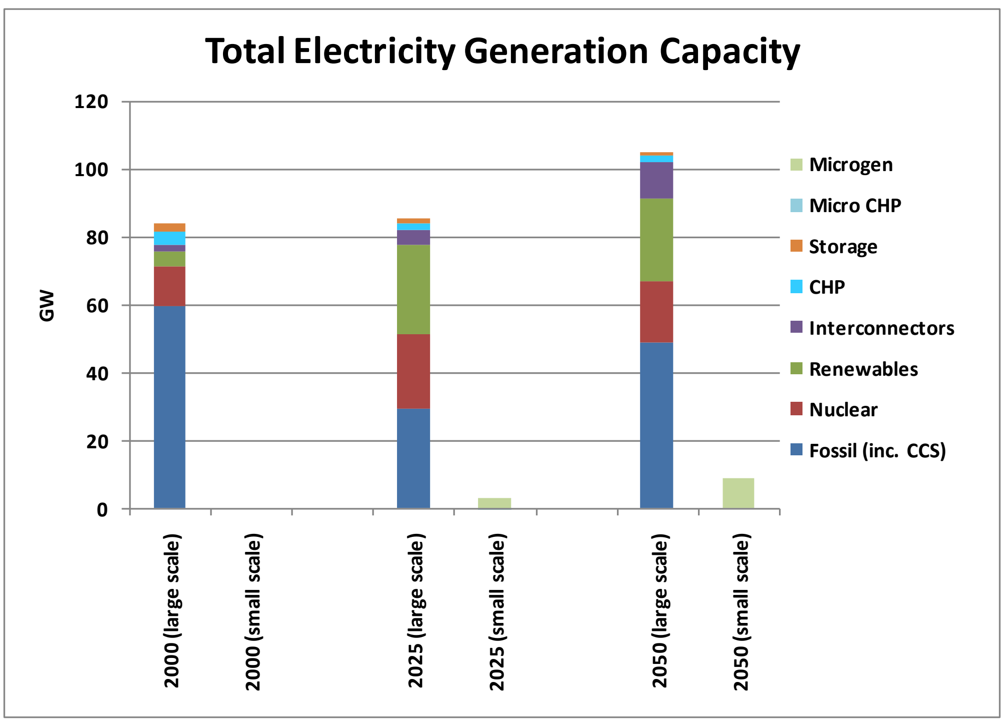


Figure 19: Multi Purpose Networks – Electricity generation capacity (in GW) (distinguishing large scale vs. small scale generation)

This run shows the highest level of electricity storage. This is due to the significant levels of non-flexible plant which the model is being forced to build as part of the assumptions for this run. Storage is used to allow continued operation of non-flexible plant during the night, with the stored electricity released to contribute to day time demands. The major storage technology is plug-in hybrid vehicles. By the end of the period these are mostly provided by LGV fleets.

Transport electricity demand shows a significant growth from 2015 onwards; however the high capacity electricity system has no problems in meeting this demand.

A transition to plug in hybrid cars in the middle of the period is followed by a successive transition to fully electric vehicles, which come to take around two thirds of the market, with conventional petrol and diesels vehicles making up the remainder. Buses are fully electrified, and once again some important interactions with electricity supply-demand management are provided by the plug-in hybrids in the LGV fleet.

The decarbonisation effort in this scenario is again led by the electricity sector, though as in ESCO other sectors are thereby decarbonised through their use of electricity. Electricity emissions however begin to rise again by the end of the period, as the carbon price declines. In 2050, the emissions from the electricity sector are reduced by 79%, contributing to a 45% reduction over the system as a whole.

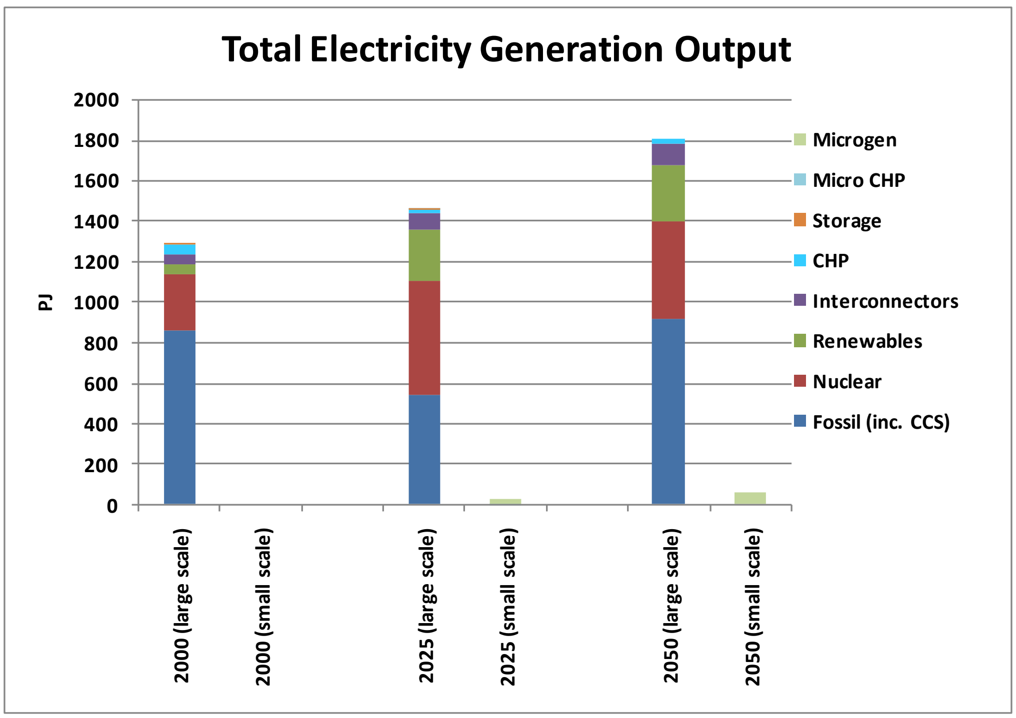


Figure 20: Multi Purpose Networks – Electricity generation output (in PJ) (distinguishing large scale vs. small scale generation)

Key messages:

- ***Government forcing of specific technology types through concerted policy initiative may result in an over capacity system which may not be, strictly speaking the most economically optimal.***

- ***However, this would nonetheless be a flexible system, with capacity to respond in the event of a failure or disruption of a key technology.***
- ***A clear and credible long term signal is vital to encouraging the investment to deliver a genuinely low carbon system.***

A more detailed discussion of these points is contained in Appendix B.

3.5.5 2025 way-markers

The way-markers identified for this scenario are:

- Lack of strong national and international policy lead on environmental matters.
- Lack of coherent focused energy policy for GB including various government and market led approaches to energy infrastructure developments.
- Evidence of several parallel trends in energy infrastructure development (e.g. different scales and technologies of generation incentivised/subsidised, various initiatives aiming towards consumer participation in electricity supplies).
- Consumer attitude towards energy and environmental matters is highly varied across the population and across time – no national consensus on the severity of the problem and subsequently the way to tackle it.
- Varied level of consumer activity in electricity supplies and networks – both across the population and through time as customers move into and out of activity in their electricity supply.
- First evidence of underutilised (stranded) assets as various energy policies deliver results that shift energy flows away from specific parts of the electricity networks.

4 Scenario Comparisons

This section compares the scenarios from a qualitative perspective (based on the context, network and way-markers sections set out in the previous chapter) and from a quantitative perspective (based on the LENS modelling exercise).

4.1 Context, Network & Way-markers

Very different contexts have been set out for the five network scenarios developed in the LENS project. The context for each scenario is based around the themes of the LENS project and these are presented in Table 9.

	Environmental concern	**Consumer participation**	**Institutional governance**
Big Transmission and Distribution scenario context	moderate	passive	market led
Energy Services Companies scenario context	acute	passive	market led
Distribution System Operators scenario context	acute	active	government led
Microgrids scenario context	acute	active	market led
Multi Purpose Networks scenarios context	moderate & acute	passive & active	market & government led

Table 9: Comparison of manifestation of context themes across five network scenarios.

From Table 9 it is clear that there are other combinations of the main themes (e.g. contexts for scenarios based on moderate environmental concern, with active customers). The scenarios chosen represent the best coverage of the 'scenario space' representing diverse future networks without unduly increasing the number of scenarios to the point where they lose their ease of comprehension and utility. Checks were made to ensure that other combinations of the three LENS themes and other themes did not result in very different network scenarios and in this way the project team consolidated their efforts around these five scenarios. Moreover, other themes were considered for the LENS project (e.g. a technologically based theme).

However, the three themes were selected, the possible value the themes could take and then specific combinations of themes were used to produce the background context for the scenarios after careful consideration of the diversity of the scenarios these five could give and by discounting other approaches that would not yield as interesting, diverse, plausible and challenging scenarios. The networks scenarios based on these combinations of contextual themes cover a wide range of different political approaches to delivering objectives from the electricity networks, different levels of consumer participation and different attitudes and behaviours relating to the environment.

The network scenarios are seen to be diverse in the developmental and operational issues that they present for future GB electricity networks. For the purposes of comparison the geographical pictograms are set side by side for both transmission and distribution so that similarities and differences in the scenarios can be observed and discussed.

The geographical pictograms for the transmission systems described in the five network scenarios are presented in Table 10.

The main features evident from a comparative analysis of the five scenarios are:

- Network capacity/capability required – This is mainly a function of demand (peak, energy and time profile), generation (peak, energy and time profile) and level security required. The 'Big T&D' scenario envisages a major development of the transmission network capacity while at the other end of the spectrum, the 'Microgrids' scenario outlines a situation where there is little or even no need for further transmission capacity. Clearly even if there is no further requirement for expanded transmission capacity there is still the need to renew time or condition expired assets and to maintain them through their life
- Utilisation of the network capacity (in terms of both average energy flow and the direction of flow which has a major bearing on planning and operational issues in transmission systems) – The scenarios where there is much more consumer participation and also electricity production in distribution systems lead to lower levels of utilisation in the transmission system. Peak flows might be of a similar magnitude to other scenarios but over the course of an average year it would be expected that the average power flows would be less in these scenarios.
- Geographical range of the transmission network onshore, offshore and through further interconnectors to neighbouring countries – The illustrations show the extent of plausible offshore and interconnector development activity and there is a broad range from the high end 'Big T&D' scenario to the low end of the spectrum with the 'Microgrids' scenario.
- Generation type, location and scale – This is different across the scenarios and, while in most cases it is envisaged that a mix will prevail, the balance of generation is substantially different. The main differences are the amount of offshore generation, the level of generation embedded in the distribution systems and the balance between intermittent renewables and dispatchable thermal generation.

- Operational management approaches adopted – The transmission operator takes on the major responsibility for system operation in the 'Big T&D' and 'Multi Purpose Networks' scenarios but with this role shared with other entities in the 'ESCOs', 'DSOs' and 'Microgrids' scenarios.

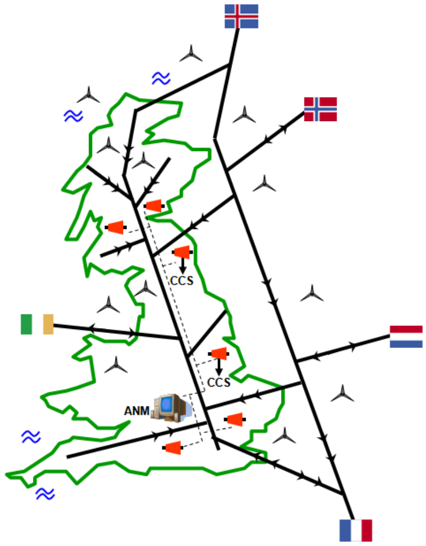
The key elements in the distribution system aspects of the scenarios are:

- Level of consumer activity in generation, demand response/conservation, electric vehicles and even energy storage - Several scenarios indicate such levels of activity in distribution networks (to varying degrees across the scenarios) as a plausible future and there are clearly major implications of this for the development, operation and regulation of distribution networks.
- New players in distribution networks appear in some scenarios (ESCOs, microgrid system operators, active consumers) and these all have the potential to change the market dynamics in distribution with consequences in the areas of network capacity requirement, level of utilisation, standard of security and quality of supply, and commercial arrangements.
- More dynamic and even bi-directional power flows as a result of new activities in distribution networks (as noted in the first bullet above) are envisaged in all the scenarios other than 'Big T&D'.

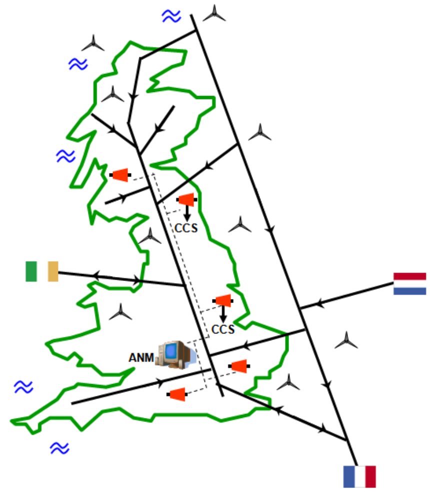
The schematic illustrations for each scenario are presented side by side for the purposes of comparison in Table 12.

The most obvious aspect of the schematic illustrations is the very different magnitudes of feed in to the GB power system at the transmission, distribution and consumer levels. The notes on high level features of each network scenario (to the right of each diagram) show that network and energy management arrangements emerge when these feed ins are a major feature of the scenario. For example, in the 'DSOs' scenario there is system balancing in the distribution network and active monitoring and management through ICT infrastructure in the distribution network and into customer premises for the purposes of managing the active components (demand response, generation, electric vehicles, etc.)

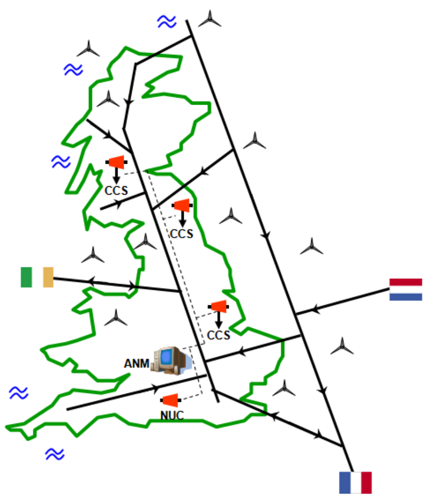
A comparative assessment of the 2025 way-markers for the five scenarios is illustrated in Table 13.



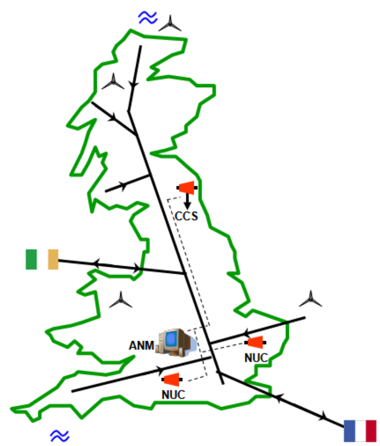
Big Transmission and Distribution



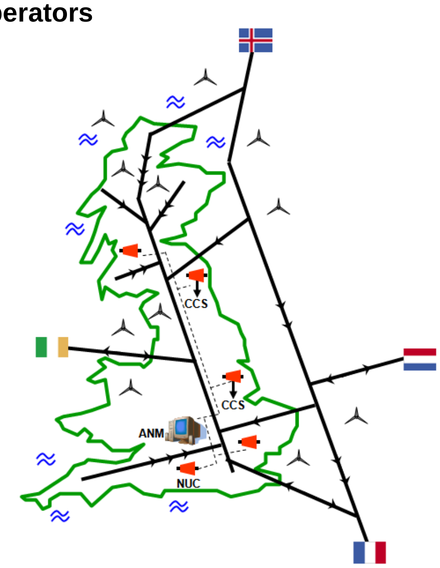
Energy Services Companies



Distribution System Operators



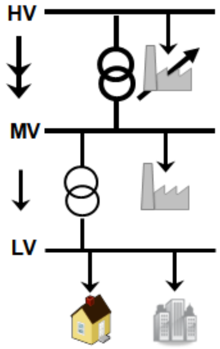
Microgrids



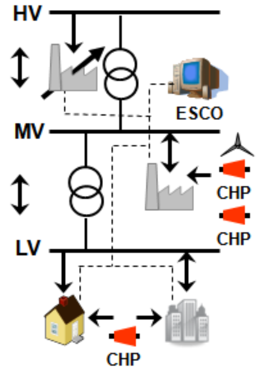
Multi Purpose Networks

Table 10: Comparison of geographical pictograms for the transmission system.

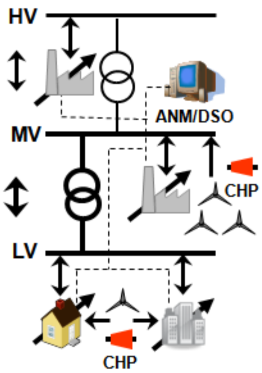
The geographical pictograms for the distribution systems described in the five network scenarios are presented in Table 11.



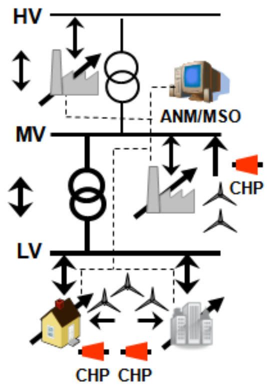
Big Transmission and Distribution



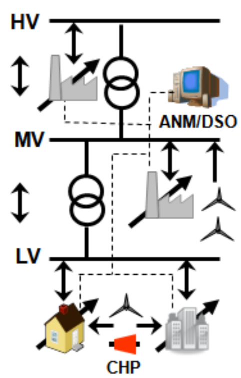
Energy Services Companies



Distribution System Operators

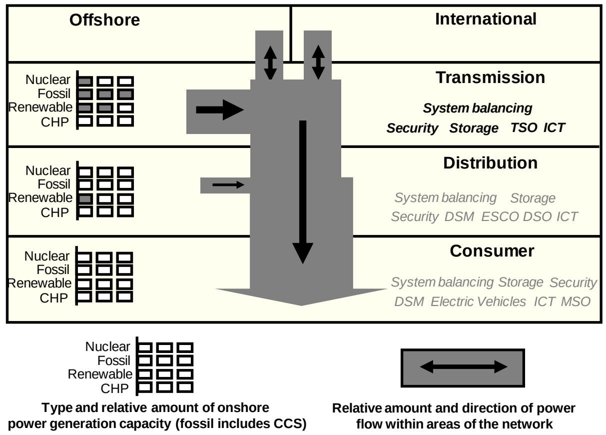


Microgrids

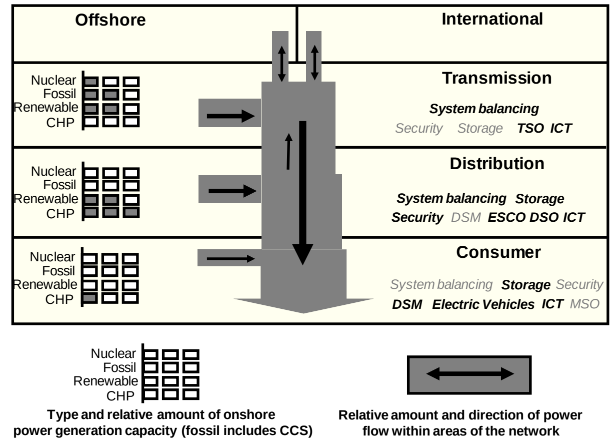


Multi Purpose Networks

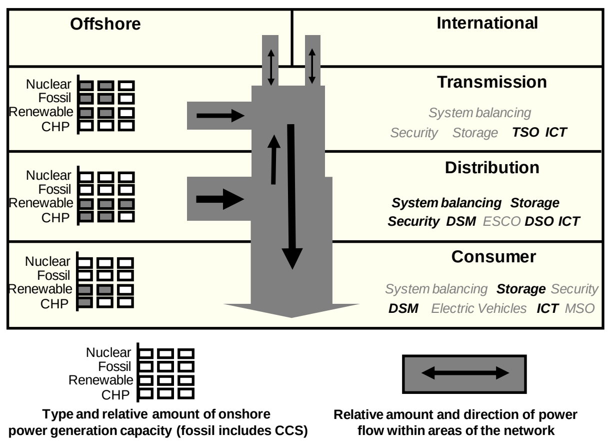
Table 11: Comparison of geographical pictograms for the distribution system.



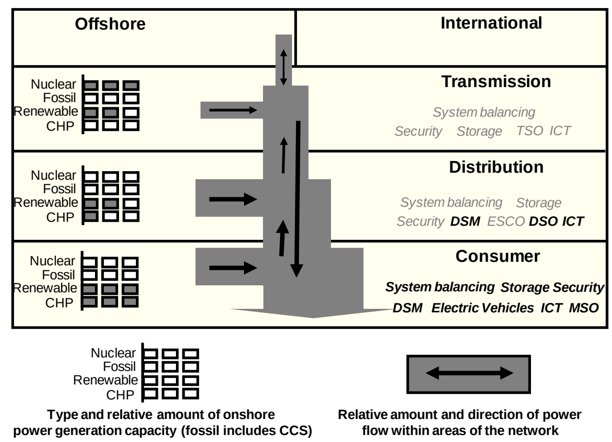
Big Transmission and Distribution



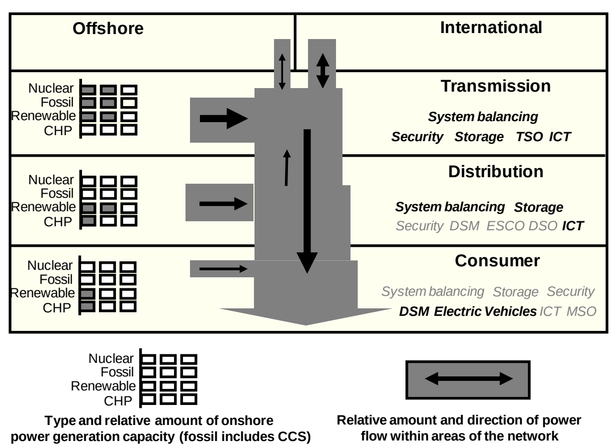
Energy Services Companies



Distribution System Operators



Microgrids



Multi Purpose Networks

Table 12: Comparison of schematic illustrations for the five network scenarios.

The comparison of 2025 way-markers across the scenarios illustrates a good level of diversity in trends that might be expected to emerge by the year 2025. The common way-markers across the scenarios are those which seem to have a greater likelihood of occurrence as they would indicate a marker on the pathway towards several scenarios (e.g. strong renewable electricity production by 2025 is on the pathway towards four of the scenarios. While this is a useful outcome, it does not help the user of the scenarios to identify which of the scenarios is emerging at 2025. To identify more clearly which of the 2050 scenarios may be emerging at 2025 the unique way-markers must be identified such as the development of DNO focused DSM in the 'DSOs' scenario or the strong EU interconnector activity in the 'Big T&D' scenario.

2025 Way-marker	Scenario				
	Big Transmission & Distribution	Energy Services Companies	Distribution System Operators	Microgrids	Multi Purpose Networks[12]
Strong growth in large scale renewable electricity generation	*	*	*	*	
Continued demand growth	*				
Growth in demand management in customer/supplier relationship		*		*	
Growth in demand management linked to DNOs			*		
Growth in distribution connected generation		*	*	*	
Growth in micro-generation			*	*	
Attitude to environment	moderate	strong	strong	strong	mixed
Strong EU interconnector activity	*				
Strong parallel developments in networks					*
Strong regional variations in network developments					*
Energy services market growth		*	*		
Power networks communications and control infrastructure development		*	*	*	
Transmission system utilisation flattening or reducing		*	*	*	
More sophisticated DNO operational approaches for active networks		*	*	*	

Table 13: Comparison of key 2025 way-markers across scenarios.

[12] The Multi Purpose Networks scenario does not yield to this analysis as effectively as the other scenarios. There is an case for reflecting the 2025 way-markers as potentially encompassing all the possibilities in the table to reflect the 'mixed' nature of this scenario. However, it has been decided to characterise the scenario in terms of a smaller number of way-markers unique to this scenario.

4.2 *Modelling Results*

The LENS scenarios are complex and multi-faceted storylines, and thus have driven model runs which are affected by numerous simultaneously varying drivers. This can make analysis complex, as it may not always immediately be clear which input change is having the greatest effect on the results. However, such issues can become clearer when results are compared across all runs. This brief section therefore aims to bring together the key insights that are raised from a consideration of the LENS model runs as a whole set.

	2000	2050				
		Big T&D	ESCO	DSO	MG	MN
Total final energy demand (PJ) [1]	**6,189**	**6,468**	**5,807**	**4,910**	**4,558**	**5,785**
Transport	1,855	2,142	1,542	1,292	1,255	1,538
Residential	1,961	1,920	1,921	1,625	1,431	1,920
Other (Industry, Services & Agriculture)	2,374	2,407	2,345	1,993	1,872	2,327
Total electricity demand (PJ) [2]	**1,176**	**1,522**	**1,623**	**1,243**	**1,044**	**1,662**
Transport	20	85	330	126	263	343
Residential	403	587	473	378	195	531
Other [3]	754	851	819	739	585	788
Total electricity generation capacity (GW)	**84**	**102**	**121**	**105**	**113**	**114**
Large scale generation:						
Fossil (inc. CCS)	59	68	55	27	9	49
Nuclear	12	0	13	19	27	18
Renewables	4	20	24	22	16	24
Interconnectors	2	11	10	10	12	11
CHP	4	2	1	0	0	2
Storage	3	1	1	1	1	1
Sub-total	**84**	**102**	**104**	**81**	**66**	**105**
Small scale generation:						
Micro CHP	0	0	0	0	24	0
Microgen	0	0	17	24	23	9
Sub-total	**0**	**0**	**17**	**24**	**48**	**9**
Total electricity generation output (PJ)	**1,288**	**1,652**	**1,874**	**1,501**	**1,462**	**1,860**
Large scale generation:						
Fossil (inc. CCS)	854	1,173	1,016	457	100	913
Nuclear	282	0	334	502	713	482
Renewables	46	271	300	279	209	279
Interconnectors	52	182	103	103	103	103
CHP	45	27	8	7	7	27
Storage	10	0	0	0	0	0
Sub-total	**1,288**	**1,652**	**1,761**	**1,348**	**1,131**	**1,804**
Small scale generation:						
Micro CHP	0	0	0	0	142	0
Microgen	0	0	113	153	189	56
Sub-total	**0**	**0**	**113**	**153**	**331**	**56**
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%	30%	47%	61%	71%	45%
Electricity sector reduction	0%	67%	88%	95%	99%	79%

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 14 – Comparison across scenarios of modelling results for 2050 (vs. 2000)

Nuclear, CCS, Wind: There is very close competition between these major low carbon technology groups, however as the model cost-optimises, it tends to pick the single least cost option rather than a portfolio, until it is forced to do so by other constraints (such as resource availability, or increasing construction or operational costs).

It is important to bear in mind, particularly when looking at a single model run which is dominated by one of these technologies, that fairly small variations in the cost assumptions applied to each one, which remained within the plausible bounds of error in each case, could produce different 'winners', and remain within the bounds of possibility. Nonetheless, when comparing all five LENS runs for which the same input assumptions for these technologies are used, different balances between these technologies emerge, which are driven by other changes in the model.

In the LENS runs, coal with CCS tends to be the first large scale low carbon technology to be deployed in response to a growing carbon price, and does particularly well at medium range carbon prices. However, the higher the carbon price, the better the prospects for nuclear, to which coal CCS begins to lose out. This is due to the residual emissions from CCS which are increasingly costly at higher carbon prices. Coal CCS is preferred to gas CCS as it is a more cost effective option at the relatively high resource prices assumed in these runs. Since a greater proportion of gas turbines' overall cost is fuel cost, these technologies are more sensitive to higher fuel prices.

With each of these key technologies it is also important to stress that the model assumes that they are commercially proven and ready to deploy (though CCS is only available to be selected by the model from 2025). Therefore, such results effectively assume that steps are taken in the meantime to develop them where necessary, and that significant technological obstacles are avoided or overcome.

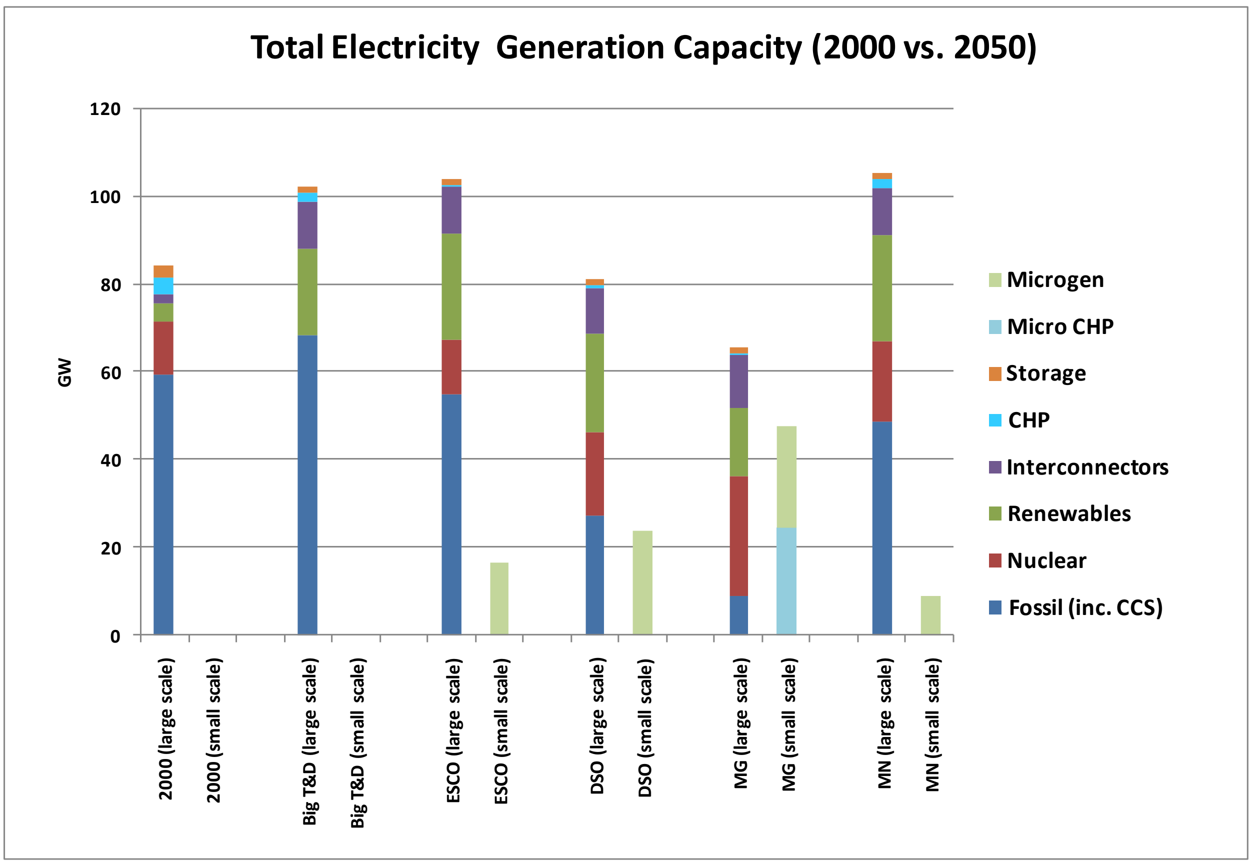


Figure 21 – Comparison across scenarios of electricity generation capacity in 2050 (vs. 2000) (distinguishing large scale vs. small scale generation)

Natural Gas: Despite not featuring strongly as a large scale electricity generation technology, natural gas is persistent in all runs feeding into residential, service and industrial heat demand. In runs with transmission constraints, it is used for small scale CHP. In the initial runs its use in the residential and service sectors is unconstrained by the carbon price which does not extend to these sectors. In DSO and MG a high carbon price does extend to these sectors; however its use cannot be phased out of the residential sector, despite the incentive from the high carbon price to do so, because the access to transmission electricity, the main alternative low carbon energy vector, is restricted.

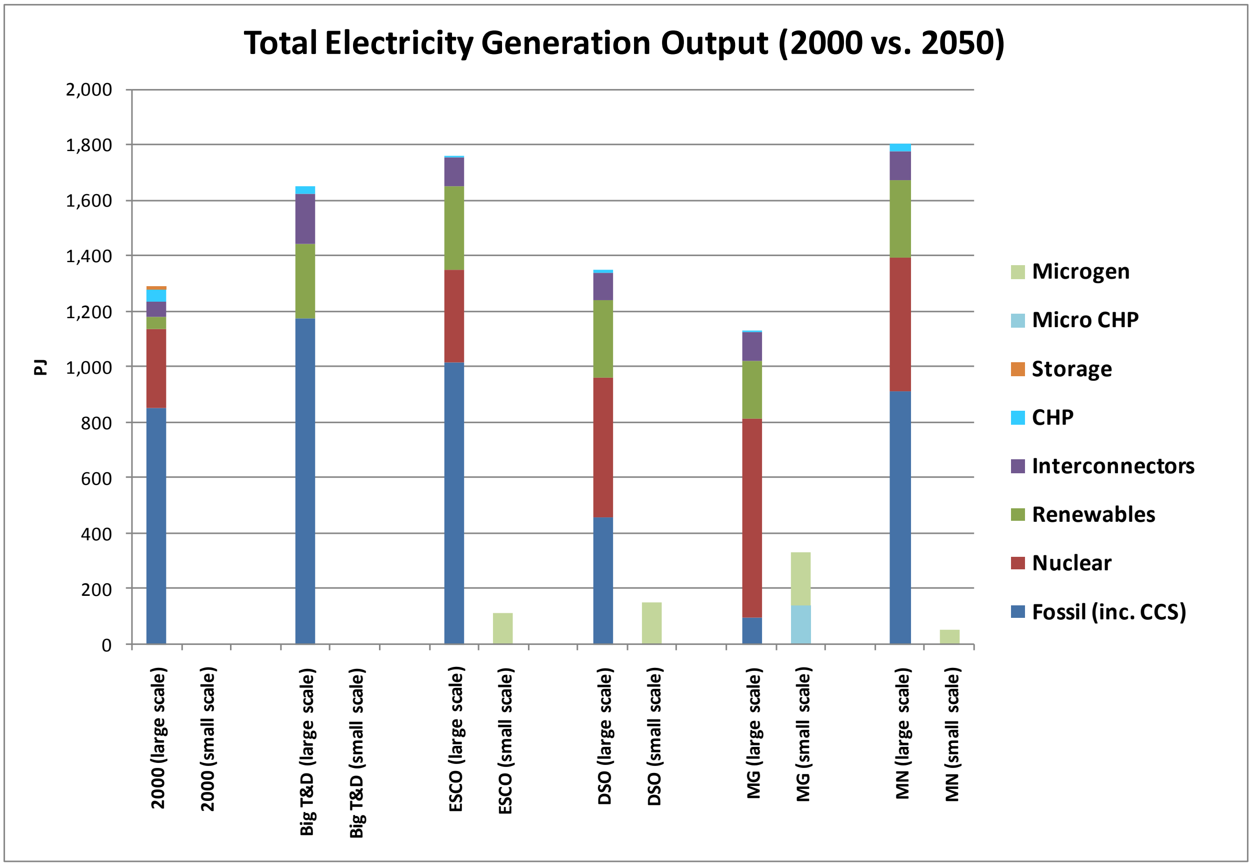


Figure 22 - Comparison across scenarios of electricity generation output in 2050 (vs. 2000) (distinguishing large scale vs. small scale generation)

Biomass and CHP: CHP is not favoured in general by the model. At low carbon prices the model tends to rely on the existing infrastructure of gas and electricity to provide heat and power separately. At high carbon prices CHP's emissions mean that it is not a sufficiently low carbon option to be selected. Thus, in the context of MARKAL's perfect foresight- meaning that it knows what the carbon price will be for the whole period- CHP seems to suffer for having only an intermediate carbon saving potential. However, when access to transmission electricity is severely constrained in Microgrids, in combination with a high carbon price, it does use CHP with natural gas. However, this results in residential emissions for this scenario cannot be reduced below those in DSO, despite the higher carbon price in Microgrids- the model cannot make CHP a low carbon option, hence its general resistance to deploying it.

An obvious response to this would be to ask why the model does not source a low carbon alternative to natural gas for CHP and heat production, in the form of bioenergy resources. This is because the bioenergy resource is prioritised elsewhere. Landfill and other waste biogas is used for electricity generation, and other biomass resources are converted through Fischer Tropsch processes into biodiesel, which is extensively used by heavy goods vehicles (HGVs) at high carbon prices. It is also worth noting that in the current model access to sources of imported biomass is very limited given the current uncertainty as to the levels of availability of such sources due to sustainability and land use concerns. Further investigation is needed into what would be a feasible low carbon fuel for CHP, bearing in mind potential limitations of bioenergy resources, sustainability implications of importing and transporting to point of use, and competition with other end uses..

Demand reductions: The model finds it difficult to meet demands when the carbon price is high and access to transmission is limited, and resorts to major demand reductions. The implications of such demand reductions for the wider economy are interesting to interrogate. Most neo-classical economic analyses would in general expect energy service demands to follow an upward trend in a healthy economy, although with saturation effects meaning that some energy service demands could 'level off'. The occurrence of significant demand reductions, over and above those delivered by efficiency improvements, arguably throws up the challenge that the MG and DSO runs represent futures which forego some beneficial economic growth. However, this is really only the first step into what could be a much wider debate about the real relationship of energy consumption to economic growth, as well as about whether the conventional understanding of economic growth itself can be challenged by broader conceptions of national welfare.

Distributed generation: The model does not in general favour large amounts of distributed generation; nonetheless under positive cost and performance assumptions these technologies played a significant role even in a scenario where transmission was not constrained (ESCO scenario). These positive assumptions imply significant breakthroughs for these technologies. To justify these assumptions there would be an important role for an intermediary organisation such as an ESCO to bring down costs through economies of scale, remove perceived barriers and risks to consumers, and to regulate the effect of numerous variable electricity sources putting power onto the distribution network. It is also evident that the development of legislation such as the Code for Sustainable Homes would have a key impact on the viability of this resource, as installations in new build are likely to be more cost effective than retrofits. In runs where transmission networks were constrained, the contribution of distributed generation became increasingly important.

The role of electricity in decarbonisation: The runs confirm that the electricity sector is likely to have a crucial role in the decarbonisation of the UK energy system. At relatively low carbon prices decarbonisation in the electricity sector is able to contribute to sizeable system wide carbon reductions. As carbon prices rise and extend to other sectors, the importance of the electricity sector increases as the principal carrier of low carbon energy for sectors which are switching to electrified low carbon options.

Electricity system size: Big T&D has the smallest electricity generation system of all runs in terms of installed capacity. This can be explained in two ways. As renewables have a much lower availability factor than thermal plant, and the capacities given are rated capacity, a renewables heavy generation mix will have a greater capacity for a given level of final electricity demand. However, it is also related to the fact that in scenarios with higher carbon prices the electricity sector is being required to 'work harder' to produce low carbon energy for other sectors which are now penalised for direct use of fossil fuels.

Wider system interactions: The major system interaction is with the transport sector. This sector is currently a major source of emissions, but among the hardest to decarbonise. Decarbonisation could take place through the use of biofuels, electric vehicles, or hydrogen. The wide use of electric vehicles would clearly have major impacts on the electricity generation mix, but it is also possible that large amounts of electricity would be involved in the production of hydrogen, particularly if carbon mitigation policies were applied strictly to the transport sector. Indeed, with optimistic assumptions for small scale electrolysis, the model would have chosen to produce all hydrogen from electrolysis in the DSO and MG scenarios, had it not been constrained. The effect of such a technology breakthrough could be huge for the electricity sector, the model indicating in sensitivity analysis that it could be required to increase its output by one third. Even apart from this particular sensitivity analysis, the effect of increased electricity demand as a result of technology change in transport has been dramatic in the model runs, leading in DSO and MG to huge increases in nuclear power - this is because at the kind of carbon prices which are stimulating transport decarbonisation, it is also the case that nuclear is a more cost effective option than CCS which is penalised for its residual emissions.

Demand Reductions: In the two runs with the elastic demand function enabled, a comparable trend of demand reductions occurs in the middle of the period as carbon prices rise - demand reductions offering a comparatively cost effective way of avoiding the growing penalty of the carbon price. It is worth reflecting on what would be implied by such demand reductions: reduced use of transport, meaning fewer journeys, particularly by car and domestic flights; reduced service and residential electricity demands, which could mean restrictions on energy guzzling appliances; and reduced output of agriculture and industry, which could be interpreted as meaning lower economic growth in the economy as a whole. As described by the narratives of these two scenarios, such demand reductions imply societies in which there is a strong consensus for all actors to accept the reduced use of energy which would be stimulated by a high carbon price and, arguably perhaps, some loss of the benefits of the services which would have been associated with these. In the scenario narratives, this acceptance is driven by a deep rooted and pervasive environmental concern - it hardly needs to be stated that this would imply some quite significant social changes.

Do these runs imply that major demand reductions are the only means of achieving deep carbon emissions reductions? No - however, they do suggest that if high carbon prices could be created by policy means, at a time when low carbon technological alternatives were not sufficiently well developed in terms of cost and performance, then an economically rational response could be to reduce energy service demand and forgo the consumption associated with that. This is precisely the effect that can be observed in the middle periods of the DSO and MG runs. However, as low carbon technologies do become more available, and as their costs start to come down, a rising carbon price need not be associated with energy service demand reductions. In the MG and DSO runs, the accelerated technology development which begins to pay dividends in the later years, means that despite the mid period slump in energy service demands, the last 10-15 years sees *rising* demands in key energy services such as transport and residential electricity.

The assumptions which make these technologies available at reduced costs in later years imply a solid R&D programme in the UK, as well as international consensus on technology development. The runs emphasise that if it was considered desirable to avoid major demand reductions at the same time as achieving considerable emissions reductions, then ensuring that the necessary investment is flowing into various low carbon technology options (not only in the power sector), and at as early a stage as possible, would be crucial.

	2000	2025				
		Big T&D	ESCO	DSO	MG	MN
Total final energy demand (PJ) [1]	**6,189**	**6,287**	**5,961**	**5,775**	**5,641**	**5,939**
Transport	1,855	1,911	1,635	1,853	1,842	1,635
Residential	1,961	2,057	2,054	1,807	1,780	2,054
Other (Industry, Services & Agriculture)	2,374	2,319	2,272	2,115	2,020	2,250
Total electricity demand (PJ) [2]	**1,176**	**1,335**	**1,399**	**1,102**	**864**	**1,343**
Transport	20	33	100	33	33	100
Residential	403	563	563	418	271	539
Other [3]	754	740	736	652	560	704
Total electricity generation capacity (GW)	**84**	**87**	**88**	**83**	**83**	**88**
Large scale generation:						
Fossil (inc. CCS)	59	44	40	24	25	29
Nuclear	12	3	15	19	10	22
Renewables	4	31	25	21	11	27
Interconnectors	2	5	4	4	4	4
CHP	4	3	3	2	2	2
Storage	3	1	1	1	1	1
Sub-total	**84**	**87**	**88**	**71**	**53**	**85**
Small scale generation:						
Micro CHP	0	0	0	0	8	0
Microgen	0	0	0	12	22	3
Sub-total	**0**	**0**	**0**	**12**	**30**	**3**
Total electricity generation output (PJ)	**1,288**	**1,456**	**1,526**	**1,287**	**1,203**	**1,488**
Large scale generation:						
Fossil (inc. CCS)	854	953	759	417	423	537
Nuclear	282	85	397	488	267	567
Renewables	46	245	256	191	151	254
Interconnectors	52	137	77	77	77	77
CHP	45	31	31	24	19	23
Storage	10	6	6	6	6	6
Sub-total	**1,288**	**1,456**	**1,525**	**1,202**	**943**	**1,464**
Small scale generation:						
Micro CHP	0	1	1	1	83	1
Microgen	0	0	0	85	177	24
Sub-total	**0**	**1**	**1**	**85**	**260**	**24**
CO_2 reductions from 2000 (Mt)						
Energy system reduction	0%	14%	34%	37%	36%	37%
Electricity sector reduction	0%	16%	60%	74%	74%	72%

[1] 1 PJ = 0.278 TWh
[2] Sectoral electricity demand figures do not include that proportion of electricity demand that is met by small scale electricity generation.
[3] Industry, Services, Agriculture, Hydrogen and Upstreams

Table 15 – Comparison across scenarios of modelling results for 2025 (vs. 2000)

5 Scenario Implications

This section sets out views on the implications of the scenarios presented in the previous section, from the perspective of the LENS academic team. It forms the academic team's contribution to the work on implications of scenarios being undertaken by Ofgem.

Implications are first presented for each scenario in turn. This discussion is followed by the academic team's views on cross-scenario implications.

5.1 Scenario-Specific Implications

Users of the scenarios will be able to establish their implications against their interests and responsibilities and this is one of the primary purposes of the scenarios. This section provides a high level view of some of the more obvious implications of the scenarios, for each scenario in turn.

5.1.1 Big Transmission & Distribution

- This scenario paints a picture of expanded electricity networks (transmission and distribution). Given the current situation of tight planning controls and investment appraisal/approval for natural monopoly network businesses then there are clear implications of this scenario in terms of planning, consenting, funding, pricing and implementing the larger networks described.
- The scenario describes the need to develop network capability not just in the form of adding more circuits with larger capacity. It is envisaged that new technologies would be deployed to achieve the increase in network capability required. The framework for investing in these new assets including the right balance of risks and rewards for adopting new approaches would require to be considered.
- The scenario sets out greater scope for interconnection of the GB system networks to mainland European power systems. This raises issues of ownership and operation of the new interconnections (bearing in mind that there are precedents) and also the greater level of inter-dependence on European power system operators and the energy and ancillary service markets in those countries. This is relatively uncharted water for GB given the limited interconnection of the physical system and markets at present.
- The scenario paints a bleak outlook for consumer participation in electricity supplies and networks so the viability of achieving any environmental targets within the electricity sector through consumer participation is questionable. The desirability of managing an electricity network based on passive consumers given potential environmental, energy security and economic concerns does not seem logical.
- The model runs indicates an important role for CCS- this will be dependent on

efforts to develop and commercialise this technology over the next few years

5.1.2 Energy Service Companies

- The Energy Service Company (ESCO) business model may require a degree of integration of energy supply and network operation functions to achieve the economic efficiency promised by this scenario. Regulatory and commercial arrangements to facilitate an ESCO-centred industry model will be very challenging given the desire to maintain, if not enhance, competition, transparency, fairness and efficiency in energy supplies.
- Given that the supply of heat becomes a service in the ESCO scenario then the technical, commercial and regulatory arrangements for local heat networks is an issue that would need to be considered. While much of the heat supply might be on commercial or industrial campuses or in new build residential areas there will be a degree of retrofitting heat networks to a proportion of the populace. The ownership, operation, competition, and regulation of such heat supply infrastructure to ensure fairness, efficiency and customer choice are important.
- With ESCO organisations interfacing with consumers regarding their energy supplies, the knock on effect of these arrangements on the electricity network could be significant with implications for system peak demands, volume energy flow and profiles of net demand at various levels within electricity networks being altered. The system management arrangements and the interfaces between ESCOs, DNOs and TSOs will be critical and new codes for planning and operating networks as well as for market operation would likely be required.
- ESCOs would likely handle large volumes of customer data regarding energy consumption (electricity, gas fuels, heat) as well as any production through microgeneration facilities on site. The metering, billing and settlement arrangements for customer accounts would be an important issue, as would the use of the data within the ESCO and externally by other parties (e.g. the network operator) for reasons of system operations or planning.
- The model found that removing 'barriers to uptake' on novel technologies such as electric vehicles and microgeneration stimulated uptake without major cost reduction assumptions. This emphasises a potential gain to be had of using new regulatory arrangements, possibly through ESCOs, to overcome social and behavioural barriers which are preventing uptake of cost effective measures and technologies
- The model questions the feasibility of supplying heat from CHPs as a long term low carbon option. The new infrastructure required is a key constraint. The model identifies that natural gas fuelled CHP may offer medium term decarbonisation, but in the context of longer term more extensive decarbonisation, it prefers meeting heat demands with low carbon electricity. The model did not prioritise low carbon bioenergy resources for CHP, raising an important question as to the most effective use of limited sustainable bioenergy resources.

5.1.3 Distribution System Operators

- With the DSO taking a greater responsibility for system operations (generation management, security, etc.) then the relationships between DSO and TSO would become more inter-dependent and complex. This would require the development of new operating and planning codes, processes and supporting tools in each of these organisations.
- Distribution network companies will manage a far more complex situation with many more generation sources and active consumers embedded within distribution networks. The capabilities, resources, knowledge and skills for this substantially different task are a key issue for consideration. At a time when the skills 'crunch' is already a serious issue, the need for greater numbers of highly skilled people in distribution companies is potentially problematic unless other means of managing the situation (e.g. deployment of enhanced technology) are utilised.
- The DSO effectively becomes a market player in this scenario by taking on management of demand and generation resources and perhaps utilising energy storage to achieve system management goals. The regulatory changes and operating codes required for this eventuality are an issue for consideration.
- The management of much more complex and active distribution networks probably implies the greater use of advanced information and communications technology (ICT). The investment in and delivery of such advanced ICT systems is far from trivial with security, privacy and appropriate use of the information all key issues to be resolved.
- The model identifies that developments in a range of energy related sectors could have major impacts on the electricity networks. The development of hydrogen technologies in this run exerts a large increase in demand for electricity, as well as natural gas, for the production of hydrogen.
- The model also shows that load spreading technologies, such as plug in hybrids, but also potentially hydrogen production at times of low electricity demand, could be crucial in managing a low carbon electricity portfolio with less dispatchable plant.

5.1.4 Microgrids

- Microgrids is perhaps the most technically challenging scenario with a very large emphasis on the deployment of advanced technologies close to or on customer premises. The technical viability of this model extended to significant proportions of the populace and business/public sectors is crucial given the relatively few working demonstrations at present (e.g. power parks, rural/island communities).
- As well as technical challenges, this scenario also raises many commercial and regulatory challenges from a much more highly decentralised energy infrastructure in terms of network ownership, network operation, competition and security of supplies. The whole model of energy supplies from decentralised sources as a mainstream option rather than a market niche (as at present) has many serious and fundamental questions although none of this diminishes its plausibility.

- One serious issue with the microgrid scenario is the transportation of fuel sources of all kinds to the local level. Clearly gas and electricity are the mainstream option at present but changes to this model (i.e. greater volumes of gas fuels for micro-CHP or transportation of solid, liquid or gaseous biofuels) have major infrastructure ramifications. The investment required for such changes and the commercial and regulatory issues it raises are substantial.
- The commercial and technical arrangements between microgrid system operators (MSOs) and DSOs/TSOs for network services are a key issue in terms of stable and secure operation of many microgrids embedded within the regional and national network infrastructure. Services such as provision of backup reserves, balancing and more technical network services such as voltage control would create essential interfaces between MSOs, DSOs and TSOs.
- Who would come forward as MSOs is another issue given that distribution network companies (public or private/independent) would be in a good position to establish and operate microgrids. Whether this arrangement is satisfactory from a competition and business separation standpoint is of material importance.
- The model finds it extremely challenging to meet energy service demands with a diminished availability of transmission access, and resorts to significant demand reduction. With the potential availability of renewable resources being stranded, this raises the question of whether the avoidance of significant investment in transmission capacity is desirable for low carbon futures, whatever the success of smaller scale options.

5.1.5 Multi Purpose Networks

- Given the multi-faceted nature of the electricity generation and the accompanying networks in this scenario there are clear issues in terms of benchmarking network performance where there is such a high level of heterogeneity across networks. Whether it would be appropriate to expect the same levels of performance from such diverse networks and even how to measure and compare network performance (economic and technical) would become complex issues.
- This scenario highlights more than others the possibility of serious levels of stranded assets in networks where things have moved on to leave legacy network underutilised or even new network investments stranded as a result of changing energy policy. The arrangements for rewarding efficient investment in assets and penalising poor developments would require that the investment planning and regulatory arrangements were very flexible.
- One issue arising from this scenario is that, although a picture is created of a spectrum of constrained networks to underutilised networks with stranded assets, there is a likelihood that because of the general feeling of uncertainty there could be substantial periods where little or no energy investment is being made either by generation developers, network companies or consumers. This could lead to periods of serious shortages of capacity (generation, network, demand side) making system operation very difficult.

- The mechanisms to deal with such eventualities could be considered although the answer might be that the market would reflect these ‘pinch-points’ through prices and provide adequate signals for action.
- Managing power systems which have moved far from a ‘one size fits all’ approach in terms of mixed levels of consumer participation, mixed and diverse generating facilities and widely differing network infrastructure could well be a big challenge. The regulatory provisions for many ‘special’ or one-off arrangements would be very difficult to administer.
- The model produces a system which is significantly over capacity, and has significant levels of unused capacity towards the end of the period- a situation which is far from economically optimal. On the other had this is arguably a system which would be robust to supply shocks or technology failures.
- The model chooses a range of kinds and scales of technologies, including small scale distributed technologies and electric vehicles, as well as more conventional large scale plant. If these were unevenly distributed geographically this could present different challenges for the different regional systems.

5.2 Cross-Scenario Implications

The scenarios should be viewed as a set so that the broad range of future possibilities can be studied and assessed. Studying only scenarios believed to be more plausible risks missing some important indicators of future directions by adopting too narrow a view. This sub-section provides a high level discussion of points that are raised across the full set of five scenarios and is presented by way of comparisons and contrasts across scenarios.

- The development of primary power carrying infrastructure differs across the scenarios, with high demand for network capacity in the ‘Big Transmission and Distribution’ scenario and lower demand for network capacity in other scenarios. In contrast one relatively common element across the scenarios is the development of more extensive communications and control infrastructure. Such ‘light current’ infrastructure extends to varying extents all the way down from transmission systems (dealing with greater numbers of generation sites, interconnectors and demand response), through distribution systems, where distributed energy resources and demand side management become more prevalent, to customer premises, where ICT enabled work and home sites become ‘linked’ into the management infrastructure for the power system.

- The level and nature of consumer participation varies across the scenarios from passive to highly active. The nature of consumer activity ranges from the self-motivated or self-initiated action on the part of electricity customers to 3rd party provided solutions by new market players such as described in the Energy Service Companies scenario. With consumer activity being one of the main LENS themes, tracking the progress of customer interaction with their electricity supplies and the electricity networks could provide good insights into the development trajectory for the networks.

- Organisational implications appear to be very important and these differ widely across the scenarios with new players (e.g. ESCOs, microgrid operators) and new roles emerging over time (e.g. for DSOs managing much more active and complex distribution systems).

- Changing and diverse organisational arrangements across the scenarios and through time brings with it the ongoing requirement for clarity of responsibilities for security, quality, efficiency and economy of electricity supplies. More complex institutional arrangements combined with complex technical requirements in power systems could provide an unwanted lack of clarity regarding allocation of responsibilities and it is likely that government and regulators have a key role to play in managing this situation.

- Many of the scenarios paint pictures of future electricity networks with several technical and operational challenges in areas such as system operation in high renewable and high interconnection situations, microgrid-type operation in local areas, the development of DSO functions, and management of demand response. This could create problems for a contracting skills base within the power sector, and it would be expected that recent initiatives to attract and retain skilled and knowledgeable personnel into the power sector should be maintained and expanded to meet this challenge. The risks that managing more complex electricity networks brings are not insubstantial and the right allocation of risk and reward to individuals and organisations will continue to be important so that the right skills, people, technologies and other resources are in place in a timely manner to meet the challenges presented by futures such as those envisaged in the scenarios.

- Regulatory arrangements to supervise more complex markets, provide incentives for worthwhile services and reward performance are not trivial. Taking just one example, the reward mechanism for DSOs (or otherwise distribution network companies operating more active distribution networks) would need to recognise the additional resources, challenges, risks and potential for innovation in the distribution companies and reward appropriate risk taking and deployment of resources and innovative approaches. The basis for such a framework of obligations, rewards and penalties might be based on other incentive schemes in operation today but there might also be reasons why this would not be appropriate.

- Interconnectors to neighbouring countries take on various roles in different scenarios such as bulk import; two way bulk exchanges based on market operation; and large scale and small scale pan-European balancing (due to intermittent renewables and/or micro-generation). The arrangements for managing much greater flows in interconnectors in operational time frames and the necessary developments of the GB transmission system to support greater interconnector activity go beyond those in place today in both scale and scope. Responsibilities for ownership and operation of interconnectors (given the multi-national nature of interconnectors) are central to development of the GB power system along these lines.

- In similar fashion to interconnectors, the development of offshore grids is already at the conceptual planning stage. Taking such developments to a totally new scale towards 2050 and with the prospect for several GW of offshore generation resource in several of the scenarios, there is a need for very radical thinking about arrangements for offshore power systems from a technological, economic and regulatory viewpoint and this is underway at present.

- Active management of distribution networks (HV, MV and LV) and consumer demand becomes more prevalent in several scenarios. Currently this is predominantly a research and development activity with a few exceptions (notably under distribution IFI projects). The regulatory and commercial frameworks for active networks and the technical challenges they bring require advances beyond the current business models prevalent today.

- Network capacity requirements are relatively similar across some scenarios, with higher network capacity requirements in transmission networks evident in the 'Big Transmission and Distribution' scenario for example, and with higher network capacity requirements in distribution networks evident in the 'Distribution System Operators' and 'Microgrids' scenarios. In contrast to this picture of future network capacity are the widely varying levels of network utilisation across and within the scenarios. For example, intermittent renewable generation resources will produce a lower utilisation of network capacity than high load factor thermal generation but a higher requirement for operational management for system balancing. In distribution networks, the influences of demand side management, distributed electricity generation resources and energy storage (each in different measures in different scenarios) will likely make the utilisation of network capacity variable across the country and through time. The frameworks for planning network capacity additions, for managing the utilisation of the capacity and for charging for the use of the network capacity may need to evolve far from the situation at the time of writing.

- Across the scenarios (to varying degrees) there is projected a future with more (in number and level of activity) active distribution networks. The technological, commercial and organisational arrangements for management of more active networks by the distribution companies is an area where it is likely more effort will be placed in future. The regulatory arrangements (e.g. incentives and capital expenditure allowances) are also likely to have to adapt to futures with more active distribution networks.

- With different institutional governance arrangements across the scenarios and a spectrum of different approaches from strongly government led to strongly market led approaches it is likely that the issue of network development on a strategic (or to some 'speculative') basis versus development on a responsive (or to some 'reactive') basis will be one of the major debates in future. Each approach has various advantages and drawbacks and the Multi Purpose Networks scenario illustrates some of these existing side by side in one scenario with sometimes strong regional differences in network capacity and utilisation evident. Flexible approaches to investment in network and support infrastructures and flexible regulation are likely to be required.

- Energy system modelling shows that consideration of the potential evolution of the networks needs to take a broad view of the drivers, opportunities and technological developments across all energy using sectors. In particular, transport has been shown to have a significant effect on networks across all scenarios, in terms of increasing electricity demand (for electric vehicles or for hydrogen production) as well as offering an opportunity for load spreading and system balancing with 'plug-in' vehicles. The viability of CHP may also depend on the availability of bioenergy resource, which has numerous other competing uses and interactions with other sectors. It seems clear that planning for the evolution of future networks will benefit from a 'whole system' view.

6 Conclusion and Key Insights

This section provides the high level conclusions that are drawn from the LENS scenarios project and the assessment of the implications of the scenarios. The section provides a valuable guide to the key outcomes of the project and uses of the scenarios.

6.1 Key Insights from the Scenarios

The first and most fundamental insight gained from the LENS project is that there is a relatively ***broad range of plausible outcomes*** for electricity networks in GB in the longer term. The LENS project has focused around three main themes but many diverse issues have been considered and find a home within the five network scenarios. The five network scenarios paint very different pictures for the architecture of networks, operational arrangements of networks, the main players in developing operating and using the networks, the different objectives for the regulation of networks and so on. So, the first outcome is, as might have been expected, that there is a ***relatively large amount of uncertainty*** regarding the future direction of electricity networks in GB. Scenarios provide a tool for stakeholders to assess this uncertainty and start the process of considering the most appropriate strategies in the near term to position themselves and the GB electricity networks for the long term. It has not been the objective of the LENS project, or of the scenarios produced in the LENS project, to develop a consensus about any given likely future or of the best strategy that any stakeholder should pursue. Instead, the objective is to provide the tool (i.e. the set of five scenarios) to help stakeholders assess current policies, strategies and decisions in the light of the longer term. Furthermore, the LENS project has provided a start to the consideration of the implications of the scenarios and this process must necessarily continue now the scenarios have been established.

It is worth noting that each of five scenarios, in a unique way for each of them, ***challenge the status quo*** in electricity networks, although arguably 'Big T&D' and 'Multi-Purpose Networks' are most like the situation prevailing today. It is evident from the study of the issues for electricity networks which were inputs to the LENS project, the themes chosen for the project, and the scenario outputs that a period of change is being entered. It might be argued that the GB electricity networks have undergone continuous change over time but there have been periods of much greater change such as the interconnection of the transmission system (1930s) and rural electrification (1950s and 1960s). The driving forces of the GB electricity networks now include fuel security, climate change, consumer participation in energy supplies and energy networks, and advances in energy technologies across a wide front. The scenarios show that these driving forces (and others) provide the stimulus for a period of substantial change in the GB electricity networks in the coming years. Each scenario paints a different picture of the nature and extent of this change and with that comes uncertainty about the correct next steps for any stakeholder.

However, an important outcome of the scenarios project is that the scenarios provide a good 'wind tunnel'[13] in which to test prospective strategies.

It is emphasised that the scenarios, as a set, provide the broad range of outcomes of the context in which electricity networks will exist and the broad range of network outcomes as well. As such it is entirely to be expected that ***elements of different scenarios might evolve in parallel with each other in reality***. This is not really a deficiency of the scenarios approach but it does require that users of the scenarios are somewhat imaginative with their use of the scenarios. For example it is entirely plausible that while transmission networks follow a path of development as outlined in the 'Big Transmission and Distribution Scenario', distribution networks could emerge with elements of the 'Energy Services Companies', 'Distribution System Operators' and 'Microgrids' scenarios. Development of enhanced transmission network capacity, offshore grids and further interconnectors to the European mainland could run in parallel with more demand side management, distributed generation, electric vehicles and the necessary active network management in distribution networks. This is clearly an issue of the degree of development of the main elements in each scenario and the scenarios could be counted a success if each of the possible developments was identified and put in the context of a plausible set of circumstances that would bring such a development about.

The 2025 way-markers have been included to provide 'closer in' markers of the development of the contextual background for GB networks and the developments in networks that might occur along the route towards each of the five scenarios. The way-markers provide a tool to assess the emerging pathway along which networks seem to be developing and this allows users of the scenarios to draw conclusions about the emergence of particular scenarios.

If ***recent developments*** such as in the Government Renewable Energy Strategy, the Crown Estates Round 3 offshore wind letting arrangements , offshore transmission arrangements , and the Climate Change Committee's ministerial advice on the greenhouse gas reduction target for 2050 are taken into account then these provide ***pointers towards particular scenarios***. These recent developments point towards stronger growth in renewable electricity which is consistent with several of the scenarios. However, if the view is formed that there is an emphasis on large scale renewables and especially from offshore sources then that would reinforce a view that the most likely trajectory at present is towards the 'Big T&D' scenario. It is important to note that, while it might seem that recent announcements either add to or subtract from the value of the scenarios, the long term trends and socio-politic-economic trends that the scenarios are based on encompass these emerging developments. The LENS scenarios are based on the major themes of environmental concern (with heightened concern a feature of several of the scenarios), an active role for various network stakeholders including customers and mixes of market and government led approaches to meet societal objectives. These themes are consistent with the emerging developments since the LENS project began examples of which were noted.

[13] Scenarios are often said to provide a good 'wind tunnel' in which to test strategies and this refers to the idea of putting any prospective strategy to the test to see how well it fares in different future conditions that might emerge (i.e. the scenarios).

Technology plays a key role in each of the scenarios. Information and communications technology seems to have a major part in each of the scenarios – in some cases to facilitate customer participation in electricity markets and networks, in other cases to support the network operators managing more complex future networks (at transmission and distribution levels). The driving force of electricity generation and demand technologies (including electrical or even hydrogen powered vehicular transport and building technologies) lies behind the changing requirements for the GB electricity networks and the developments in these related technologies will determine much of the change that networks must respond to. Key power technologies including power electronics based equipment that can stretch the operating envelope of existing transmission and distribution infrastructures seem to have a role to play in several of the scenarios. The blend of ICT, generation and supply side, and network technologies provide many opportunities for network companies to respond to the challenges of the scenarios in innovative ways. It is worth noting that the EU SmartGrids initiative seeks to push forward the sophistication of power networks using these technologies and more.

Network infrastructures (whether gas, electricity, heat, transport or communications) seem to have an increasing effect on each other. This interaction and interdependence has been evident in gas and electricity infrastructure for some time in GB. The scenarios highlight greater levels of ***interaction and interdependence*** of network infrastructures. Electric vehicles will have a major impact on electricity demand. Communications networks will provide the vital artery for the flow of information that will keep the electricity networks operating securely, efficiently and effectively. They will enable customers to play a more active role in their electricity supplies and the management of the electricity network. The gas network will provide the fuel not just for large central generation installations but in some scenarios for combined heat and power micro-generation too. In this case the additional demands on the gas infrastructure will be challenging. The prospect of heat networks fed from renewable heat sources and operated by energy service companies (in the 'ESCOs' scenario) could have a large effect on customer demands for electricity and gas and thus on electricity networks by 2050.

Network infrastructures are constructed of long life assets and the interactions between the different networks (as noted above) and the uncertainties surrounding the development and use of these assets presents very ***real risk of for stranding of assets in future***. This risk has always existed but in recent decades, with a seemingly inexorable rise of demand and network infrastructure, asset stranding has not been a headline issue in GB. The scenarios present futures in which the demands placed on the electricity network are subject to high levels of uncertainty and very different outcomes. The success of network investment strategies in the near term will depend on how robust these strategies are against a range of plausible futures. The scenarios project provides a basis against which to test the robustness of these strategies. For example, in distribution networks, plans will be set for network investments in the coming five year price control period. Some scenarios suggest that networks will have to be actively managed to support generation and customer side activity. It is easy to see how investment in the wrong type of assets now might leave those assets stranded or obsolete in some futures.

In transmission networks, large investments in general network reinforcement, offshore grids and interconnectors are looking more and more likely. In some scenarios these investments will be exactly the correct approach while in others there are risks that the assets could be underutilised or at least not provide the flexibility required for more complex system management requirements in future. It is important to note that the network owners (transmission and distribution) will still retain the obligation to maintain the network assets irrespective of the level of utilisation until the point of complete obsolescence or stranding is reached.

6.2 Key Findings for Transmission and Distribution Networks

Looking across the scenarios at a high level it is possible to make general statements based on the scenarios and the implications that have emerged.

In ***transmission networks***, the key findings across the scenarios relate to the different levels and types of network development appropriate to the scenarios. In some scenarios an approach is taken to expand the network to connect to the most economic onshore renewable sources with some limited offshore development. In that situation, the other generation types would be large scale fossil (with and without carbon capture and storage) and nuclear. Such a situation alongside a downward pressure on network capacity from distributed generation and micro-generation and demand conservation measures would lead to relatively lower requirement for transmission capability. Equally plausible is the situation at the upper end of transmission network expansion with massive offshore grid development, reinforcements and extensions of the network to renewable resource rich areas of the country and development of further interconnectors to neighbouring countries. Flexible system development, system management and regulatory approaches are required when faced with diverse futures such as these. It is worth noting that at either end of the spectrum for transmission networks there exist ‘green’ and ‘not so green’ outcomes depending on the type, scale and use of the installed electricity production facilities. Future roles of the transmission network will include maintaining the high level of security and performance of the transmission network enjoyed by consumers in GB, managing high penetrations of renewables, providing and securing system balancing to interconnected countries, and managing potentially higher levels of interaction with DNOs in planning and operational timeframes. Different mixes of base load, flexible and intermittent generation operating in systems with non-dispatchable and dispatchable distributed generation make system balancing, stability and security more challenging for the GB system operator.

In ***distribution networks***, the key findings across the scenarios are that there is likely to be a higher level of activity in distribution networks from distributed generation, active consumers, demand conservation and management, electric vehicles, private/autonomous networks (e.g. microgrids) and energy storage. The scenarios approach has shown plausible driving forces in the background socio-political context and plausible routes to such futures with these higher levels of activity in distribution networks. As a result of this distribution network companies will have to manage their networks more actively. The scenarios picture a range of possibilities of different levels of active management undertaken by different players (e.g. distribution network companies, energy service companies, microgrid operators and customers.

Distribution network companies will also likely have to coordinate planning and operational matters more closely with the transmission companies. In addition, distribution companies will have to coordinate system operations with the emerging new participants such as aggregators of active customers (e.g. ESCOs), microgrid network operators, independent and private network operators and even, potentially to individual customers. It is difficult to make generalisations about likely development of distribution network infrastructure since there are strong regional variations and strong legacy issues across the distribution companies. However, with the background set out above, it is clear that quite new technologies, new approaches and new system designs and architectures will likely be required to meet the challenges of the new situations that distribution network companies are likely to face.

6.3 Concluding Comments

Scenarios are a useful tool for promoting strategic thinking about the longer term future. The network scenarios produced in the LENS project and presented and assessed in this report are a valuable resource for GB network stakeholders in developing plans for the development of the GB electricity networks. The scenarios illustrate the complex dynamic between the background context for electricity networks (e.g. policy, markets, environment, consumer led requirements, etc.) and the networks that may be required. The scenarios show that there might be a period of more rapid change in electricity networks due to factors such as climate change, fuel security concerns and change in energy consumer attitudes and behaviours. These scenarios are clearly not the only word on the future of electricity networks but they do present a broad view of possible futures taking into account inputs from GB network stakeholders and beyond.

Other specific outcomes for electricity networks are possible. It is highly unlikely that any one of the five scenarios presented here will emerge in reality as described here. However, the breadth of plausible outcomes for electricity networks covered by the set of five LENS scenarios provides a valuable input to strategic thinking about the GB electricity networks.

It is already evident that the LENS scenarios are proving useful as a starting point for further study among stakeholders. For example, two major research initiatives funded by the UK research councils, ‘FlexNet’ and ‘Transition Pathways’ are using the LENS scenarios as the basis for their research. The ‘FlexNet’ project is investigating network technological developments that provide flexibility for system operations and development to deal with uncertain futures, while the ‘Transition Pathways’ project is studying aspects of the pathways that the UK energy system may follow towards a low carbon future Other stakeholders may choose to assess current development plans and strategies in the light of the scenarios. The network companies, for example, might assess research and development programmes or asset renewal strategies in light of the pictures of future networks presented in the scenarios.