Ofgem LENS Project

Draft Scenarios Report

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This report contains forward looking network scenarios for power networks in GB 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 expectations that are based on current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual outcomes or events including data to differ materially from those expressed or implied in the scenarios in this report. There are a number of factors (including risks and uncertainties) that could affect the scenarios and could cause them to differ materially from those stated, implied or inferred from the forward-looking scenarios contained in this document.

The data tables in Appendix B have been generated under a range of input assumptions which have been developed as part of a scenario process which is outlined in detail in the main body of this report. The data should not be regarded as projections or predictions nor should reliance be placed on the data set out in the data tables.

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Executive Summary

The objective of the LENS project is 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. This report represents the output of more than nine months of intensive scenario development activity for electricity networks. The result is a set of five draft scenarios for GB power networks in 2050 that are rich in narrative and quantitative modelling support.

The report provides a reference point and summary of the two previous project reports: the first on scenario development inputs to the LENS project and the second report presenting the initial LENS scenarios. The work to produce the set of scenarios set out in this report included substantial consultation with stakeholders through Ofgem consultations and other inputs from academic peer reviewers and a large volume of work related to power network scenarios. It is worth noting that no previous activity has been conducted that draws together so much material to produce a set of scenarios describing GB power networks in the long term.

The report describes the process that has been followed since the publication of the interim scenarios in May 2008 to progress this project and produce the scenarios presented in this report. The steps in this process include reflection on and then incorporation of consultation and workshop inputs, consideration of inputs from academic peer reviewers, quantitative modelling of the scenarios using the MARKAL MED model, and the development of 2025 waymarkers for the scenarios. The academic team have also produced an initial set of implications of the scenarios for networks and their regulation.

Follow on steps include: consultation on this draft set of scenarios and production of a final scenarios report, further consideration of the implications of the scenarios, and dissemination and use of the scenarios.

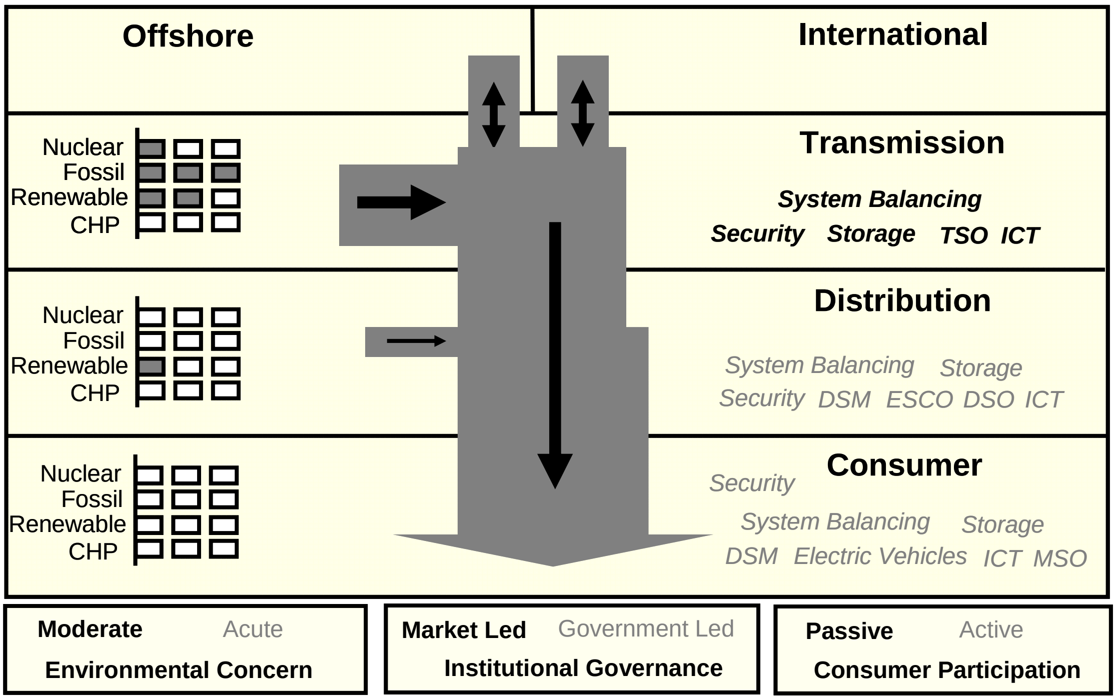
The scenarios themselves are entitled:

- Big Transmission and Distribution (‘Big T&D’)
- Energy Service Companies (‘ESCOs’)
- Distribution System Operators (‘DSOs’)
- Microgrids
- Multi Purpose Networks

The outlines of the scenarios along with high level quantitative modelling results are presented below as the major outcome of the activity. It is important to note that the quantitative modelling and scenario theme/narrative development processes have been conducted in a parallel and closely integrated manner. However, the quantitative and qualitative scenario development steps are distinctly different and produce different types of results. Studying the differences closely has allowed enhanced insights to be incorporated into the scenarios and this is the main objective of the modelling work – to enhance the insights that the scenarios offer rather than dictate the content of the scenarios. The academic team make no claim that the models reflect the scenario narratives exactly so some differences are evident and the reasons for these differences and their implications are discussed in the relevant sections of the report.

Big Transmission & Distribution scenario

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



'Big Transmission and Distribution' scenario schematic illustration.

Key Aspects of the Big Transmission & Distribution scenario:

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

A selection of the headline draft quantitative modeling results for this scenario is presented in the table below. The inputs to the model for this scenario and a full discussion of the results are provided in the report.

Generation type		**Network**	**Installed capacity (GW) in year:**	
			2025	**2050**
Large thermal (no CCS)		T&D	40	27
Large thermal (CCS)		T&D	4	41
Nuclear		T&D	3	0
Large wind	Offshore	T&D	7	7
	Onshore	T&D	5.6	5.4
Marine		T&D	0	3
Other large renewable		T&D	18	4
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	5	11
CHP	Large (industrial / commercial)	T&D	3	2
TOTAL T&D			86.6	101.4
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only		
TOTAL DISTRIBUTION ONLY			0	0
TOTAL			86.6	101.4

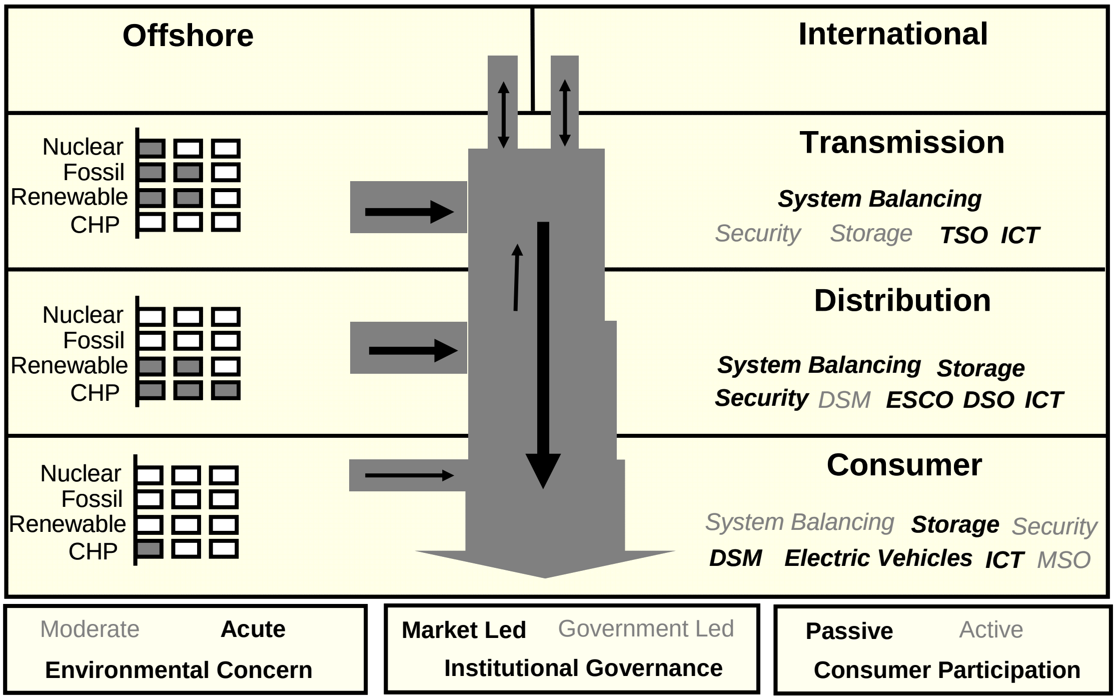
'Big T&D' Installed Capacities by network connection – Draft results

Energy Service Companies scenario

Energy Service Companies (ESCOs) are at 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 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.

This scenario can be illustrated schematically as follows and this presents the main qualitative features of the scenario narrative. A full explanation of this schematic is provided alongside the full scenario narrative.



'Energy Service Companies' scenario schematic illustration.

Key Aspects of the Energy Service Companies scenario:

- Consumers remain relatively passive towards their energy supply and while the majority of people are concerned about the environment they strongly believe that it is the duty of government and the market to address the issues.
- Although the belief persists that markets are best placed to service consumer demands at the same time as meeting social and environmental needs, strong intervention is not ruled out to address environmental issues.
- The potential for markets to meet the energy services demands of consumers is met through the emergence of energy service companies (ESCOs).
- Centralised electricity generation 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 power networks is to support a vibrant energy services market. The transmission and distribution infrastructure is required to support a super-supplier or energy services company (ESCO) centred world.
- ESCOs do all the work at the customer side and the transmission and distribution networks contract with ESCOs to supply network services, allowing the network companies to operate the networks more actively.
- There are wide ranging developments and vibrant markets in energy services including micro-generation, on-site heat and power, demand side management, telecommunications and electric vehicles.
- The services supplied by the networks include transmission system connection to strategic, large scale renewables and also access to municipal scale CHP and renewables tailored to local demands.
- System management is aided by the degrees of flexibility provided by ‘empowered’ customers with high capability information and communications technologies (ICT).

A selection of the headline draft quantitative modeling results for this scenario is presented in the table below. The inputs to the model for this scenario and a full discussion of the results are provided in the report.

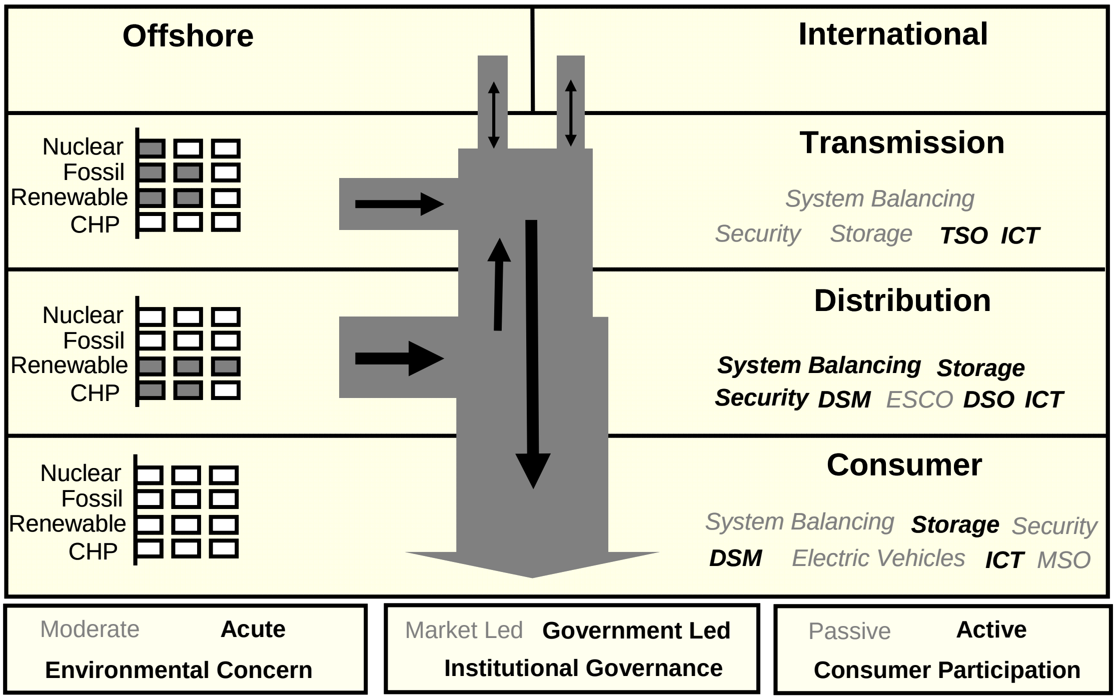
Generation type		Network	Installed capacity (GW) in year: 2025	2050
Large thermal (no CCS)		T&D	25	15
Large thermal (CCS)		T&D	15	40
Nuclear		T&D	15	13
Large wind	Offshore	T&D	5.8	6
	Onshore	T&D	8.6	8.4
Marine		T&D	0	5
Other large renewable		T&D	11	4
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	4	10
CHP	Large (industrial / commercial)	T&D	3	1
TOTAL T&D			88.4	103.4
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	0	16.7
TOTAL DISTRIBUTION ONLY			0	16.7
TOTAL			88.4	120.1

‘Energy Service Companies’ installed capacities by network connection – Draft results

Distribution System Operators 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. A feature of this scenario is a decision to push for a hydrogen economy as part of a cohesive EU initiative. Consumers are active in their electricity supplies because of attitudes to the environment and a desire to secure the best possible supply of electricity based on price, service and reliability.

This scenario can be illustrated schematically as follows and this presents the main qualitative features of the scenario narrative. A full explanation of this schematic is provided alongside the full scenario narrative.



'Distribution System Operators' scenario schematic illustration.

Key Aspects of the Distribution System Operators scenario:

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

A selection of the headline draft quantitative modeling results for this scenario is presented in the table below. The inputs to the model for this scenario and a full discussion of the results are provided in the report.

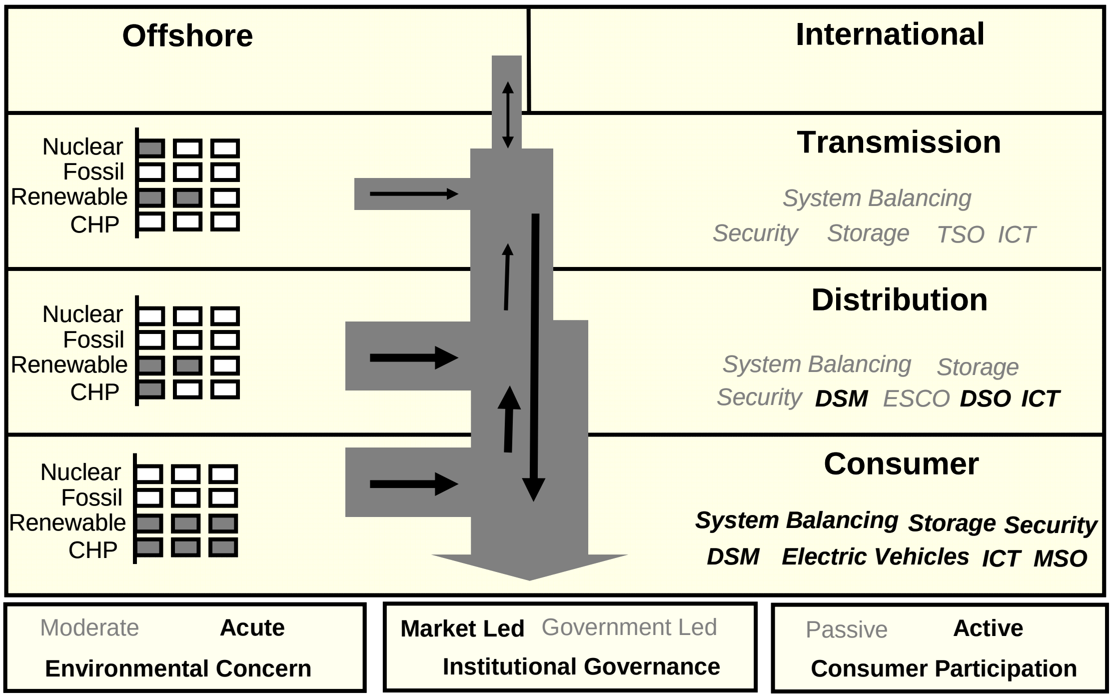
Generation type		**Network**	**Installed capacity (GW) in year:**	
			2025	**2050**
Large thermal (no CCS)		T&D	19	10
Large thermal (CCS)		T&D	5	18
Nuclear		T&D	19	19
Large wind	Offshore	T&D	0.9	5
	Onshore	T&D	8.6	7.8
Marine		T&D	0	5
Other large renewable		T&D	12	5
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	4	10
CHP	Large (industrial / commercial)	T&D	2	0
TOTAL T&D			71.5	80.8
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	11.7	23.7
TOTAL DISTRIBUTION ONLY			11.7	23.7
TOTAL			83.2	104.5

'Distribution System Operators' installed capacities by network connection – Draft results

Microgrids scenario

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

This scenario can be illustrated schematically as follows and this presents the main qualitative features of the scenario narrative. A full explanation of this schematic is provided alongside the full scenario narrative.



'Microgrids' scenario schematic illustration.

Key Aspects of the Microgrids scenario:

- 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.

A selection of the headline draft quantitative modeling results for this scenario is presented in the table below. The inputs to the model for this scenario and a full discussion of the results are provided in the report.

Generation type		**Network**	**Installed capacity (GW) in year:**	
			2025	**2050**
Large thermal (no CCS)		T&D	21.5	4.1
Large thermal (CCS)		T&D	5	5
Nuclear		T&D	10	27
Large wind	Offshore	T&D	0	1.5
	Onshore	T&D	5.56	8.36
Marine		T&D	0	1
Other large renewable		T&D	5	5
Storage		T&D	0	1
Imports (interconnector capacity)		T&D	4	12
CHP	Large (industrial / commercial)	T&D	2	0.5
TOTAL T&D			53.06	65.46
CHP	Small (household)	Distribution only	7.3	24.5
Microgen (inc. microwind, solar etc)		Distribution only	21.8	23.2
TOTAL DISTRIBUTION ONLY			29.1	47.7
TOTAL			82.16	113.16

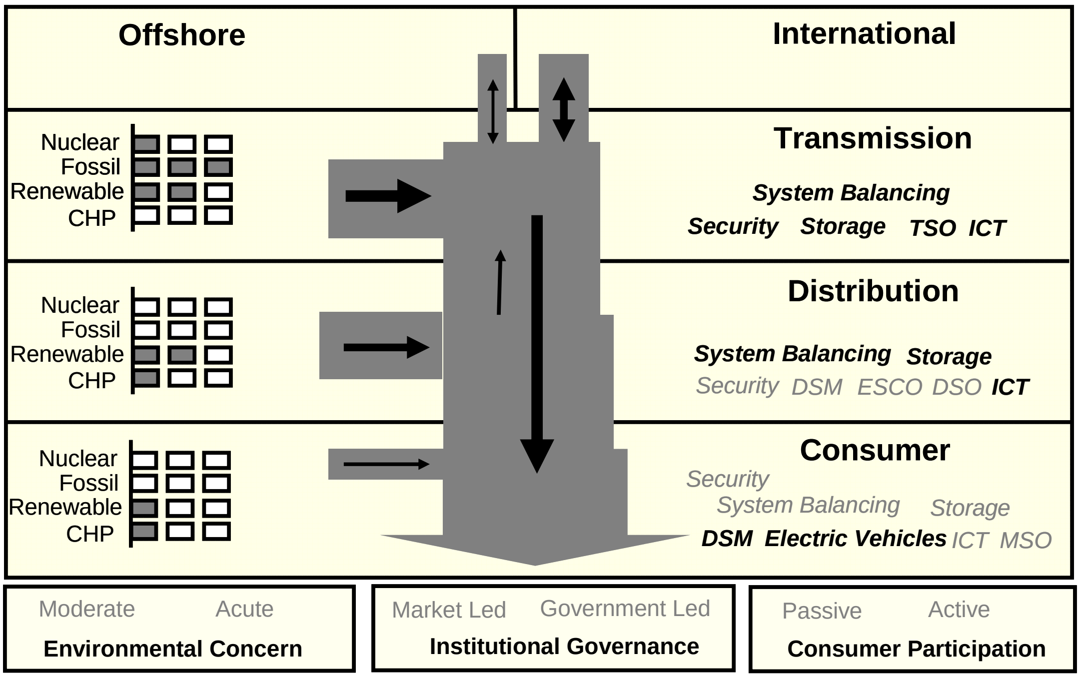
‘Microgrids’ installed capacities by network connection – Draft results

Multi Purpose Networks scenario

Network companies at all levels respond to emerging policy and market requirements. TSOs still retain the central role in developing and managing networks but DNOs 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.

This scenario can be illustrated schematically as follows and this presents the main qualitative features of the scenario narrative. A full explanation of this schematic is provided alongside the full scenario narrative.



'Multi Purpose Networks' scenario schematic illustration.

Key Aspects of the Multi Purpose Networks scenario:

- There is a pervasive feeling of uncertainty and a resulting ambiguity within society towards environmental issues and the influence this has on energy infrastructure development. Environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental observations and reports/statistics.
- A lack of global consensus on environmental issues contributes to the uncertainty regarding environmental action.
- There are various market led and Government led approaches pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of fuel supplies and immediate economic concerns.
- Differing attitudes towards energy consumption develop among consumers resulting in varied types and levels of consumer participation depending on the geographic area, social demographics and services provided by energy companies.
- There are many types of generation in the national portfolio with centralised thermal generation and offshore renewables both prominent groupings. Combined heat and power and microgeneration are deployed in areas with the right mix of public investment, services from energy companies and demand from consumers.
- There is a strong potential for stranded assets and investment redundancy in the power sector.
- Attempts have been made to exploit many energy technologies over time and there exists a large diversity in electricity production and demand side management initiatives implemented.
- The network is characterised by diversity in network development and management approaches as a result of changing energy policies and company strategies over time.
- Substantial differences exist in network capabilities with excess capability in some areas and constraints in other areas.
- Electricity networks fulfil different roles including bulk transfer, interconnection, backup and security, and meeting renewable and demand side objectives.
- Challenges in managing diverse system architectures are accompanied by opportunities from the diversity of generation, network and demand side provision.
- The commercial implications of the lack of consistency in energy policy and the subsequent diverse network infrastructures that emerge means that the stranding of certain power system assets becomes more apparent over time.

A selection of the headline draft quantitative modeling results for this scenario is presented in the table below. The inputs to the model for this scenario and a full discussion of the results are provided in the report.

Generation type		**Network**	**Installed capacity**	
			2025	**2050**
Large thermal (no CCS)		T&D	20	13
Large thermal (CCS)		T&D	11	36
Nuclear		T&D	21	18
Large wind	Offshore	T&D	1.2	0
	Onshore	T&D	8.6	8.3
Marine		T&D	5	11
Other large renewable		T&D	12	5
Storage		T&D	2	2
Imports (interconnector capacity)		T&D	4	11
CHP	Large (industrial / commercial)	T&D	2	2
TOTAL T&D			86.8	106.3
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	3.2	7.8
TOTAL DISTRIBUTION ONLY			3.2	7.8
TOTAL			90	114.1

'Multi purpose networks' installed capacity by network connection – Draft results

A comparison of the headline draft modeling results across the five scenarios is presented below. It should be noted that the model runs do not reflect the scenario narrative content exactly and any differences are fully discussed in the report. The differences actually reveal important aspects of the scenarios.

	2000	2050				
		Big T&D	ESCO	DSO	MG	MN
Total Primary Energy Demand (PJ)	**8,624**	**8,463**	**7,631**	**6,021**	**5,148**	**7,492**
Total Final Energy Demand (PJ)	**6,189**	**6,468**	**5,807**	**4,910**	**4,558**	**5,785**
Total Electricity Generation (PJ)	**1,288**	**1,652**	**1,874**	**1,501**	**1,462**	**1,860**
Total Electricity installed capacity (GW)	**84**	**101**	**120**	**105**	**113**	**114**
Total Final Electricity Demand[1] (PJ)	**1,176**	**1,449**	**1,665**	**1,370**	**1,376**	**1,657**
Relative size of electricity sector to whole system (%)[2]	**19**	**22**	**29**	**28**	**30**	**29**
Relative size of distributed generation to total electricity generation (%)[3]	**0**	**0**	**14**	**23**	**42**	**7**
Electricity CO_2 reductions from 2000 (%)	**0**	**50**	**88**	**95**	**99**	**78**
Whole system CO_2 reductions from 2000 (%)	**0**	**24**	**54**	**61**	**71**	**46**

Headline draft results summary of the model runs in 2050

1 Includes electricity used for hydrogen electrolysis as well as end use electricity

2 Total Final Electricity Demand (PJ) / Total Final Energy Demand (PJ)*100

3 Total distributed generation installed capacity (GW) / Total electricity installed capacity (GW)*100

The report contains the full details of the scenarios and the process by which they have been generated.

Initial views on implications of the scenarios are also presented in the report and some of main issues that arise across the scenarios include:

- Potential need for large scale network developments (enhanced transmission capacity and European interconnection) and the feasibility of this over the longer term.
- Support mechanisms and underpinning technology for consumer participation such as smart metering and pervasive use of information and communications technology at an individual consumer level.
- Potential complexity of distribution network management and the roles to be played by the network operator, supply companies and consumers.
- The growth of small scale generation and demand side management and the requirement for a much enhanced flow of data and information in operational time-scales throughout the network from transmission down to (and even within) individual consumer sites.
- The regulatory tools to encourage appropriate network developments and incentivised good management of a much more complex situation in most scenarios is a key issue for future consideration.

1 Introduction and Overview

1.1 Background

This document is the third academic report of the LENS project and summarizes key stages of the project to date before going on to describe the latest progress of the scenario development process culminating in draft scenarios for power networks in GB towards 2050.

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 [1] and Pierre Wack [2] 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.

The Long Term Electricity Networks Scenarios project arose as a result of the Energy White Paper [3] 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 [4] set out an approach to develop scenarios for the GB electricity networks sector for 2050 with the objective of understanding the implications for the power transmission and distribution networks in GB and their regulation.

The LENS interim report of May 2008 [5] described the evolution of proposed inputs and themes and presented two sets of scenarios entitled energy scenarios and network scenarios. In addition, the Ofgem open letter of May 2008 [6] set out the next steps for the LENS project, after the publication of the interim report, as: completion of the merging process; MARKAL-MED Modelling of the scenarios; development of 2025 way-markers; the publication of a draft scenarios report; and further consultation and a final report in September 2008.
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This draft scenarios report details progress on the steps outlined above and presents a single, consolidated set of scenarios that incorporate recent stakeholder input, the initial MARKAL-MED modelling results, 2025 way-markers for each scenario and a set of immediately recognisable implications of the scenarios.

1.2 Document Structure

This report is the penultimate LENS report following the publication of the May 2008 interim report and documents the recent activities leading to a single set of draft electricity network scenarios for Great Britain.

Section 1 describes the background and document structure.

Section 2 gives a brief overview of the LENS project up to the point of publication of the LENS interim report in May 2008 [7].

Section 3 describes the process of merging the energy and network scenarios into a single set of scenarios, each containing detailed network characteristics within an overall energy context. Also described are the development process for 2025 way-markers and a discussion of the MARKAL-MED modeling process.

Section 4 presents the consolidated draft network scenario narratives, modeling results and insights and 2025 way-markers.

Section 5 presents the academic team's initial thoughts on scenario implications for networks and regulation.

Section 6 details next steps including a further stage of consultation and the finalization of the scenarios.

Appendices providing supporting detailed material on modelling activities, a list of abbreviations, references and a bibliography for the report are contained in sections 7-11.

2 Development of Network Scenarios: Progress to Interim Report

2.1 Methodology

The LENS project commenced with the open letter of June 2007 [8], initial workshop and consultation [9].

The project methodology was then defined and published in November 2007. At this time, the approach for the LENS scenario development was clearly laid out and explained in terms of nine key stages.

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

This eight step approach described in the methodology formalised the general ideas of recipients, focal questions, information and issues gathering, key themes, pathways, storylines/narratives, implications and strategies as proposed by pioneers of scenario thinking such as personnel within Shell [10] and Pierre Wack [11]. A more recent study of the California energy crisis as recorded by Ghanadan and Koomey [12] was also noted as an important influence. It should be noted that the steps 1 to 7 are led by the LENS academic team and step 8 is an activity led by Ofgem with academic team input (and a review of implications of the scenarios is provided in this report).

The recipient of the LENS scenarios was 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.

The other significant definition included in the methodology was the focal question. The focal question allows the scenario developers to produce a set of high quality, plausible and consistent scenarios that address the key issues for the recipients of the scenarios. 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 [in 2050]?’

The methodology also provided further detail on the intended approach for each of the other key stages and proposed a guide timetable of milestones for the project.

2.2 Scenarios Inputs Report

On completion of the information gathering stage (Dec 2007) a report on LENS inputs was published [13] that reviewed previous scenario work relating to the energy and electricity markets and proposed a set of inputs for the LENS project. The inputs used to create the LENS scenarios needed to address each aspect within the focal question and any other relevant drivers to provide a diverse set of external factors that could influence the requirements of networks and thus the development of the GB power networks. Following this logic, the review and analysis of potential inputs led to the definition of a set of ‘high-level’ inputs and a set of ‘network specific’ inputs. Subsequent stakeholder consultation and workshops broadly approved these inputs and a finalised set of inputs incorporating stakeholder feedback was defined.

High Level Inputs

- ***Consumer Behaviour***
- ***Economic Landscape***
- ***Energy Demand and Other Energy Supply Networks***
- ***Environmental Landscape***
- ***Political/Regulatory Landscape***
- ***International Context***

Network Specific Inputs

- ***Electricity Demand***
- ***Electricity Generation***
- ***Security, Quality and Performance of Supply***
- ***Transmission and Distribution Network Architecture***
- ***Network Technology Development and Deployment***
- ***Power Network Sector Structure and Strategies***

- ***Transitional Issues***

Definitions of these inputs are available in the full inputs report.

2.3 Themes

The LENS inputs report also initiated the definition of what would become the LENS themes. For clarity, some key scenario terminology is reiterated here.

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

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

Themes describe long term societal dynamics that provide the backdrop against which all actors make their decisions. A theme might be conceived of as an axis with two more or less opposite extremes at either end of it, in which case a theme could generate more than one type of scenario.

The function of defining themes is to give a coherent and internally consistent basis for making simultaneous assumptions about the numerous inputs to each scenario. Hence themes are the broad and high level dynamics that differentiate the scenario storylines from one another and allow a rich description of the circumstances and driving forces that shape the development of power networks in GB.

Following a review of themes used in previous scenario studies and proposed initial themes from stakeholder consultation and workshops, a small subset of potential themes were defined and are shown in the influence diagram below.

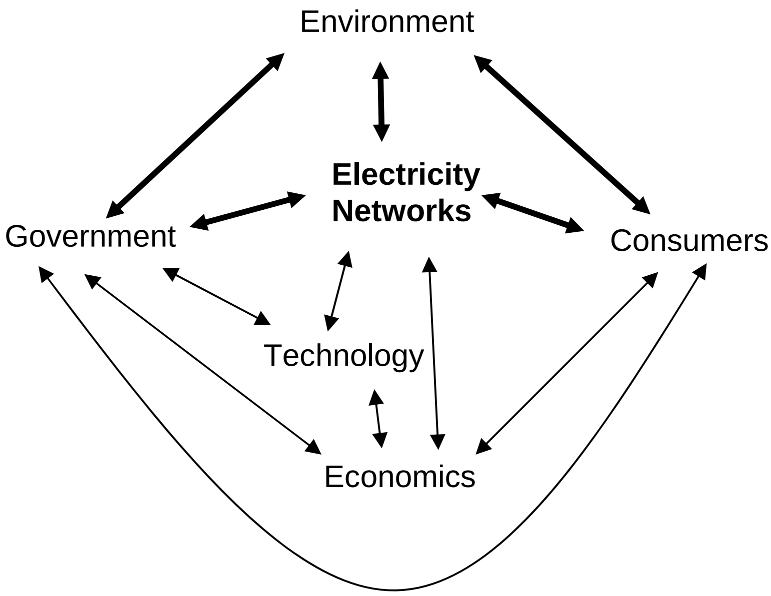

Figure 1 : LENS themes influence diagram

Further review and analysis led to a final definition of three themes. This process and a more detailed definition of the themes are described in further detail within the LENS interim report.

- **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). High environmental concern implies that environmental issues are of a high priority and are one of the primary influences on the decisions of the above parties.

- **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 liberal markets, the approach to natural monopolies, network access, planning, and infrastructure investment.

The purpose of these themes was to create an outline picture of the “context” within which networks exist and subsequently identify implications for electricity use and generation. By developing broadly defined scenarios a rich and varied set of implications for networks could be created and explored and hence the resulting network scenarios would represent a comprehensive range of possibilities that directly arise from the theme interactions.

The method chosen to develop scenarios from the chosen themes was the use of orthogonal axes. When the axes of the three themes were represented graphically as in Figure 2 a three dimensional space comprising of eight octants was created. Each of these octants contained a unique combination of themes and hence there were eight possible scenarios as illustrated in Figure 3.

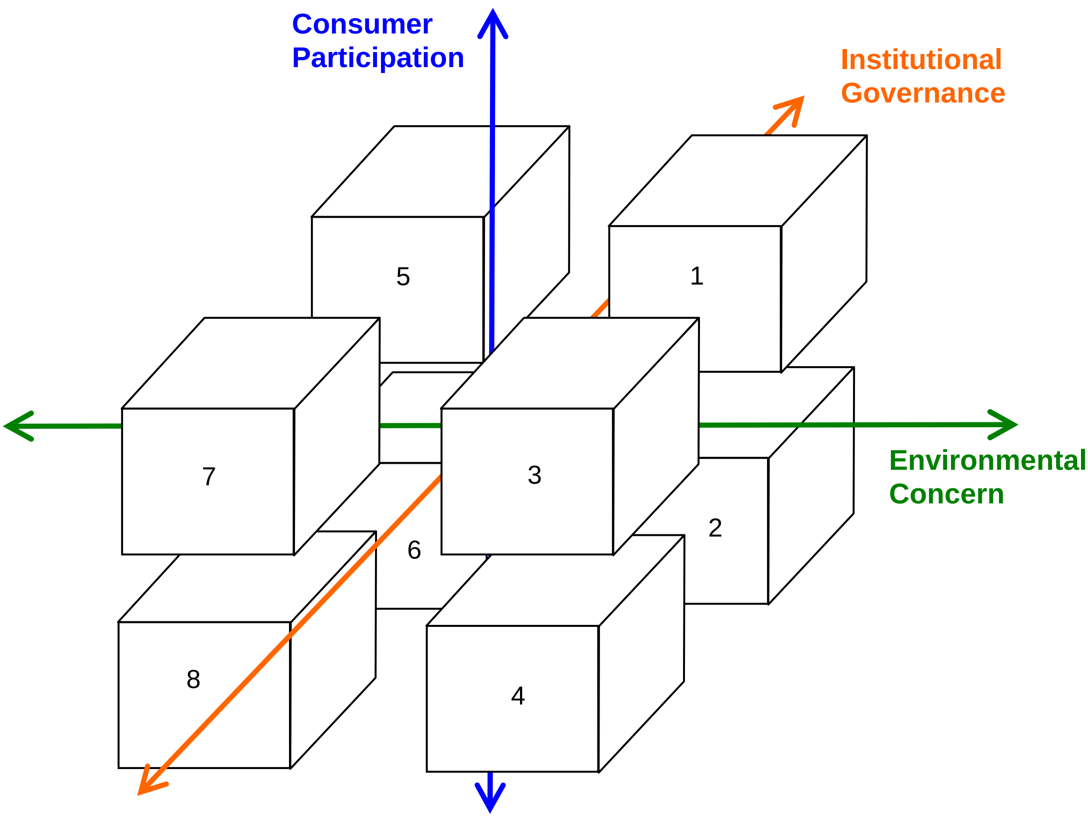

Figure 2: Interaction of three LENS themes.

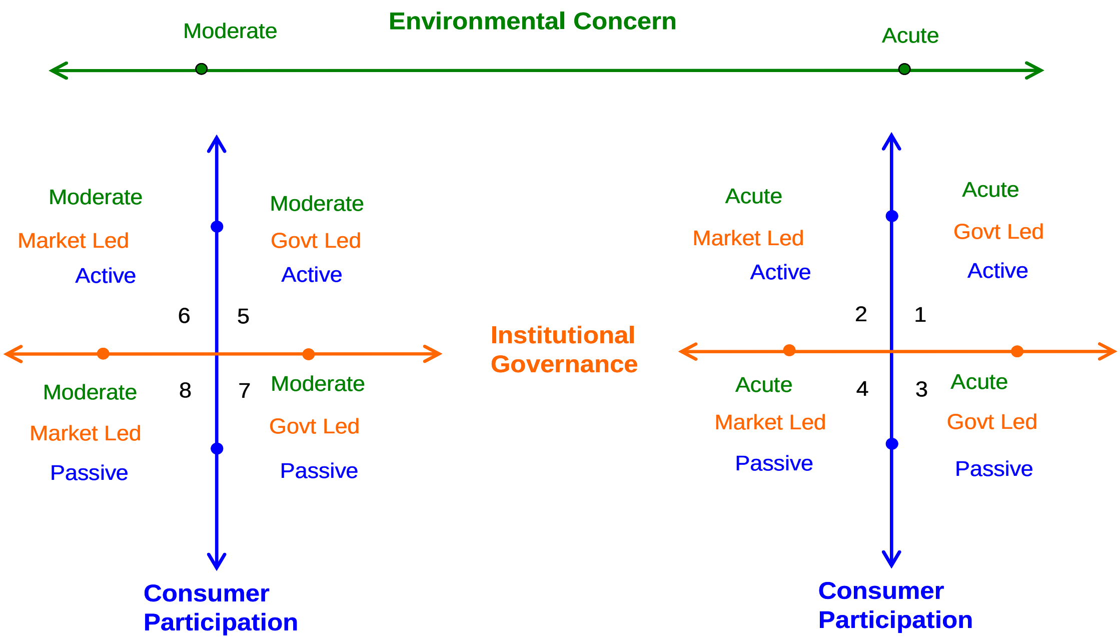

Figure 3: Eight possible initial scenarios identified from themes.

From this initial definition of high level theme interaction the scenario development process could begin.

2.4 Interim Report

The interim report of May 2008 detailed the process of scenario development including all of the key stages since the information gathering stage and the publication of the inputs report. As described above, a revised set of inputs was defined that integrated feedback from the December consultation. Using these inputs and the stakeholder feedback on themes, an iterative process of identifying the most suitable themes for scenario development followed. With a finalised set of themes, scenario generation tools (mainly orthogonal axes) were used to produce a range of possible scenarios and from this range of scenarios a subset was chosen that was deemed to be (a) the most plausible in the way the themes interacted and (b) the most likely to produce interesting and useful network scenarios.

As the scenario development progressed, the concept of network scenarios and how to achieve them gradually evolved. As a result, a process to develop network scenarios was developed that included an intermediary stage of energy scenarios. The intention behind this process was to create energy scenarios that provided a high level view of the world in which electricity networks exist, creating a clear link between the interactions of our chosen themes and the general outline of the scenario. With this stage complete, the implications for networks could start to be explored. It was considered possible that several types of networks could plausibly emerge from one energy scenario and also that the same type of network could emerge from more than one energy scenario.

The initial scenarios produced by the high level themes were hence deemed to be energy scenarios from which network scenarios would be derived via further analysis. These energy scenarios are described in Table 1.

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

Table 1: Energy scenarios characteristics.

The narratives for these energy scenarios were then developed via an iterative process of drafting, review and refinement. In order to identify the numerous potential network scenarios within each energy scenario, a method of describing the network scenarios at a sufficiently detailed yet high level was required. The approach taken was to identify a set of key network uncertainties or “parameters” that once established could be used to categorise potential network scenarios. A mapping process used these parameters to identify numerous possible network scenarios which were then reviewed and consolidated into a final set of five.

- **Big Transmission and Distribution**

  Transmission and distribution infrastructure development and management continues much as expected from today’s patterns with growing requirement for networks as demand grows unhindered and relatively unmanaged operationally.

- **Energy Service Companies**[4]

Transmission and distribution infrastructure is required to support a much more vibrant energy services market place with 'super-suppliers' or energy service 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). In earlier stages of the project this scenario was titled Energy Services Market Facilitation. This has been modified to reflect stakeholder feedback and a general desire for a more direct title.

- **Distribution System Operators**

Most electricity production is connected to distribution networks, thus reducing the role for the transmission network which only serves to connect the strategic and economic renewable resources in certain parts of the country. As a result of the much higher levels of generation and demand activity in distribution networks, the distribution operations function is much more active with local balancing, constraint management and market facilitation being taken on by distribution operators.

- **Microgrids**

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

- **Multi-purpose Networks**

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 others 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.

Despite the energy to network scenario mapping exercise having clear benefits in demonstrating that the resulting network scenarios could plausibly arise from a wide range of energy contexts and as a whole cover a suitably wide range of plausible outcomes for electricity networks in 2050, there was also thought to be some drawbacks to this approach, as discussed further in this section. Hence,

[4] This scenario was previously entitled 'Energy Services Market Facilitation' and although strictly speaking this was the title in use at this stage of the scenarios process, the name has been changed here (as well as throughout this report) to avoid confusion.

one of the key next steps for the project, as identified in the recent LENS interim report, was to merge the energy and network scenario narratives.

Other key steps in the development of the draft scenarios were identifying 2025 way-markers and the results of MARKAL-MED-MED modeling, both of which are discussed in detail in the following sections and are shown in Figure 4 below.

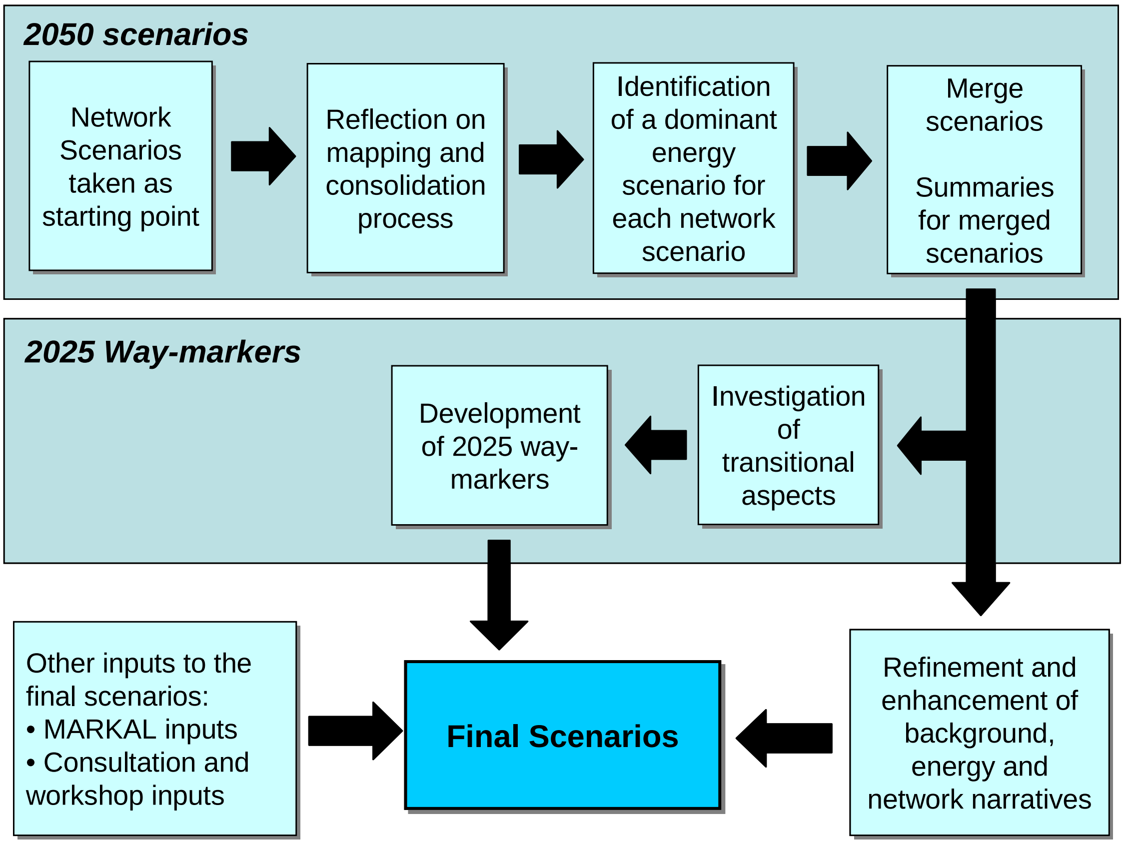

Figure 4: Development process of draft scenarios

3 Further Development of Network Scenarios

This section details the further scenario development steps that have been undertaken since the publication of the LENS interim report in May 2008.

In addition to the three main steps outlined below (merging the energy and network scenarios, 2025 way-markers and modelling), the academic team also reflected on the feedback from external academic peer review and incorporated changes to the scenarios in response.

3.1 Merging Energy and Network Scenarios

Clear benefits can be seen in the energy to network scenario mapping exercise undertaken in the scenario development process; namely demonstrating that the resulting network scenarios could plausibly arise from a wide range of energy contexts and as a whole, cover a suitably wide range of plausible outcomes for electricity networks in 2050. However, presenting two sets of scenarios describing broad energy context and network specifics with no explicit link between the two is problematic in some ways. Primarily, the usability of the scenarios could be deemed overly complex without clear links between the network descriptions and the broader social, political and environmental context. The approach could be seen as fragmented and the potential confusion would defeat one of the main advantages of scenarios, which is to provide a straight forward, holistic and internally consistent view of the future.

To address these issues and progress towards a final set of scenarios a process of merging energy and network scenarios has taken place.

The focus of the LENS project remains firmly on electricity network scenarios, therefore the objective of the merging process was to produce network scenarios that included the broader context within which the networks develop and demonstrate clear links to the underlying driving forces.

Given the above, the logical approach was to take each network scenario as a near finalised product and focus on the content of the energy scenarios. This allowed the identification of an appropriate broad context narrative that was merged with the network scenario narrative.

On reviewing the draft energy and network scenarios there were immediately obvious similarities between the two sets of scenarios, as discussed below. The following table, reproduced from the interim report also helps demonstrate the dominant influence of some energy scenarios on specific network scenarios.

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

Table 2: Mapping of energy scenarios to network scenarios.

A - Switch me on (Subsets 1, 2 and 3 identified various combinations of demand and generation features that could plausibly exist within the Switch me on context.)
B - Fix it for me (Subsets 1, 2 and 3 identified various combinations of demand and generation features that could plausibly exist within the Fix it for me context.)
Ci - Government green agenda (Subsets 1, 2 and 3 identified various combinations of demand and generation features that could plausibly exist within the Government green agenda context).
Cm - Dynamic green markets (Subsets 1, 2 and 3 identified various combinations of demand and generation features that could plausibly exist within the Dynamic green markets context)
D - Reactive approach

This table represents the potential network scenarios that arose from the five energy scenarios and how they contributed to the draft network scenarios.

It can be seen that 'Big T&D' was strongly influenced by energy scenario A, 'Microgrids' was heavily influenced by Cm and 'Multi Purpose Networks' directly arose from D.

If we look for relationships between the two sets of scenarios at a high level then we can see that 'Big T&D' logically fits within a context of high demand, centralised generation and attitudes and behaviour not greatly different from today. This points to a close link to the 'Switch Me On' scenario.

Microgrids intuitively fits within a context of self-sufficiency where localised generation and DSM is prevalent due to the environmental concern of active consumers. This seems to be closely related to the 'Dynamic Green Markets' scenario.

Energy Service Companies must have a context that promotes the rise of ESCOs within an overall push for emissions reductions. The passive nature of consumers and liberal market approach of the 'Fix it for Me' scenario fits well with these high level requirements.

The 'DSO' scenario requires a context that promotes large amounts of renewable generation connected to the distribution network, significant overall demand reduction and DSM schemes that place a significant onus on the management of these networks. The government green agenda scenario contains strong themes of demand reductions (hydrogen economy and efficiency) and a drive towards renewable generation that fit well with the DSO scenario.

The Multi Purpose Network Scenario arises as a direct consequence of the reactive approach context where an atmosphere of ambiguity and uncertainty results in many differing requirements and roles for electricity networks.

The above discussion details some clear links between the energy and network scenarios in addition to some more intuitive associations. These perceived correlations between energy and network scenarios are demonstrated below.

Network Scenario	**Energy Scenario**
Big T&D	Switch Me On
Energy Service Companies	Fix it For Me
Distribution System Operator (lean transmission)	Government Green Agenda
Microgrids (Small Transmission and Distribution)	Dynamic Green Markets
Multi Purpose Networks	Reactive Approach

Table 3: Primary influence on network scenario from energy scenario.

These high level similarities were used as a starting point to commence the merging process. The process recognised that although a dominant energy scenario had been identified for each network scenario and this would form the basis of the context narrative, some energy scenarios contributed to multiple network scenarios in the mapping process (as demonstrated in Table 2). Therefore, from the basic starting point, some sections of the dominant energy narrative were checked for consistency with respect to multiple network scenarios. For example, Energy Service Companies (ESCOs) was influenced by both Fix It For Me and Dynamic Green Markets. Hence, the broad context for

ESCOs primarily emerged from the Fix it for Me narrative but also drew on some elements of Dynamic Green Markets narrative.

In summary then, a dominant energy narrative was assigned to a network scenario as shown in table 2. The energy narratives were then iteratively reviewed and adjusted to form the broad social, political and environmental context for each network scenario.

The iterative process of review and adjustment was governed by three main rules to ensure the richness and plausibility of the scenarios was not maintained.

- Firstly, the context narrative must be consistent with the network narrative to produce a holistic, internally consistent scenario.
- Secondly, any morphing and adjusting of energy scenario narratives to create the context narratives must be consistent with the themes originally used to create the energy scenarios. I.e. the context narratives are clearly shaped by the underlying driving forces identified by the themes.
- The resulting energy scenario contexts in each merged scenario covered an appropriately broad 'scenario space'. Appropriate broadness of the scenario space is taken to be commensurate with the original draft energy scenarios.

In practice the iterative process leading to the context narratives did not involve wholesale changes to the dominant energy scenarios identified above. Instead there were small steps of focussing and expanding on areas of particular relevance to the network scenario and removing or adjusting areas that were not consistent with the network scenario whilst ensuring the narrative retained clear links to the interactions of environmental concern, institutional governance and consumer participation. In addition, each network scenario was 'broadened' by the inclusion of consistent elements of the other contributing energy scenarios. The final stage of narrative development was to incorporate feedback from the MARKAL modelling exercise, the results of which are described in more detail in subsequent sections. The analysis of the modelling results highlighted some areas of possible feedback into the scenario narratives. This feedback was incorporated where it did not impact the internal consistency and added to the overall plausibility of the narrative. In the few cases where the modelling results contrasted to a stance taken in the narrative the underlying reasons to this are explored and discussed in the modelling analysis.

The merged scenarios are presented in section 4.

3.2 Quantifying the LENS Scenarios through modeling with MARKAL-MED

3.2.1 MARKAL-MED and its application to the LENS project

3.2.1.1 Introduction to MARKAL and MARKAL Elastic Demand (MED)

The MARKAL (Market Allocation) model is a partial equilibrium, least cost optimisation, simulation model, supported by the Energy Technology Systems Analysis Programme (ETSAP), itself an implementing agreement of the International Energy Agency (IEA)[5]. 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. When considering low carbon energy futures it is therefore possible to programme the model to deliver its solution within a predefined exogenous CO_2 constraint (*forcing* the model to choose low carbon alternatives), or to put a price on each tonne of CO_2 emitted (*incentivising* the model to choose low carbon alternatives).

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 an extremely 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

5 See: http://www.etsap.org/markal/main.html

through the projects in which UK MARKAL is employed[6]. In its various forms the model has been used to support UK Government Energy White Papers [14] the Draft Climate Change Bill [15] reports submitted to the G8 Climate Change process [16][17], and has been a key tool employed by the UK Energy Research Centre[7].

The five LENS scenarios are focused on the UK electricity networks, but are also located within a wider energy system and social context. Hence it was decided that the representation of the scenarios within an energy system model such as MARKAL would add richness to their interpretation, by allowing some consideration of whole system interactions and drivers, and the implications of these 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. The version of MARKAL employed in the LENS project is MARKAL Elastic Demand (MED). Some more details of this particular model variant will now be given.

The standard MARKAL model optimization is on (discounted) energy systems costs - i.e. the minimum costs of meeting all energy services. In the figure below this represents the area under the supply curve (producer surplus) where energy service demands are unchanging - i.e. are a straight vertical line.

In MED, these exogenously defined energy service demands have been replaced with demand curves (actually implemented in a series of small steps). Following calibration to a reference case that exactly matches the standard MARKAL reference case, MED now has the option of increasing or decreasing demands as final energy costs fall and rise respectively. Thus demand responses combine with supply responses to any alternate cases (e.g. one with a CO_2 constraint). Demand changes according to individual constant price own elasticities; these can be asymmetric to rises/falls in prices and can change dynamically through time to represent consumer preference. Cross price elasticities are set to zero (i.e. no modal switching).

Now the MED objective function maximises both producer and consumer surplus - the combined areas in the figure below. This includes annualized investment costs; resource import, export and domestic production costs; taxes, subsidies, emissions costs; and fuel and infrastructure costs as before in the standard model. However in addition the MED model calculates welfare losses from

[6] 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

[7] See: http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM2007/ESM.aspx

reduced demands - i.e. if consumers give up some energy services that they would otherwise have used if prices were lower there is a loss in utility to them which needs to be accounted for. This is often used by economists as a valid measure of social welfare. It captures a key economic impact of changing energy prices (although MED does not capture trade and competitiveness effects, or government revenue impacts).

The demand elasticities take the form:
$(D/D_0) = (P/P_0)^{-E}$, where D and P are demand and prices, D_0 and P_0 are reference demands and prices and E is the elasticities which generally vary from 0.24 to 0.61.

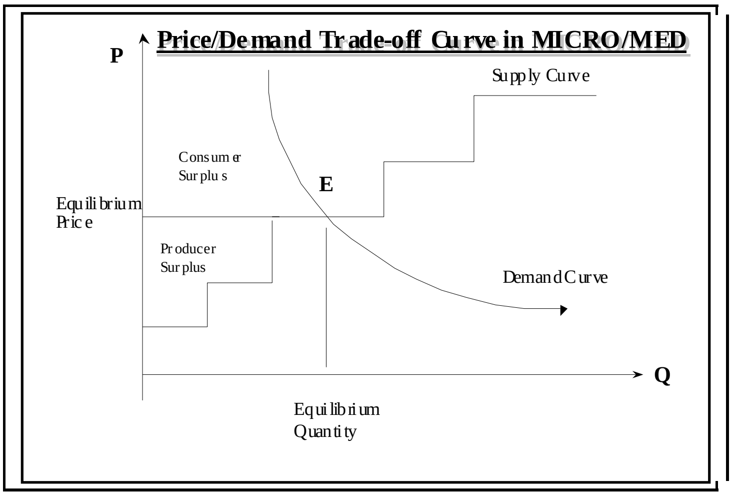

Figure 5 Representation of supply-demand equilibrium in MARKAL Elastic Demand

3.2.1.2 The use and interpretation of MARKAL for scenario analysis

The process of characterising the cost and performance of technologies up to four decades away inevitably admits major uncertainties. Therefore it should be clear that any single MARKAL model run cannot be considered in any way a prediction of the future. The interest is rather in comparing the different outputs which are delivered when the model is run under different assumptions. The process is sometimes described as a 'what if...?' analysis. Each different run embodies different assumptions about the future performance and cost of technologies, levels of energy service demand, global energy prices etc- and the question in each case is 'what if' these assumptions are realised- then what would be the most economically efficient response of the energy system? An equally important part of analysis of any MARKAL run is therefore an understanding of the implications of the assumptions that go behind that run. For example, if a technology which is currently at the research stage is considered by the model to be available to deploy in the year 2020, an important supporting 'off-model' question would be, what needs to happen between now and 2020 in order to make that technology commercially available and justify that assumption?

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 LENS scenarios explore the implications for electricity networks of a range of policy, technological and behavioural drivers. In doing so, they have produced descriptions of possible futures which enter into a very high level of technical detail, specifying in many cases particular generation technologies and particular fuels. One option for using MARKAL as a supporting tool for the scenarios could be in a highly constrained manner- that is, to take the technological descriptions from the scenarios and force MARKAL to recreate them more or less exactly. While such an approach would produce model results which directly illustrate the scenario descriptions, the added value of this in terms of generating insights is limited- it simply generates model results which reproduce exactly what the model has been told to do. An alternative approach is to attempt to reproduce as closely as possible the broad drivers which are indicated within the scenario storylines as being fundamental to the development of each kind of future, without specifying precisely the final technology mix, and seeing what the model comes up with. It should not be surprising under this approach that the model may sometimes come up with different technological solutions. However, rather than necessarily interpreting such a result as the model invalidating the scenario, or vice versa, it should be possible to interpret both outputs in a complementary fashion. Indeed, the differences between what was generated through an intuitive, largely qualitative approach, and a quantitative approach within a classical economic system-wide optimising framework, are likely to throw up some of the most interesting questions in the final analysis. It should be remembered that both kinds of approaches have a certain 'point of view', and therefore that each one can throw light on the other, in particular by way of contrast.

In this context it may be helpful to make some further brief points about MARKAL's particular 'point of view':

- It optimises from an energy system perspective, with equal ability to make interventions across all sectors, according to what is cost optimal for the whole system. It also does so with 'perfect foresight', that is to say it considers each point of data from the whole time period at the same time in calculating a solution, meaning that it cannot be 'surprised' by sudden changes in input data, such as resource price spikes. Therefore it does not fully represent the 'multi-actor' nature of the real energy system, nor does it truly mimic individual investor decisions, or the effect of the political uncertainties or incentives, or the lack of transparent information which inevitably influence these decisions in the real world.[8]

- The optimisation framework means that it is engaged in a 'technology race'- when it finds the cheapest technology it will continue to use it until a physical, policy, technological, or resource constraint forces it not to. It is therefore in general less likely to produce broad technology portfolios, if there is in economic terms a 'clear winner'.
- Its temporal scope extends over a 50 year reporting period. It is therefore less well suited to depicting issues of hour by hour system balancing, such as may become particularly acute with high penetrations of renewable energy. Nonetheless, various system constraints are intended to ensure that the technology mix it produces is broadly compatible with a system which would have the means to balance.

The modelling activity for the LENS project threw up some interesting challenges, as certain aspects of some of the scenarios, in particular the focus on reduced use of the transmission system and distributed generation technologies, have not featured strongly in any previous MARKAL runs. This is because MARKAL will (logically perhaps) tend to try and make use of investments once committed to them (such as the transmission network, which is in the model as part of the calibration with the currently existing system), and also tends to favour the economies of scale of large scale generation, whilst its fairly limited spatial resolution arguably may not capture the full efficiency benefits of smaller scale generation. Despite this, in an effort to see if the model will produce results which reflect some of these scenarios, technology cost and performance assumptions of certain key technologies have been adjusted, in some cases quite substantially, from the base data. Most of these assumptions are optimistic, and arguably, some might be considered somewhat speculative. However, as long as the assumptions are made transparent, this is not incompatible with a 'what if...?' approach, as described above. More specifically, the intention of this project was not to produce a set of runs whose inputs are all safely within the central band of uncertainty. Rather it was to push certain data to the margins of these bounds, to consider technological discontinuities and breakthroughs, and the extent of the impacts that these could have on the electricity networks. In the tradition of scenarios, the intention is not to focus only on the most probable, but to scan the entire 'possibility space'. For the modelling work, the key point is to be transparent about the assumptions that have been made, and to consider the implications of these assumptions alongside the final results, when trying to draw insights from the process. The input assumptions which were made to generate the range of alternative runs in support of the scenarios are explained in the following section.

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[8] However, such barriers are to a certain extent accounted for by applying different discount rates in different sectors, as described in more detail below

3.2.1.3 Linking scenarios to model runs- the process of developing model input data

In order to avoid confusion, in the specific context of this report the different results of the model shall be referred to as 'model runs'. These are of course each directly related to one particular LENS scenario; however, the term 'scenario' shall in this report be reserved for the qualitative scenario storylines developed for the LENS project, on which the model runs are based. Whilst the equivalent model runs and scenarios are intended to be complementary and very strongly linked, it is nevertheless useful to maintain the distinction, as they are different approaches which can deliver different kinds of insights.

The approach of the LENS project was that detailed qualitative scenarios should be developed through an in depth process of literature review and stakeholder engagement, and that once developed in some detail, these scenario storylines should direct the modelling process. This is something of a contrast to most other processes where models have been used in combination with scenarios. Such approaches have tended to use a model to generate a set of scenarios, these scenarios being entirely defined and parameterised by the results of the model runs.[9] The process of working back from qualitatively defined scenarios to derive comparable quantitative model runs has its own particular challenges

The LENS scenarios are complex and multi-faceted, with numerous broad societal drivers acting simultaneously and in different ways. In modelling terms, this involves the simultaneous variation of a number of separate parameters. Given the sheer quantity of information within a model such as MARKAL, such an approach can present challenges in the interpretation of results, as it may be not always be immediately clear which of the numerous changes implemented in each run of the model is most significant in producing the different results. However, such issues tend to become clearer when the full set of runs can be compared with each other, hence this report also includes a short discussion drawing out insights from across all model runs.

It is important to distinguish, and the ensuing discussion will endeavour to maintain this distinction, between model inputs and model outputs. Certain aspects of the LENS scenarios were selected as providing a basis for making changes to model inputs, for any particular model run. On the whole, these have tended to be about policy drivers, technological development, and lifestyle changes. In other words aspects of the scenario have provided justifications for altering the advantages and disadvantages of particular options available to the model within each run. The actual mix of technologies selected, levels of energy consumed, and extent of any demand side responses, are almost always model *outputs*. (The main exception to this general rule is the Multi purpose networks

[9] A well known example of this approach is the IEA's Energy Technology Perspectives report, which also uses a version of the MARKAL model.

run, due to the specific modelling challenges of representing that particular scenario, as shall be described). Given the changes in the advantages and disadvantages of the various options, the model makes its own selection of the optimum technology mix. Of course, such aspects of technology mix, though model outputs, are also well defined within the scenarios. As the model has been given autonomy over these aspects, this is where differences between model runs and scenarios may arise. However, as described above such differences are considered to be useful and interesting points of challenge to a better understanding of the implications of both the model runs and the scenarios.

Some more specific points relating to different kinds of model inputs are discussed below:

- Energy service demand reductions are in modelling terms a response to price. However in this project they are also interpreted in conjunction with raising the carbon price itself, to cover scenario descriptions which imply that energy service demands could be altered as a result of cultural and lifestyle changes.
- Assumptions about improved performance and reduced cost of key technologies are important input assumptions in all runs. Needless to say, such assumptions stray into areas of considerable uncertainty. However, these are 'what if...?' assumptions which are nevertheless consistent within the background of the appropriate scenario storyline
- The MED model does not give direct insights on GDP growth and other macroeconomic parameters; it does however enable comparison of welfare losses applying to the energy system, which may pose questions about the implications of such losses in broader macroeconomic terms
- For the model, the carbon price is the key driver relating to environmental concern, and the level of this price is varied through the model runs. The different scenarios interpret how this 'price' is generated in different ways- for example through regulations, carbon markets, or other market based instruments. In general the operation of specific policies is less explicitly defined as quantitative inputs into the model; nonetheless many of the model inputs, including the carbon price, as well as technology specific characterisations, implicitly carry assumptions about the kind of policies that would be necessary to support them, and these assumptions are grounded in the scenario storylines.
- As has been discussed above, this grounding of model input assumptions within the scenario storylines involves the simultaneous variation of several factors in as consistent a manner as possible. For example a world with high environmental concern is considered likely to be able to engage greater participation and deeper systemic change in infrastructure, which is why the scenarios which entail the biggest infrastructure and behavioural changes coincide with the highest carbon price. This is not to say however that a 'Big T&D' type scenario is inherently inconsistent with

a higher carbon price and lower CO_2 emissions. Such a scenario has been well explored in a range of previous MARKAL work, including for Energy White Papers.

Now the input assumptions which lie behind the various MED runs for the LENS project will be explained.

3.2.2 Input assumptions for MARKAL-MED model runs

3.2.2.1 The Reference Case

Every MARKAL process begins with the running of a 'reference case' from which further model runs are varied, and ultimately compared to. The LENS reference case was run 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. In the LENS reference case there is no carbon constraint, and the carbon price remains constant at £14 / tCO2 throughout the period. The results from this reference run are not presented in this report, as they do not correspond to any one of the LENS scenarios. However, the reference run is used to provide a reference point for the other scenarios in terms of CO2 emissions reductions, and changes in welfare for those runs employing the elastic demand function. It is also worth noting some other key aspects of reference case data which carry through all other runs unless defined otherwise in the input data sections below.

Resource supply curves

Domestic and imported fossil fuel resources are represented through supply curves rather than discrete values. This table, with data taken from DTI (2006) indicates the range of fossil fuel input prices which are translated into prices for the various supply steps, and for imported and refined fuels.

Year	Baseline			High Prices			Low Prices		
	Oil $/bbl	Gas p/therm	Coal $/GJ	Oil $/bbl	Gas p/therm	Coal $/GJ	Oil $/bbl	Gas p/therm	Coal $/GJ
2005	55.0	41.0	2.4	55.0	41.0	2.4	55.0	41.0	2.4
2010	40.0	33.5	1.9	67.0	49.9	2.4	20.0	18.0	1.4
2015	42.5	35.0	1.9	69.5	51.4	2.6	20.0	19.5	1.2
2020	45.0	36.5	1.8	72.0	53.0	2.6	20.0	21.0	1.0
2025	47.5	38.1	1.9	77.0	56.0	2.6	22.5	22.5	1.1
2030	50.0	39.6	2.0	82.0	59.0	2.8	25.0	24.0	1.2
2035	52.5	41.1	2.1	82.0	59.0	3.0	27.5	25.5	1.3
2040	55.0	42.6	2.2	82.0	59.0	3.0	30.0	27.0	1.3
2045	55.0	42.6	2.2	82.0	59.0	3.0	32.5	28.5	1.4
2050	55.0	42.6	2.2	82.0	59.0	3.0	35.0	30.0	1.5

Table 4 Exogenous fossil fuel import prices

It is noted that these prices would now be considered somewhat low; for example those projected by BERR in a recent Energy Price Projection update would imply significantly higher long term fuel prices[10]. For the electricity generation mix, higher resource prices would be likely to have the strongest impact on the use of natural gas, for which fuel costs are a large proportion of overall costs (as opposed to coal for example, for which capital costs dominate). Of course, higher resource prices would have less of an impact on model runs which were driven by a high carbon price, and thus were already investing strongly in renewables and alternative transport technologies. Nonetheless, they could have significant effects on the use of natural gas in the residential sector.

It should also be stressed that setting resource prices within a long range model with perfect foresight admits major uncertainties, but that these should be considered as long term averages, and should not attempt to track short term price fluctuations.

Policies

The Renewables Obligation is represented within the model, increasing from its current level to 15% in 2020, where it remains constant to the end of the period. A carbon price representing the EU ETS remains constant at £14 / tCO2 throughout the period in the reference case (this price then becomes a lever to represent a suite of carbon policies and more general 'environmental concern' within the other model runs). Other policies and measures are represented to the level at which they were agreed as at 2006, and include the Climate Change Levy, Hydrocarbon duty, transport fuel duty, LCP directive, Energy Efficiency Commitment, buildings regulations (not including the Code for Sustainable Homes). For further details, see Strachan et al (2006) [18].

10 See: http://www.berr.gov.uk/files/file46071.pdf

Energy service demands

Standard energy service demands (before demand elasticities) are based on BERR and DfT projections [19][20]. These demands already account for legislated programmes (such as the energy efficiency commitment (EEC) phase 1 and 2 through to 2020). Demands are subsequently disaggregated further into specific end uses or sub-sectors. Annual increases in energy service demands are given in Table 5. For further details, see Strachan et al (2008) [21] and Kannan (2007) [22].

		2000 - 2030	2030-2050			2000-2030	2030-2050
Industry	Chemicals	0.44%	0.19%	Service	Cooking	0.11%	0.00%
	Iron & steel	0.44%	0.19%		Cooling	1.50%	0.91%
	Non ferrous metals	0.45%	0.18%		Other electrical	0.41%	0.31%
	Other industry	0.44%	0.19%		Space heating	0.00%	0.00%
	Paper & pulp	0.44%	0.19%		Water heating	0.05%	0.07%
Residential	Cooling	9.13%	2.73%		Lighting	0.33%	0.42%
	Other Electrical	0.88%	0.52%		Refrigeration	0.04%	0.00%
	Space Heating	0.70%	0.04%	Transport	Air (domestic)	4.13%	4.30%
	Water Heating	0.50%	0.31%		Bus	0.97%	-0.10%
	Lighting	0.83%	0.49%		Car	1.09%	0.39%
	Refrigeration	0.84%	0.49%		Rail freight	0.94%	2.52%
	Cooking hob	0.83%	0.49%		HGV	0.93%	0.14%
	Cooking oven	0.83%	0.49%		LGV	1.60%	1.28%
	Chest freezer	0.72%	0.43%		Rail passenger	1.16%	2.76%
	Fridge freezer	0.86%	0.51%		Shipping (dom)	0.11%	0.51%
	Upright freezer	0.98%	0.57%		Two wheels	1.44%	-0.48%

Table 5 Annual growth of energy service demands in reference case

Discount rates and hurdle rates

The reference case employs a market discount rate of 10% to trade-off action in different time periods as well as annualise technology and infrastructure capital costs. It therefore reflects the expected rate of return an investor would have for investment in any technology. This 10% market discount rate is higher than a social rate of time preference (3.5%). It is also higher than a risk free portfolio investment return and accounts for the higher return that investors require to account for risk. The 10% discount rate is a standard 'default' figure which applies to investments throughout the model. However, there are some exceptions, notably for conservation and efficiency options in the buildings sectors and advanced technologies in the transport sector. Here, the reference case uses technology specific 'hurdle' rates which reflect non-cost barriers to uptake, and effectively raise the required rate of return on capital. Inter-temporal trade-offs as well as variable costs continue to use the model discount rate. Hurdle rates apply only to capital costs and thus effectively increase the investment barriers to these new technologies. Set at 15%, 20% and 25% these hurdle rates represent information unavailability, non price determinants for purchases and market imperfections (e.g., principal agents issues between landlords and tenants). Therefore, for certain runs, as will be described below, these hurdle rates have been reduced on key technologies, to account for the effect of a policy or regulatory development which is able to overcome such market imperfections.

Technologies
As has been mentioned, the reference case uses a vast database of energy system technologies. This database is constantly being refined and updated, but documentation on recent UK MARKAL databases is available at: http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM2007/ESM.aspx

The vast majority of this technology database remains unaltered through all LENS runs. The focus is rather on changing the assumptions behind a relatively small number of key input parameters, to analyse their potential impacts on electricity networks.

3.2.2.2 Big Transmission & Distribution

This scenario has fewest additional changes compared to the base case. However, the 'moderate environmental concern' of the scenario justifies a relatively low carbon price, and adjustments are made to facilitate investment in large scale infrastructure.

- Carbon price- rises to £30 / tCO2 by 2050. Applies to electricity and industry sectors.
- Energy Service demand- increases as in reference case (no Elastic demand).
- Interconnectors and capacity upgrades- capacity and activity constraints on imported electricity doubled compared to reference case.
- An upper constraint remains in place on plug-in hybrid vehicles, as do all hurdle rates on new technologies.

3.2.2.3 Energy Service Companies

The scenario storyline describes a society with higher environmental concern, and consumers who desire to see environmental issues addressed. Nonetheless they remain passive in their attitudes to energy supply, requiring 'uncomplicated' services. It is postulated that the responsibility for reconciling these positions will fall to Energy Service Companies who will deliver lower carbon energy to consumers without requiring active participation from them, and will extend to a range of services including vehicles

- Carbon price- rises to £60 / tCO_2 by 2050. This represents the somewhat higher level of environmental concern than in Big T&D. However, because this society is less amenable to major systemic change the carbon price is still not applied beyond the electricity and industry sectors.
- Energy Service demand- increases as in Base scenario (no Elastic demand). This indicates an unwillingness to reduce energy service demand by changing behaviour, even if it means paying more for low carbon energy services.
- No upper bound on electric battery and plug in hybrid vehicles- these were in place in the reference case to avoid unrealistically fast take up. The assumption is that ESCOs could provide ways of improving the access to market and supply chain for these technologies.
- Battery electric cars and plug in vehicles- higher discount rate (hurdle rate) applied to these technologies in reference case is reduced to standard Markal discount rate (DR) of 10%. This represents the role of energy service companies in reducing risk, overcoming market barriers, and access to information, by offering electric transport vehicles as part of electricity services package.
- Residential solar PV- 50% capital cost reduction; improved seasonal availability factors; contribution to peak moved from 0 to 0.1. These assumptions are intended to represent a significant breakthrough in the cost of PV panels through novel processes such as organic thin film, improved efficiency, and some form of storage to allow more controlled and predictable output, which enables some contribution to peak load to be guaranteed. The ESCOs would have a role in delivering these developments, both by capturing cost reductions through economies of scale, and through creating a strong market to incentivise RDD&D in PV technology.
- Residential micro-wind- 15% capital cost reduction; availability factor moved from 0.2 to 0.25. This assumes that significant reductions in installation costs could be brought about through the economies of scale available to ESCOs as opposed to individual consumers. The improved availability factor would reflect improved efficiency of devices and some form of storage or aggregated electricity regulation to allow more

controllable output.

- A maximum activity constraint was also imposed upon microwind, to ensure realistic deployment levels accounting for geographical constraints. Research for the Energy Saving Trust[11] suggests that 4% of UK electricity generation could come from microwind. 4% of the final electricity generation figure of the Big T&D run (1642 PJ) was calculated as 66 PJ, or approximately 18 TWh per year, and this figure was imposed as the upper activity level for microwind.
- Micro CHP- 25% capital cost reduction; assumes technological improvements and economies of scale.
- Micro hydrogen fuel cell CHP- 25% capital cost reduction; assumes technological improvements and economies of scale.
- Residential technologies- upper bounds removed on CHP, district heating, heat pumps.
- Service sector- efficiency and energy conservation options added (2SERCO2).

3.2.2.4 Distribution System Operators

The DSO scenario storyline describes a society where 'tackling climate change is at the forefront of UK energy policy'. There is a developing tendency for the government to take interventionist action, picking technology 'winners' to achieve its goals, most notably in a concerted push for a hydrogen economy. The environmental concern penetrates to all levels of society, as increasingly 'leisure activities and consumer preferences are influenced by environmental attitudes', implying the potential for significant changes in energy service demands as a result of lifestyle changes. There is also the growth of more active distribution networks which relieve pressure on the transmission grid. It has been shown from past experience that this is an option which MARKAL is unlikely to spontaneously choose. As discussed above, it prefers to use existing infrastructure, and sees the benefits of large scale generation. Therefore it was necessary to deploy an exogenous constraint in order to represent this effect within the model.

- Carbon price- rises to £100 / tCO2 by 2050, and is extended from electricity and industry to cover also residential, service and transport sectors. This is based on the perception that environmental concern is pervasive enough for all social actors to shoulder some responsibility. It

[11] See: http://www.energysavingtrust.org.uk/uploads/documents/aboutest/Microgeneration%20in%20the%20UK%20-%20final%20report%20REVISED_executive%20summary1.pdf

also reflects that the government's drive for a hydrogen economy is specifically motivated by reducing carbon, hence it would be likely to ensure that the transport and residential sectors are also regulated by carbon based legislation.

- Energy Service demand- elastic demand function is activated to allow behavioural response of energy service demand reduction, implying a flexibility to accept different levels of energy service.
- Reduced use of transmission system- in order to reflect a system with less reliance on large scale transmission, the total flow of large scale electricity generation to residential and service sectors is constrained. A gradually ramped down constraint reaches its tightest level in 2030 and remains there for the duration of the period. For each sector this level is 2/3 of the total amount of electricity distributed to them in reference case in 2050. That is, for residential 390 PJ, and for services 240 PJ.
- Hydrogen- capital cost of small scale electrolysis reduced to 23% of former cost, equivalent to $164/kW. This assumption would obviously represent a major breakthrough, but it is based on the most optimistic industry estimate (see http://www.itm-power.com/). In line with the assumptions about the reduced use of the transmission system, a bound of 100 PJ / a on the distribution of large scale electricity for hydrogen electrolysis has also been applied.
- Hydrogen Fuel Cell Vehicles- Fuel cell cars and buses have increased efficiency compared to the reference case. Efficiency is rated at three times that of ICE equivalent vehicles, based on upper end of IEA conclusion that fuel cell vehicles are two to three times more efficient than equivalent ICE vehicles (IEA, 2005, p. 97). The capital cost inputs for hydrogen fuel cell buses remain as in reference case. For fuel cell cars the capital cost begins at the same level as the reference case, then set at 50% more than ICE equivalent vehicles in 2020 (based on IEA, 2005, p. 103). After this the costs decline linearly to eventually reach parity with ICE equivalents in 2050 (optimistic assumption for technological development). All of the above inputs assume significant technology development, with strong government push and major involvement and interest of private sector in developing technologies. The eventual decline in cost to parity with ICE equivalents assumes the interest becomes so strong that a technology race develops between car manufacturers, as well as major economies of scale.
- Discount rates of H2 cars and buses set to Markal standard. This assumes a coordinated push for H2 economy means inertia and risk aversion regarding these technologies is less prevalent.
- Discount rates, technological performance and cost reduction for microgeneration, CHP and small scale technologies same as in ESCOs.

3.2.2.5 Microgrids

The Microgrids scenario storyline describes a world where 'climate change will be at the forefront of decision making for individuals, communities, private companies, public institutions and the Government in the UK'. There are tough targets for CO2 reduction, and UK action is taking place within the context of global consensus on the need to reduce carbon emissions, which both reinforces the willingness to set strong targets, and stimulates the global development and deployment of low carbon technologies, which brings down cost and improves performance. Consumers are 'active' in their use and interaction with energy supply, motivated to develop their own sources of energy, and to operate demand side management technologies for peak smoothing. There is an 'overall government strategy supporting distributed energy and energy efficiency', and microgeneration is strongly promoted, reducing the quantities of electricity that flow through large scale transmission. Once again, in order to represent this in MARKAL, an exogenous constraint on the transmission network has been applied.

- Carbon price- rises to £135 / tCO2 by 2050 reflecting the high and pervasive environmental concern. As in DSO, the price applies to electricity, industry, residential, service and transport sectors.
- Energy Service demand- elastic demand activated to allow behavioural response of energy service demand reduction. The high carbon price may stimulate greater demand reductions than in DSO, which reflects the even more pervasive societal concern.
- Highly reduced use of transmission- in order to reflect a system with even less reliance on large scale transmission, the total flow of large scale electricity generation to residential and service sectors is constrained. A gradually ramped down constraint reaches its tightest level in 2030 and remains there for the duration of the period. For each sector this level is 1/3 of the total amount of electricity distributed to them in reference case in 2050. That is, for residential 195 PJ, and for services 120 PJ.
- Residential solar PV- further increased seasonal availability factors; investment cost 25% of Base; peak contribution raised to 0.5. These greatly improved parameters would represent a major breakthrough in PV technology, greatly improved efficiency and advanced forms of energy regulation and / or storage at the distribution or microgrid level, to enable the aggregated output of residential solar PV to be considered more reliable in its contribution to peak load. Thus these assumptions also incorporate the scenarios descriptions of consumers with IT facilitated advanced control technologies, as well as some form of storage capability
- Microwind and other small scale technologies- inputs same as DSO and ESCO.
- Micro CHP- capital cost 50% of reference case data. Assumes major

technological breakthrough.

- Fuel cell micro CHP- starting capital cost 50% of reference case data and declines by 10% each 5 year period. Assumes major technological breakthrough and continued development.
- No bounds on CHP or district heating- same as in DSO and ESCO.
- Transport- the improvements to electric vehicles in ESCO and hydrogen vehicles in DSO are here combined. The assumption is that due to the global consensus on the need for reducing emissions, a major priority is given towards developing low carbon technologies, resulting in both options being developed and competing for the market.

3.2.2.6 Multi Purpose Networks

This scenario storyline describes conflicting policy signals, and a pervasive feeling of uncertainty and ambiguity within society over environmental issues. As well as environmental concern, the government is also responding to security of supply issues. Different attempts at different times have been made to exploit and push for a variety of energy technologies. This has resulted in a system which is diverse both in terms of electricity generation type and network arrangements. This storyline is the hardest to represent within the MED model. This is mainly related to the fact that being a linear programming optimisation model it has perfect foresight- that it is, it assesses the period as a whole, including all input parameters at every time period, to find the optimal solution over the entire period. This means that it is not possible to directly represent in MARKAL the effect of uncertainty, shocks, or unexpected policy changes. In order to represent the diversity of both networks and generation mix within this run, the approach has been somewhat different to the previous runs. It has involved forcing the model to build capacities of certain groups of technologies in different periods, representing conflicting government led drives for the technology groups at different times.

- Carbon price- rises to £70 / tCO2 by 2035 then declines to £30 / tCO2 by 2050. This indicates a changing level of concern about CO2 emissions. However, it is important to stress once again, that due to its 'perfect foresight', this price decline is foreseen by the model.
- Energy Service demand- increases as in Base scenario (no Elastic demand). The ambiguity of the perception of environmental issues is such that consumers would not accept significant lifestyle changes
- Small scale generation technology assumptions are the same as in Energy Service Companies, allowing for the scenarios description that microgeneration is installed in some regions.

- The following technology groups are forced in to reach 15% of installed capacity at different points in the time period:
- Wave and Tidal (2035); Nuclear (2025); Gas (2015); Wind (2030)
- These inputs represent the assumption that different governments will pursue different approaches to energy policy, and will attempt to create favourable conditions for different technology groups.

3.3 Developing Way Markers

Consideration of the pathway along which a scenario develops is a key component of the scenario itself. The plausibility of the LENS project scenarios in 2050 is inextricably linked to the plausibility of the pathway from now until 2050. To address this issue of plausibility it is important to describe aspects of the pathway along with the remainder of the scenario narrative.

In addition, users of scenarios often monitor current and near future developments to understand which scenarios seem to be emerging as time passes. Current events and trends can be compared against descriptions of scenario pathways to better understand the progression towards particular scenarios.

In the LENS project, three key themes were selected to describe the direction in which society in general and the energy and electricity sectors in particular would develop. In addition to these main themes and the various other issues that were identified at the 'gathering input information' stage of the project it was always intended to identify and set out a set of 2025 way-markers to establish a more tangible set of descriptions of the pathways at one point in time (2025). The way-markers are not intended to sit separately from the scenarios for the reasons given above but are intended to more explicitly describe the situation in 2025 from the perspective of what would need to or could be happening by then as a precursor to the 2050 end-points that are a major component of the scenarios.

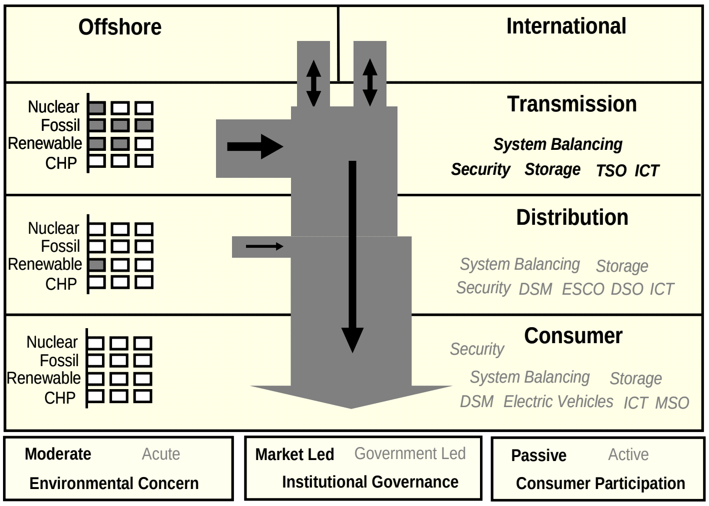
The 2025 way-markers have been generated by inspection of the content of the 2050 scenario narratives and the modeling results and projecting backwards from there (back-casting) and forwards from the present to identify likely developments in 2025.

4 Draft Electricity Network Scenarios for Great Britain

This section introduces the merged and refined scenarios developed in the third phase of the LENS project. Each scenario is accompanied by a schematic illustration and pictogram designed to convey the key messages from each scenario.

The schematic illustration serves several purposes:

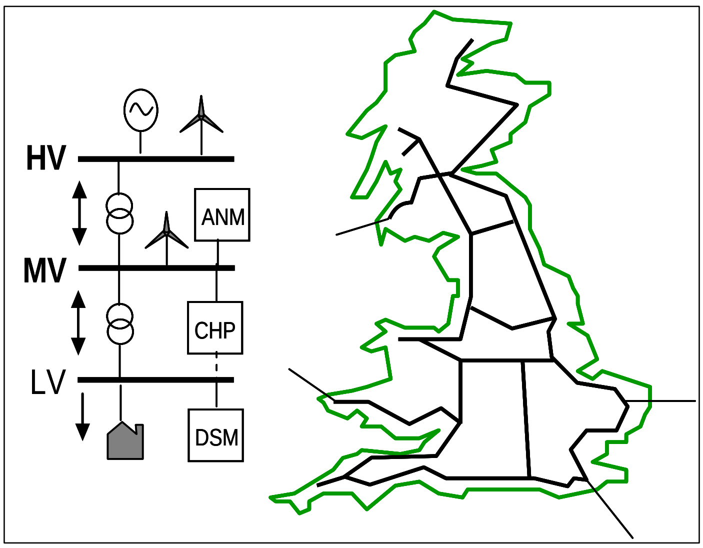
- The grey boxes on the left hand side indicate the volume (High, Medium, Low) for each of the main sources of generation connected to that element of the network. i.e. Transmission, distribution, consumer.
- The width of the flow diagram indicates relative volume of power for non quantitative comparison with other scenarios and 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 activities such as system balancing, where they are less likely this is indicated in light grey rather than black
- The headings at the bottom in bold indicate the main themes for each network scenario where they are less likely this is again indicated in light grey rather than black.

The pictogram also serves several purposes:

- It indicates the main forms of generation and technology expected to feature.
- The line thickness of the geographic network represents the volume capability required for Transmission and Distribution.



- The three level network representation indicates at which level the emphasis on complexity of management and control lies. The emphasis is indicated by bold text.

4.1 Big Transmission & Distribution

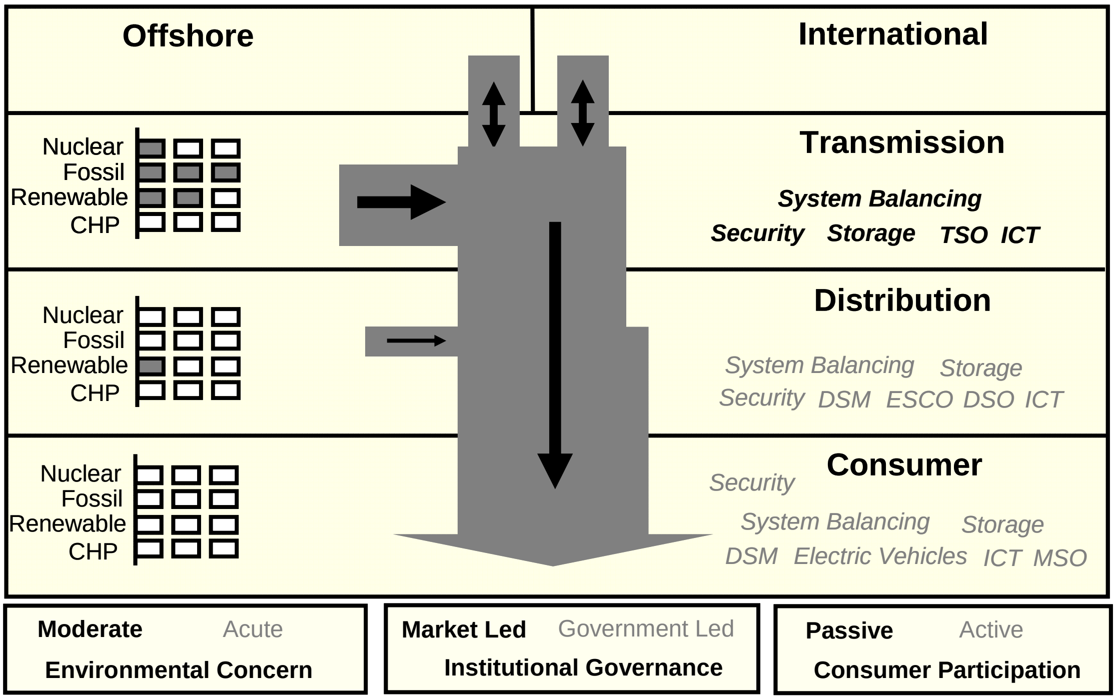


Figure 6: 'Big transmission and Distribution' scenario schematic illustration.

TSOs are at centre of networks activity

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

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

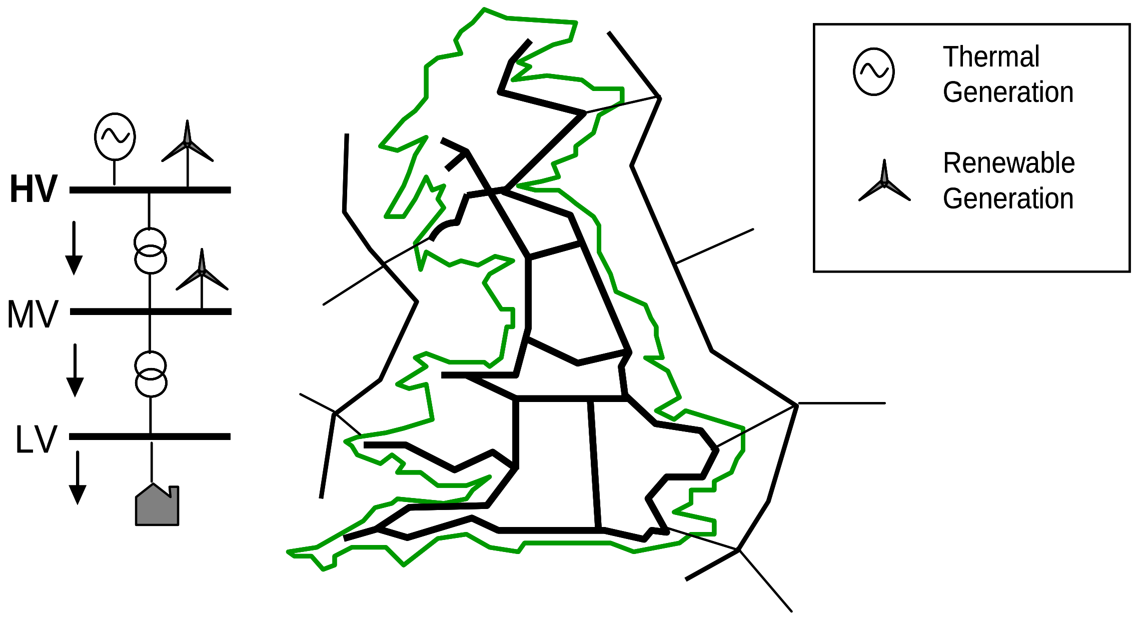


Figure 7: 'Big Transmission and Distribution' network pictogram.

4.1.1 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 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.

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. 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 creates 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.

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

Light regulation and market incentives would be used to address the moderate environmental issues, promote competition and protect the interests of consumers. This would include market mechanisms such as renewables obligations 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 to decide and the long-term security issues might find their way into markets through price premiums for secure sources of energy. Initial development of technology to address the environmental issues would fall away and development will then be focused on competition and efficiency.

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 CO_2 emissions and would feel on track to meet them with initial measures or would be less concerned about the impact of not meeting them. Public expenditure in this area is likely to be limited by a reduced urgency to meet environmental goals. Energy generation and use will not undergo a dramatic change in direction in that the focus will remain on centralised solutions. Energy policy will be mainly addressing the demands of the economy and consumer lifestyle. The environment will remain a consideration and will not be sacrificed for the sake of the economy but it will not be the overriding consideration. Government will set boundaries to ensure environmental issues are considered, however energy policy will be mainly addressing security of supply, competition and quality of supply.

The economic situation is moderately healthy with slightly lower levels of growth than recently. This and the reducing 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. The slower economic environment combines with lower investor confidence and a focus on optimising existing technology and innovation to enhance the capability of the existing infrastructure. Consumers are largely passive but would need to be careful of their spending on energy and would look for increased efficiency to translate into reasonably priced energy.

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. This will predominately stay fossil fuel based although efficiency will be improved and hybrid electric vehicles will slowly penetrate the market providing much improved emissions levels. Rail will gradually become totally electric. Public transport will be improved and there will be some movement to increased use in urban areas. 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 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.

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

Metering and charging will be a passive process for consumers. Their supply company will be given responsibility and the consumer will pay little attention as long as costs remain within expected boundaries. Consumers will be unlikely to be looking for additional services from their supply company to reduce environmental impact. There may be a gradual development towards more detailed metering providing accurate usage information and using developments in home telecoms to automate readings and billing. This will mainly be a result of natural technological development and a desire from supply companies to optimise efficiency rather than as a result of consumer demand, however there will be groups of consumers who embrace this as an opportunity to help regulate energy consumption.

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

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

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

4.1.2 Network

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

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

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 development 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 i.e. 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 power systems on system operations is also much enhanced with joint codes for operations and much more dynamic exchanges of information and coordinated responsibility across borders. This provides the opportunity for securing supplies whilst making the most of the indigenous resources in the European area with exchanges beyond Europe (e.g. Russia and Middle East for gas and Africa for renewables such as solar power).

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

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

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

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

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

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

4.1.3 Modelling results

Primary energy demand across the system as a whole is quite level over the whole time period, as increased service demands are offset by more efficient technologies. However the electricity sector grows strongly from 1288 PJ generated in 2000 to 1652 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.

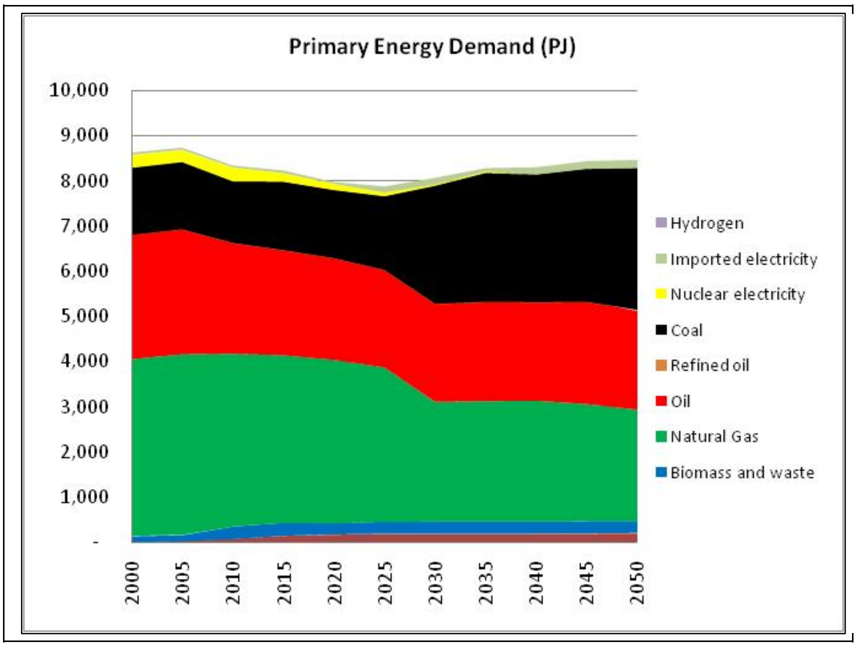


Figure 8 Big T&D Total Primary Energy Demand, 2000-2050

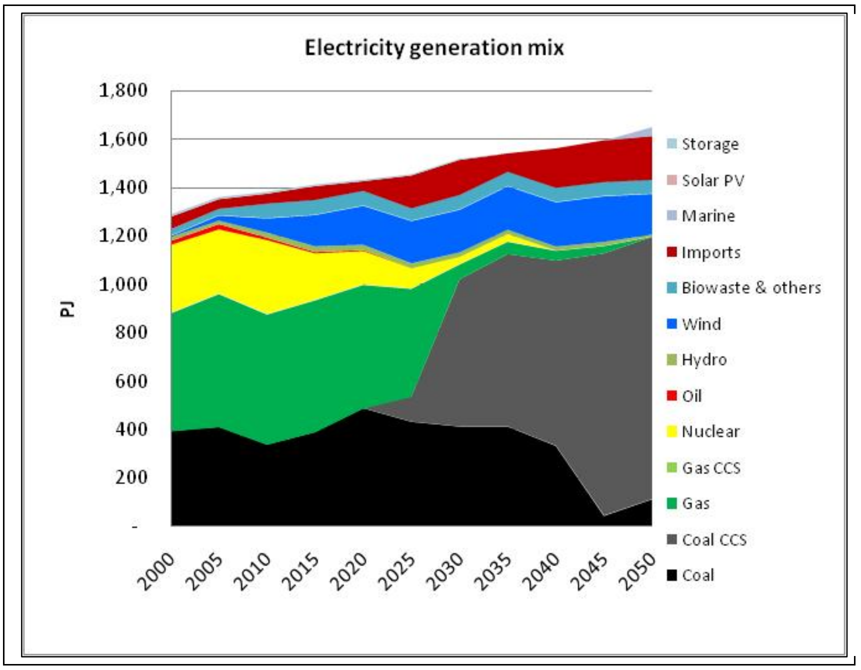


Figure 9 Big T&D Electricity Generation Mix, 2000-2050

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. 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.

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 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.

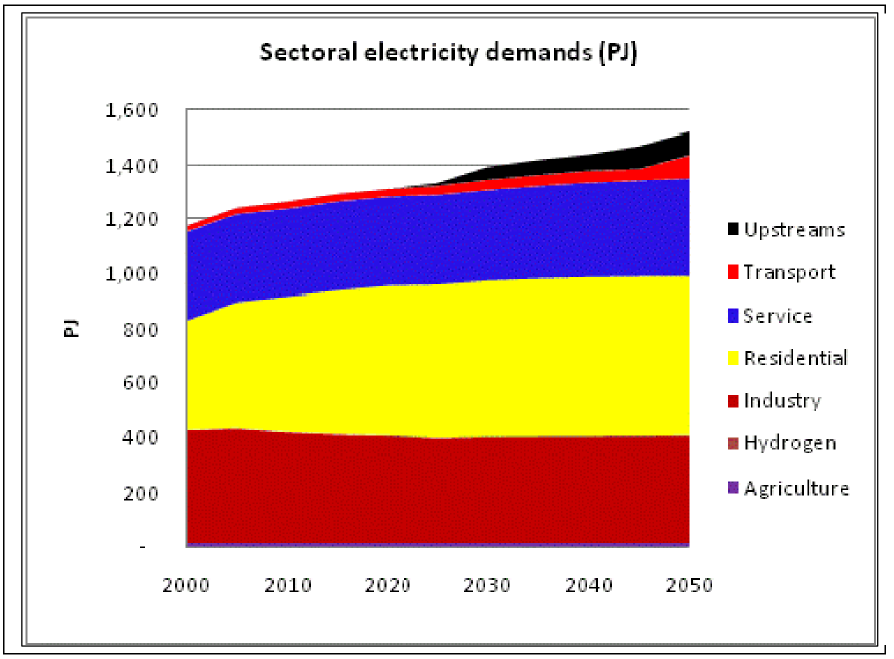


Figure 10 Big T&D Sectoral Electricity Demands, 2000-2050

This model run delivers modest decarbonisation achieving a 51% CO2 emissions reduction in 2050 from 2000 levels within the electricity sector, and a 24% 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.

Relation of model run to scenario

The model's focus on large scale generation and transmission infrastructure reflects the scenario storyline. The 'initial surge' in low carbon generation in response to government carbon policies described in the scenario is reflected in the fast installation of CCS in the middle of the period, which plateaus by the final decade, reflecting a levelling off of the carbon price, implying a slowing down in policy initiatives. The model also depicts an evident, though relatively slow and niche focused, take up of electric vehicles, as described in the scenario.

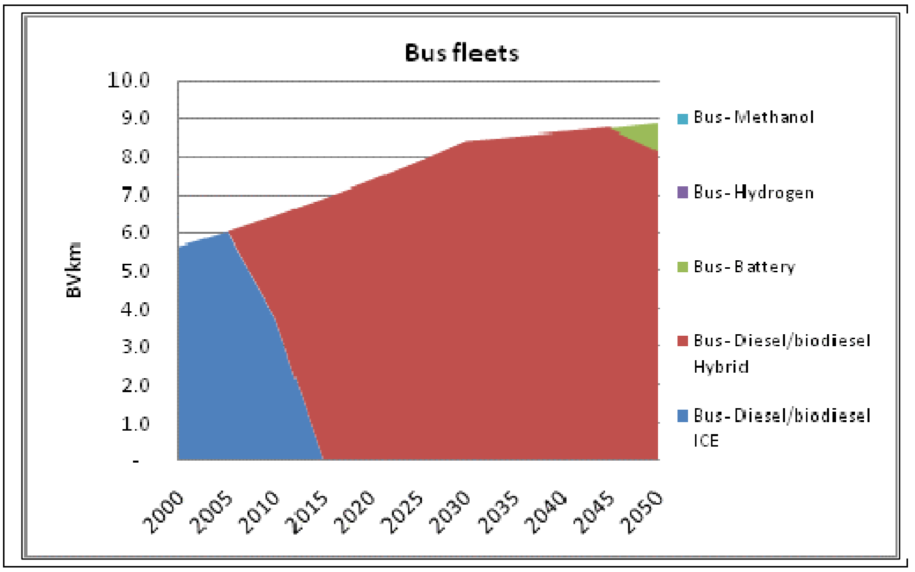


Figure 11 Big T&D Bus fleet technologies 2000-2050

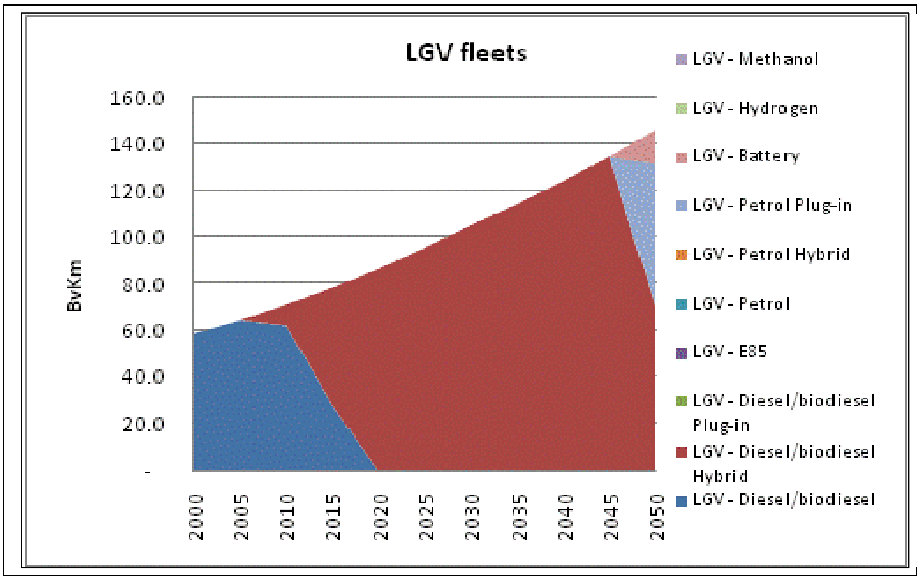


Figure 12 Big T&D LGV fleet technologies 2000-2050

The largest differences are in the precise kinds of large scale base generation technologies which are selected. The scenario sees moderate carbon concern, though without a more stringent 'deep green' philosophy bringing on a range of large generating technologies, including gas CCGT, coal with and without CCS, and nuclear. As has been discussed above, as the model cost optimises it is likely to overwhelmingly prefer one of these broadly comparable technologies, and nuclear is the main loser in this run, though gas still maintains a role for flexible plant. The preference under higher carbon prices for coal CCS rather than gas CCS is driven by the moderately high resource prices, gas powered generation being more sensitive to higher fuel costs. It is also due to competing end uses for gas, which is used for direct heat in residential and industry sectors, the model's preference indicating that it finds this a more cost effective allocation of resources than to use gas for electricity generation. In its wide use of gas for space and water heating, the model run confirms the scenario's description.

Generation type		Network	Installed capacity (GW) in year:	
			2025	2050
Large thermal (no CCS)		T&D	40	27
Large thermal (CCS)		T&D	4	41
Nuclear		T&D	3	0
Large wind	Offshore	T&D	7	7
	Onshore	T&D	5.6	5.4
Marine		T&D	0	3
Other large renewable		T&D	18	4
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	5	11
CHP	Large (industrial / commercial)	T&D	3	2
TOTAL T&D			86.6	101.4
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only		
TOTAL DISTRIBUTION ONLY			0	0
TOTAL			86.6	101.4

Table 6 Big T&D Installed Capacities by network connection – Draft results

A more detailed discussion of these points is contained in Appendices A and B (sections 7 and 8).

4.1.4 2025 Way-markers

The way markers identified for 2025 in this scenario are:

- 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.
- 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.
- 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.

4.2 Energy Service Companies

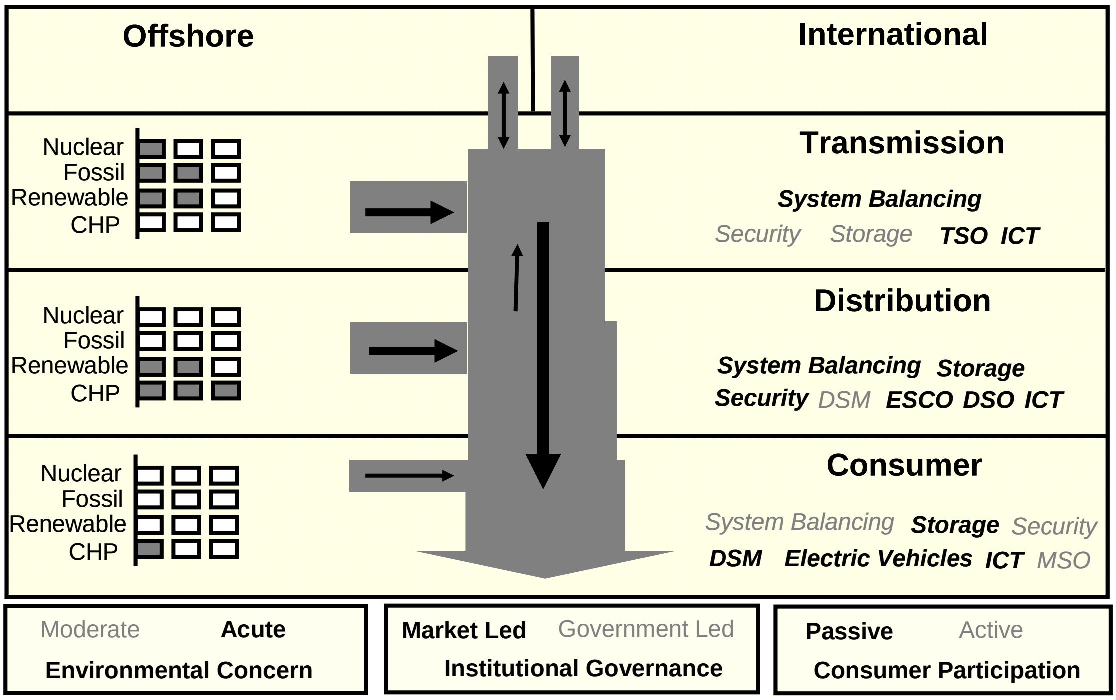


Figure 13: Energy Service Companies' scenario schematic illustration.

ESCOs are at 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 strongly feel this is the responsibility of industry and Government to solve. This high level of passivity from consumers is one of the defining features of this scenario with the majority of people being concerned about the environment but strongly believing that it is the duty of others to sort it out.

- Consumers remain relatively passive towards their energy supply and while the majority of people are concerned about the environment they strongly believe that it is the duty of government and the market to address the issues.
- Although the belief persists that markets are best placed to service consumer demands at the same time as meeting social and environmental needs, strong intervention is not ruled out to address environmental issues.
- The potential for markets to meet the energy services demands of consumers is met through the emergence of energy service companies (ESCOs).
- Centralised electricity generation 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 power networks is to support a vibrant energy services market. The transmission and distribution infrastructure is required to support a super-supplier or energy services company (ESCO) centred world.
- ESCOs do all the work at the customer side and the transmission and distribution networks contract with ESCOs to supply network services, allowing the network companies to operate the networks more actively.
- There are wide ranging developments and vibrant markets in energy services including micro-generation, on-site heat and power, demand side management, telecommunications and electric vehicles.
- The services supplied by the networks include transmission system connection to strategic, large scale renewables and also access to municipal scale CHP and renewables tailored to local demands.
- System management is aided by the degrees of flexibility provided by ‘empowered’ customers with high capability information and communications technologies (ICT).

Figure 14: 'Energy Service Companies' network pictogram.

4.2.1 Context

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

Government responds to increasingly tough targets for CO_2 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 resource 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.

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. 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 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.

4.2.2 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 or 'super-suppliers' themselves provide heat, light and power (as well as other services) 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.

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 significant interconnect 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 power networks.

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

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

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

The 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.

4.2.3 Modelling results

A slightly lower overall primary energy demand than Big T&D shows that the higher carbon price in this run is incentivising a more efficient selection of technologies. 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, generating a total of 1,874 PJ in 2050, compared to Big T&D's 1,652 PJ. 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.

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 CO_2 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.

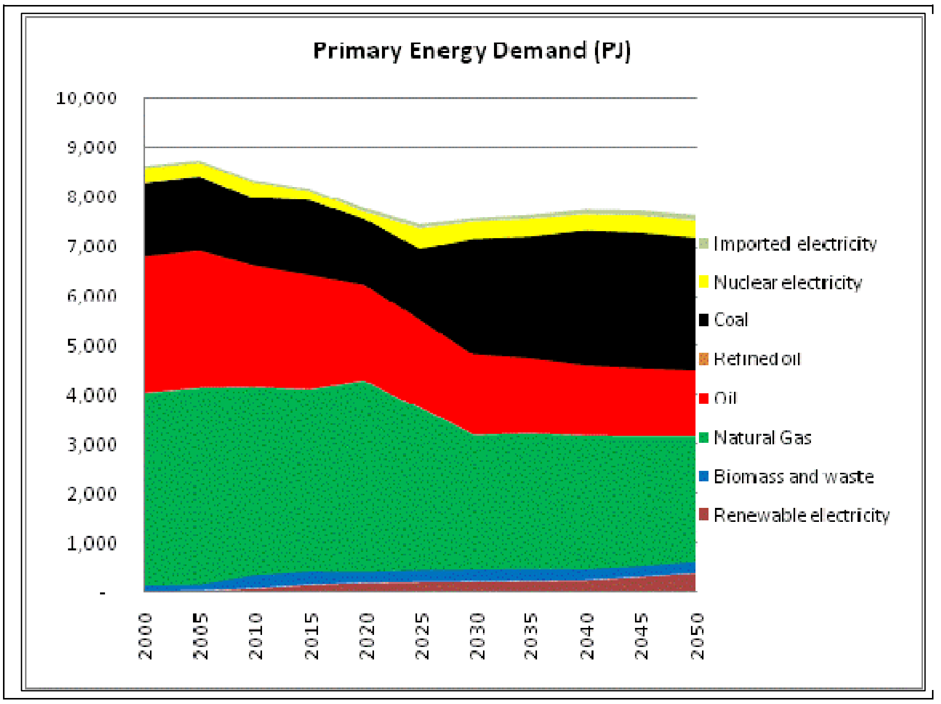


Figure 15 Energy Service Companies Total Primary Energy Demand, 2000-2050

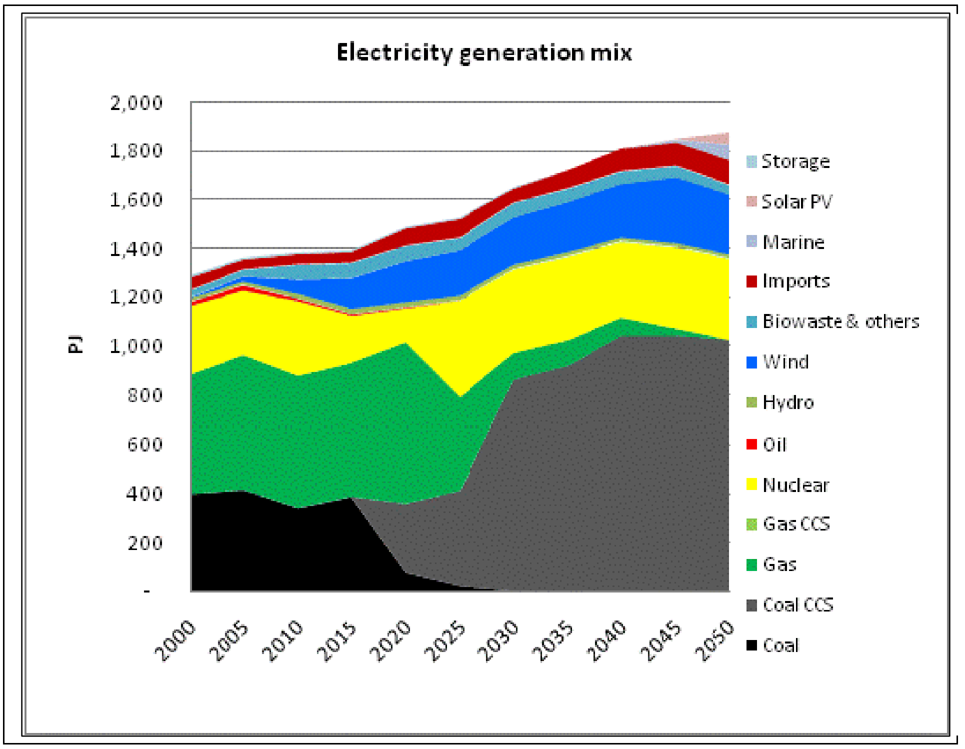


Figure 16 Energy Service Companies Electricity Generation mix, 2000-2050

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, due to the accelerated cost and performance assumptions as part of the ESCO storyline, a total of 247 PJ of electricity are generated from wind, with 27% of the total coming from micro-wind. 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 residential solar PV, marine technologies and biogas driven thermal plant.

The transport sector sees major technology changes over the period, with investment in plug-in hybrids- also stimulated by their extra advantage of providing electricity storage to allow greater penetrations of non-flexible electricity generation- followed by a major switch to battery electric vehicles in car and bus fleets.

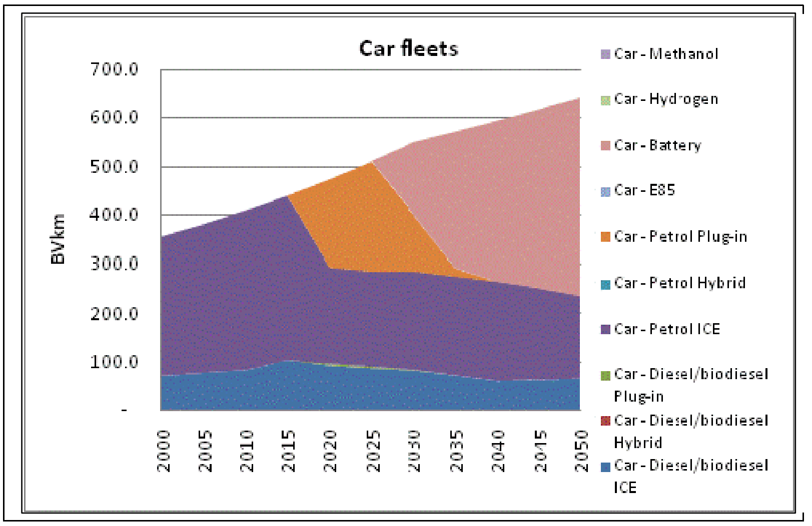
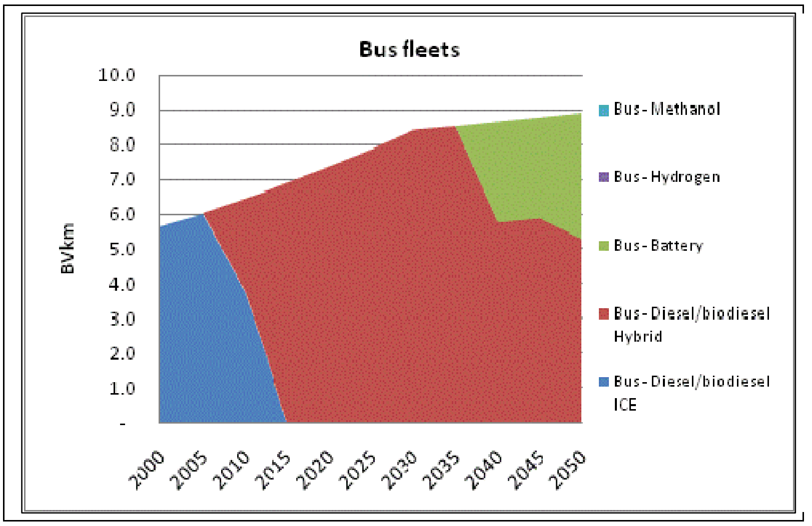


Figure 17 Energy Service Companies car fleet technologies, 2000-2050



,**Figure 18** Energy service companies bus fleet technologies, 2000-2050

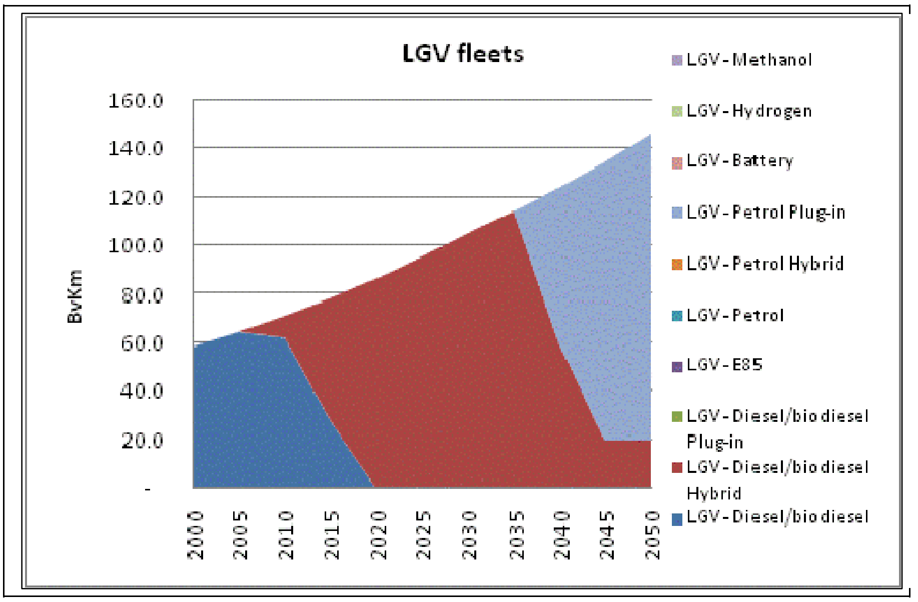


Figure 19 Energy Service Companies LGV fleet technologies, 2000-2050

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. They thus effectively achieve decarbonisation by accident. The electricity system reduces its carbon emissions between 2000 and 2050 by 88%, contributing to an overall systems CO2 mitigation effort of 54%. 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.

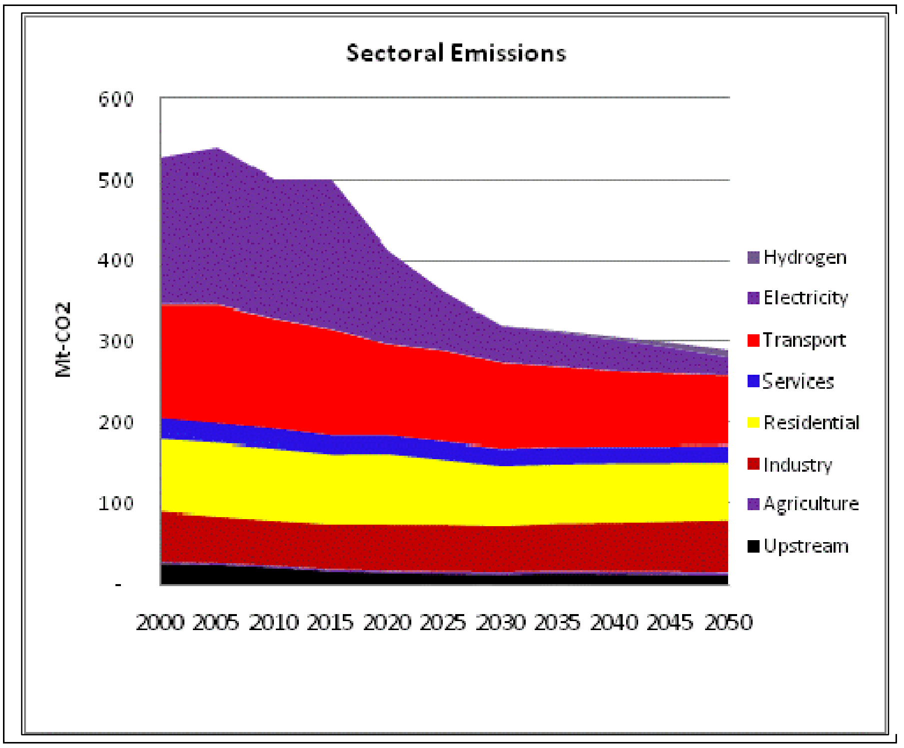


Figure 20 Energy Service Companies sectoral emissions, 2000-2050

Relation of model run to scenario storyline

The model run describes high levels of energy service demand met in the electricity sector principally through large scale low carbon centralised generation technologies. At a more detailed level, 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. This seems to suggest that given the advantages of retaining existing large scale infrastructure, small scale CHP would need specific policy support to be utilised.

Generation type		Network	Installed capacity (GW) in year:	
			2025	2050
Large thermal (no CCS)		T&D	25	15
Large thermal (CCS)		T&D	15	40
Nuclear		T&D	15	13
Large wind	Offshore	T&D	5.8	6
	Onshore	T&D	8.6	8.4
Marine		T&D	0	5
Other large renewable		T&D	11	4
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	4	10
CHP	Large (industrial / commercial)	T&D	3	1
TOTAL T&D			88.4	103.4
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	0	16.7
TOTAL DISTRIBUTION ONLY			0	16.7
TOTAL			88.4	120.1

Table 7 Energy Service Companies installed capacities by network connection – Draft results

A more detailed discussion of these points is contained in Appendices A and B (sections 7 and 8).

4.2.4 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.

4.3 Distribution System Operators

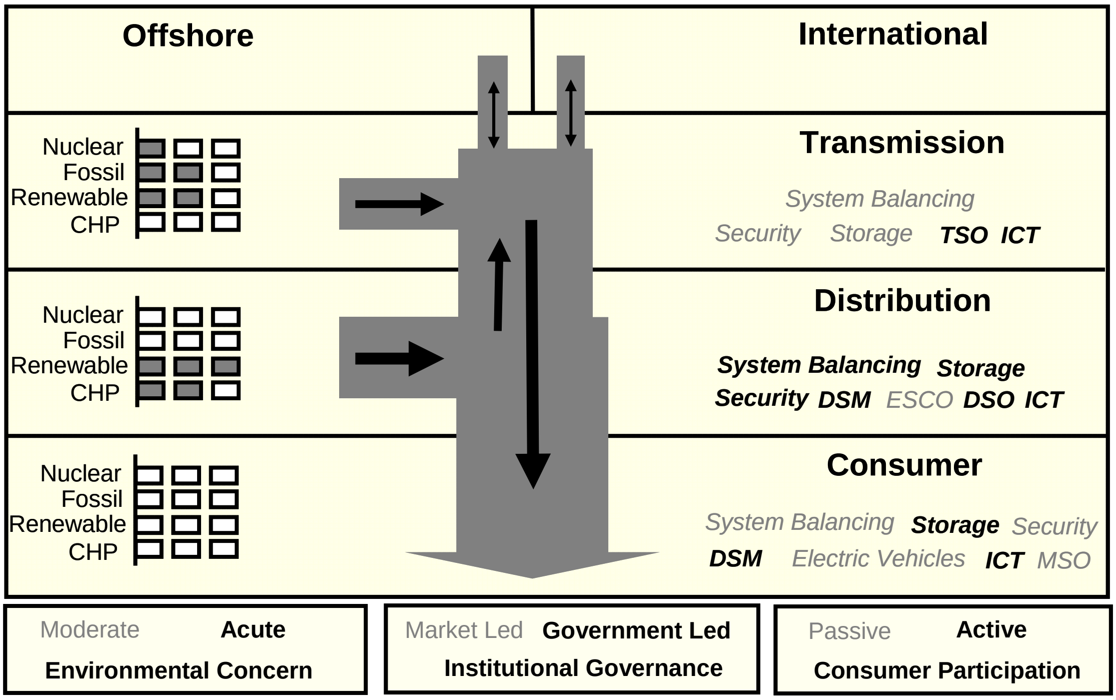


Figure 21: 'Distribution System Operators' scenario schematic illustration.

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. A feature of this scenario is a decision to push for a hydrogen economy as part of a cohesive EU initiative. Consumers are active in their electricity supplies because of attitudes to the environment and a desire to secure the best possible supply of electricity based on price, service and reliability.

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

Figure 22: 'Distribution System Operators' network scenario

4.3.1 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 manipulating markets to deliver environmental targets and protect consumers. There will still be a desire to employ liberal market approaches when possible, however there will be specific cases of strong intervention where market mechanisms are not delivering or are judged to be unable to deliver in the necessary timescales. Regulation would play its part in controlling the market and enforcing some of the interventionist policies. The Government would identify areas of importance such as the hydrogen economy and energy efficiency and provide strong leadership, funding and legislation to enable and drive through particular solutions.

The electricity market would be a 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. 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 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 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.

4.3.2 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.

The DNOs will have to manage a network with many generation sources and will require much more highly developed control facilities. The idea of distribution system operator emerges and system operations codes develop to recognise the expanded role of the DSO. The DSO is the hub of service provision and takes responsibility to manage supplies from what transmission connected generation exists, local generation facilities and other demand side schemes of control. The DSO develops the network to manage diverse generation and demand side facilities and this includes energy storage devices, responsive reactive control equipment and a substantial network management system capable of delivering high levels of service from the diverse generation portfolio to managed demand customers. 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.

4.3.3 Modelling results

Due to the effect of the elastic demand component, total primary energy shows a very clear and steady downward trend, most evidently between 2005 and 2035. Looking at the sectoral response, all sectors have reduced their energy service demand levels, implying end use efficiency, but also some significant cultural and lifestyle changes in perceived energy service 'comfort' levels.

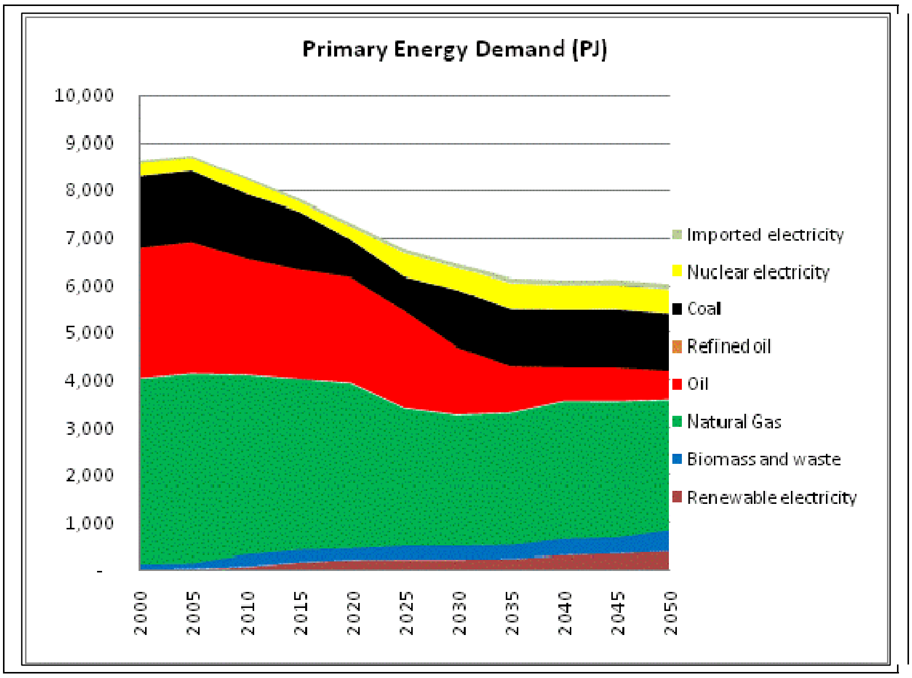


Figure 23 Distribution System Operators total primary energy demand, 2000-2050

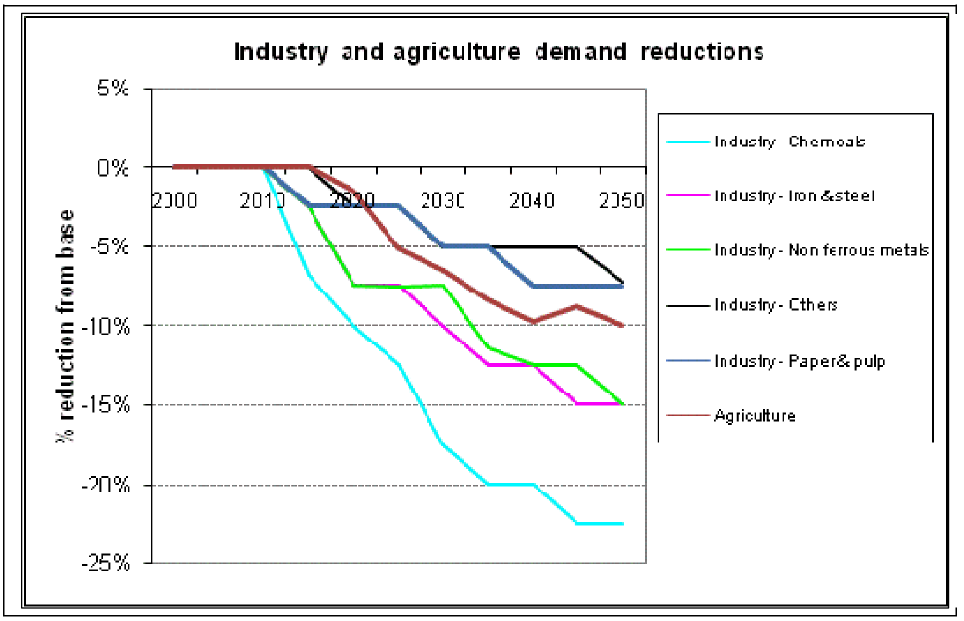


Figure 24 Distribution System Operators industry & agriculture,

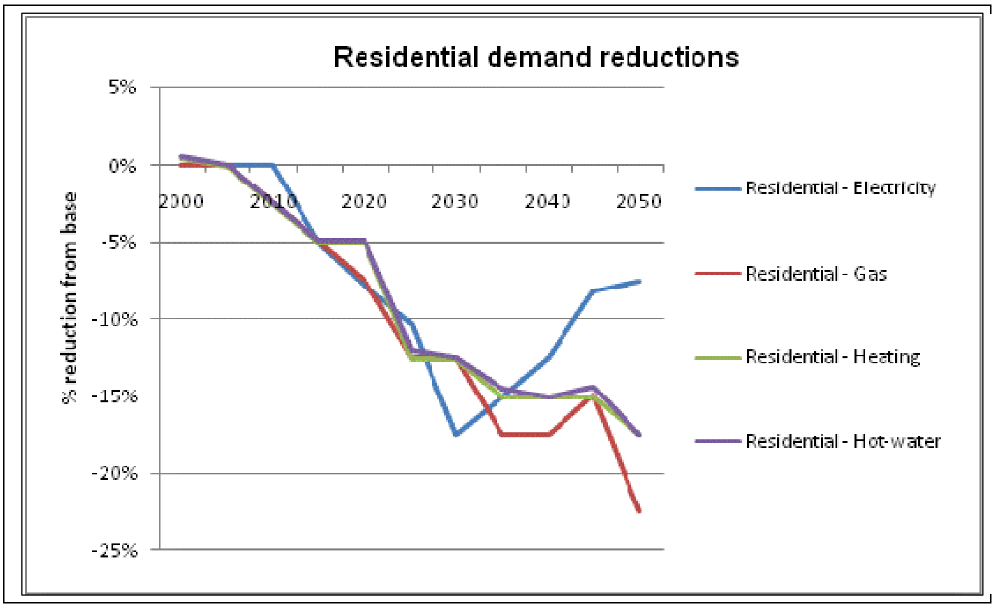


Figure 25 residential demand reductions

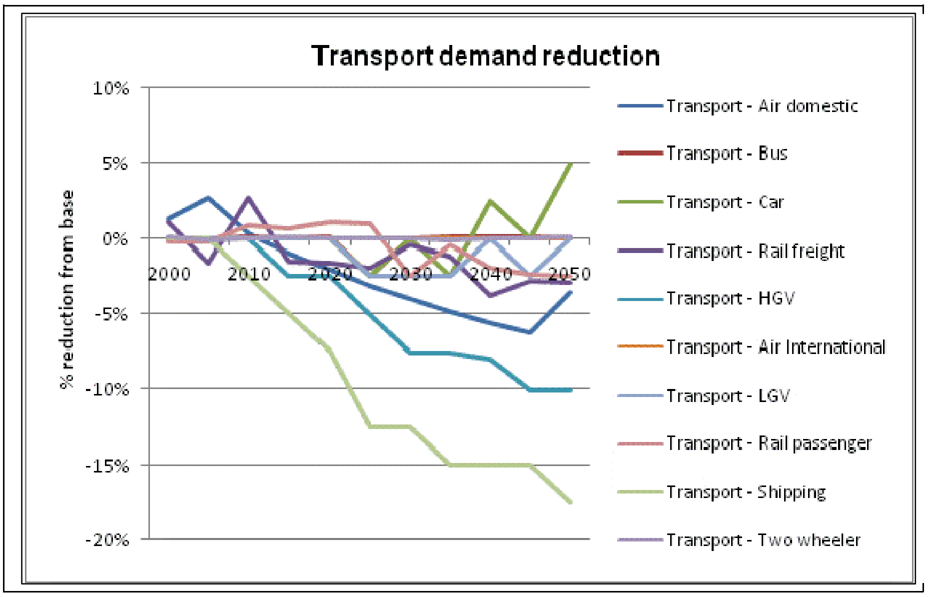


Figure 26 Distribution System Operators transport demand reductions

The constraint on the use of the transmission system to supply residential and service electricity forces the model to further reduce demand in the middle of the period. However, towards the end of the period the model starts to find more cost effective distributed options to make up some of the restricted residential and services supply deficit. Also, developments in other sectors not subject to the transmission constraint, most notably transport, generate a steadily growing demand for electricity between 2030 and 2050.

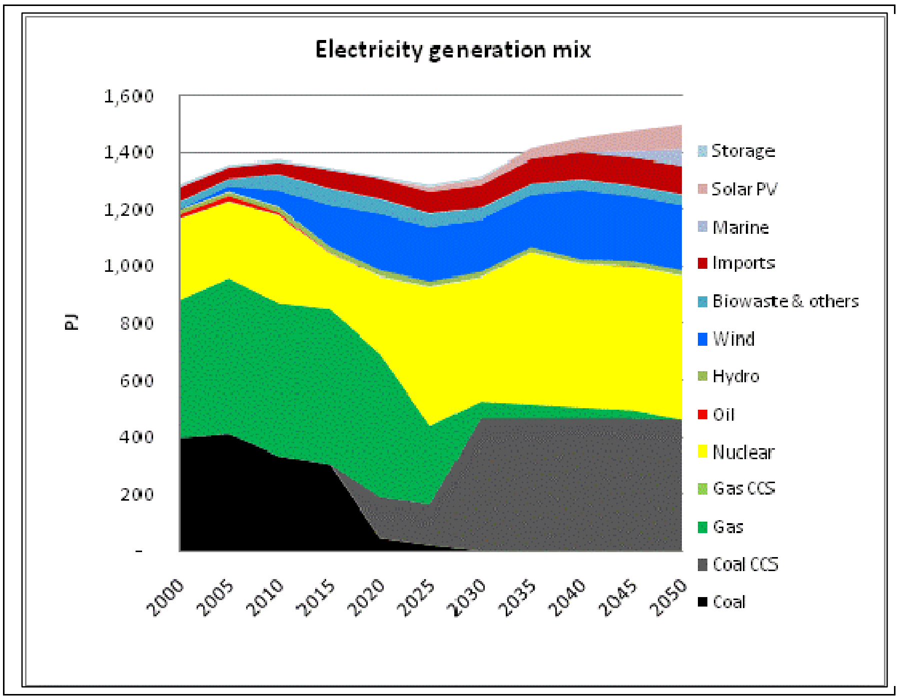


Figure 27 Distribution System Operators electricity generation mix, 2000-2050

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 5GW. The higher carbon price and the constraints on transmission mean that microwind (which avoids the transmission network) is an attractive option much earlier in the period, receiving its first major investment in 2015, and reaching its maximum capacity in 2020.

For the same reasons the prospects are also increased for residential solar PV, which also feeds in directly to the distribution level, and 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 is no longer cost effective. Tidal stream also shows strong growth in the final decade of the period, though it does not reach the level it achieved in ESCO, as transmission constraints reduce levels of large scale generation in the middle of the period. The increase in variable renewable generation during the final period stimulates a greater requirement for electricity storage options. However, this is of about half the level of that required for ESCO due to the lower quantities of variable renewables. This does not account for the variability of the distributed generation technologies. It is clear that DSOs will have to take highly innovative measures to balance these at the distribution network level- this is assumed within the model assumptions and described in more detail in the scenario storyline.

Once again the transport sector undergoes major systemic changes, driven by one of the key DSO scenario storyline themes, that the UK is part of a concerted international push to develop a 'hydrogen economy'. With the advanced technology inputs to the model intended to represent this scenario, hydrogen fuel cell cars and buses become cost effective in this run from 2030. As the carbon price is extended to the transport sector, the hydrogen on which these vehicles run has to pay for any emissions associated with its production. The model prefers small scale hydrogen generation options which avoid the requirement to build hydrogen pipelines or use hydrogen tube trailers. Rather it uses existing infrastructure- the gas and electricity networks, to move the energy over long distances, for conversion to hydrogen at the point of use using small scale steam methane reforming and electrolysis. 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 1501 PJ to 2071 PJ.

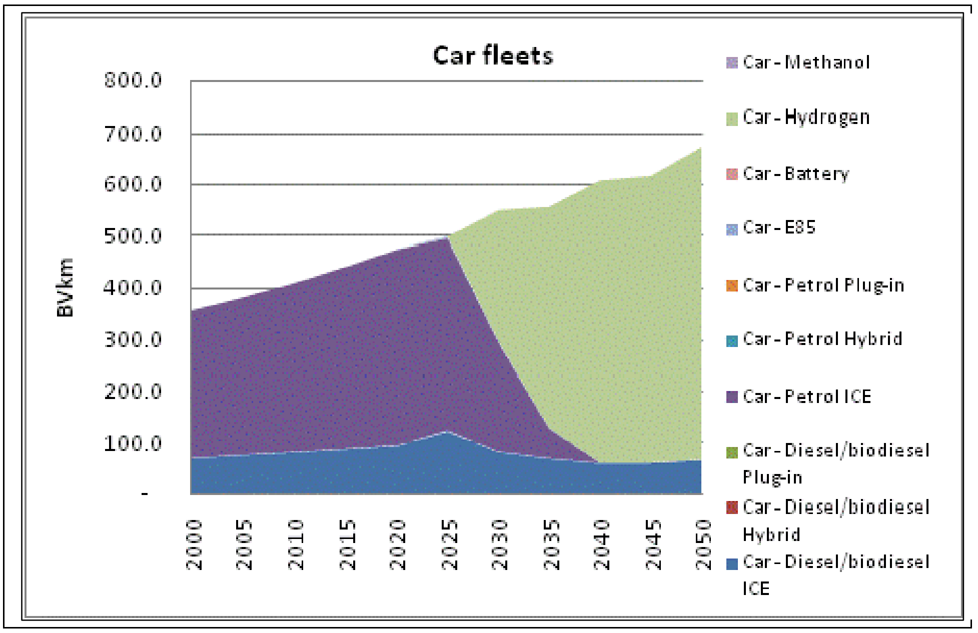


Figure 28 Distribution System Operators car fleet technologies, 2000-2050

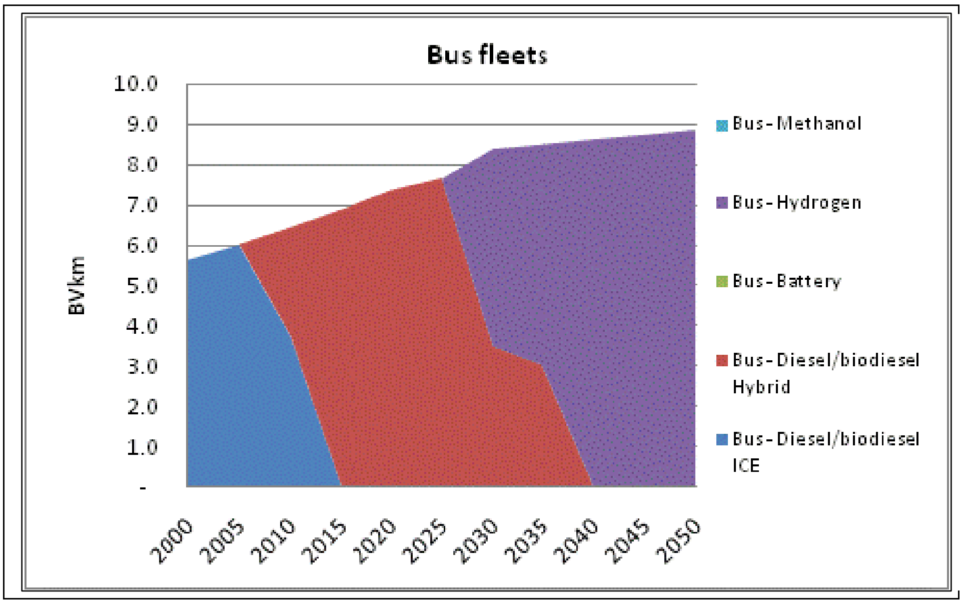


Figure 29 Distribution System Operators bus fleet technologies, 2000-2050

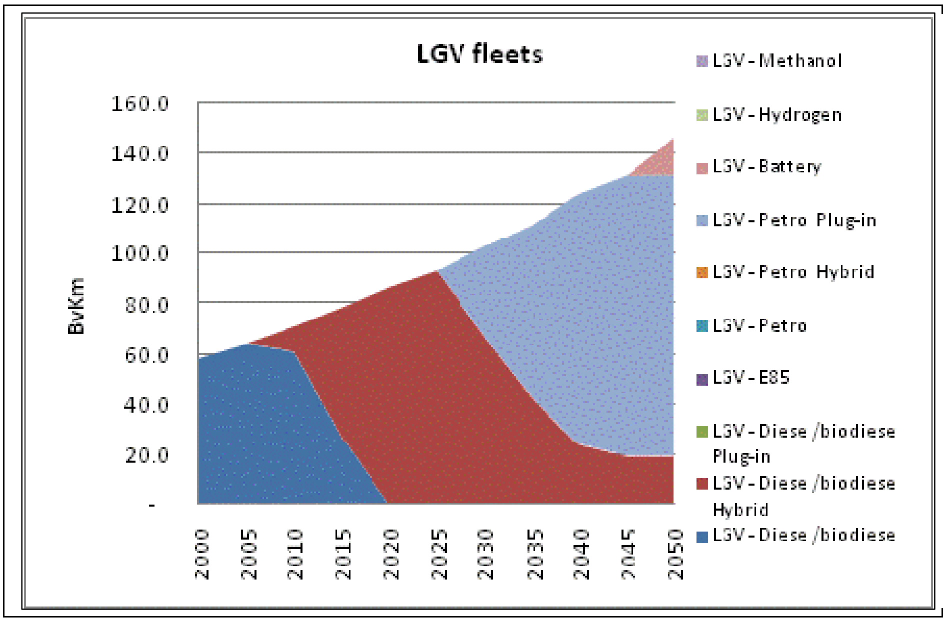


Figure 30 Distribution System Operators LGV fleet technologies, 2000-2050

The Markal Elastic Demand parameters show a sharp negative spike in the change in consumer plus producer surplus, indicating the highest impact on overall social welfare at around 2035. This correlates to a period when the carbon price is already high but the full range of low carbon technology options are not yet available or fully cost effective. The last decade and a half represents a period when a range of low carbon options are becoming cost effective allowing the system to avoid the carbon price without having to forgo energy services, as shown by the increase in consumer surplus. The change in consumer plus producer surplus compared to the base case recovers to close to zero by the end of the period.

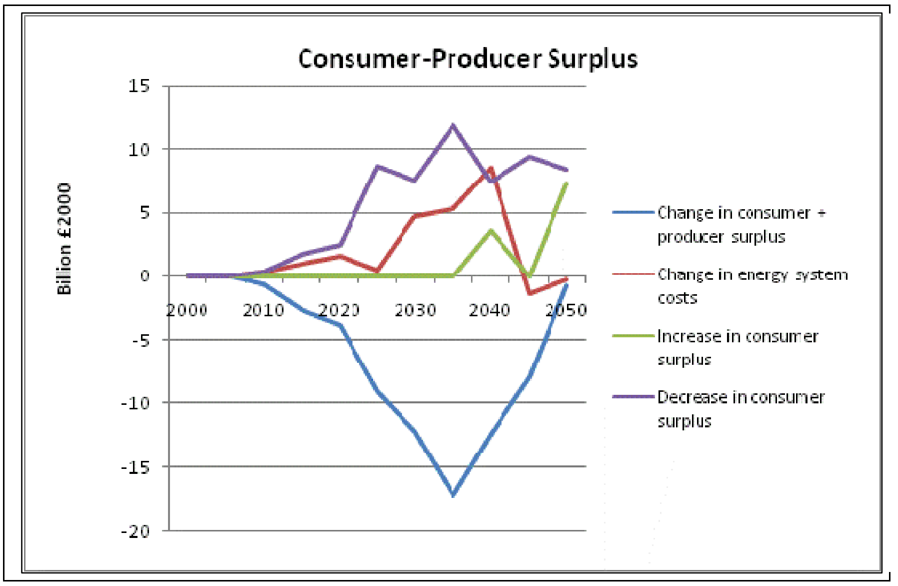


Figure 31 Distribution System Operators change in consumer-producer surplus, 2000-2050

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.

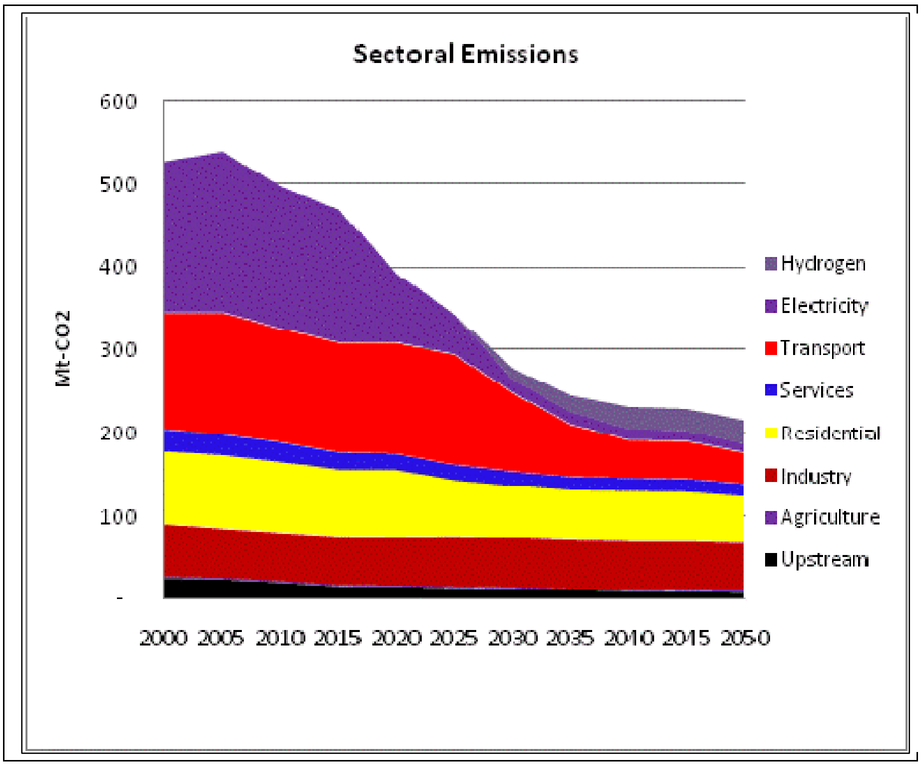


Figure 32 Distribution System Operators sectoral emissions, 2000-2050

Relation of model run to scenario storyline

The effect of the constraint on transmission delivers a need for microgeneration which becomes particularly acute as the constraint reaches its highest level in 2030. The prominent role of microgeneration technologies is in line with the scenario storyline, in particular the way-marker indicating a breakthrough for microgeneration, in part stimulated by the desire for zero carbon housing.

The model run avidly takes up hydrogen for transportation purposes in response to the carbon price but also the advanced technology assumptions which were justified as part of the scenario storyline. In terms of hydrogen generation, the model overwhelmingly prefers small scale options located at the point of use, to avoid the additional costs of hydrogen distribution infrastructure. This confirms the scenario storyline, and has potentially very great implications for both gas and electricity networks.

The model confirms the scenario's description that base load generation from large scale nuclear and fossil fuel with CCS plants remains a major part of the energy mix, as well as the importance of gas for space and water heating in buildings. However, once again the model does not pick up any form of CHP, which contrasts greatly with the scenario description. Now that the carbon price applies directly to the residential and service sectors, CHP is not enough of a low carbon option to be economically viable.

Generation type		**Network**	**Installed capacity (GW) in year:**	
			2025	**2050**
Large thermal (no CCS)		T&D	19	10
Large thermal (CCS)		T&D	5	18
Nuclear		T&D	19	19
Large wind	Offshore	T&D	0.9	5
	Onshore	T&D	8.6	7.8
Marine		T&D	0	5
Other large renewable		T&D	12	5
Storage		T&D	1	1
Imports (interconnector capacity)		T&D	4	10
CHP	Large (industrial / commercial)	T&D	2	0
TOTAL T&D			71.5	80.8
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	11.7	23.7
TOTAL DISTRIBUTION ONLY			11.7	23.7
TOTAL			83.2	104.5

Table 8 Distribution System Operators installed capacities by network connection – Draft results

A more detailed discussion of these points is contained in Appendices A and B (sections 7 and 8).

4.3.4 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.

4.4 Microgrids

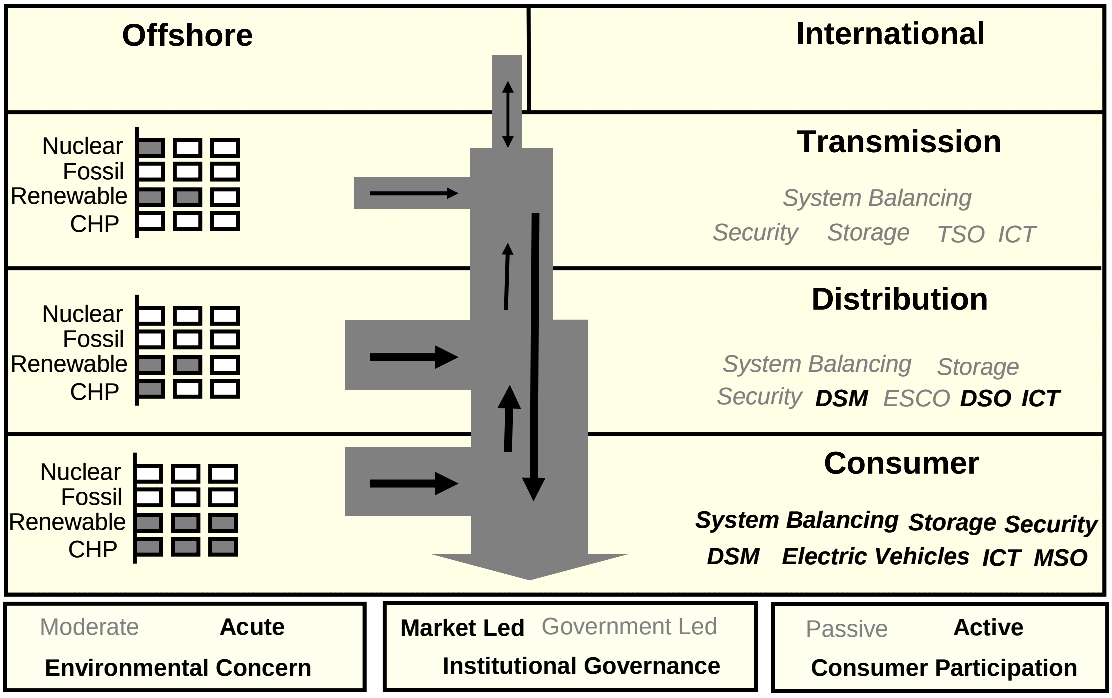


Figure 33: 'Microgrids' scenario schematic illustration.

Customers are at centre of activity in electricity networks

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

- 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.

Figure 34: 'Microgrids' network scenario.

4.4.1 Context

Environmental concern develops strongly as climate change develops to a serious degree and is indisputably linked to GHG emissions. Global initiatives will be slow to reach full agreement and impose strong mandates on emissions. However, the current level of urgency will increase steadily and international agreements on emissions capping will be achieved in the medium term. OECD countries will take a lead in targeting emissions and moving away from fossil fuel. International agreements leading to 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 also receive high levels of attention and will be taken into account when considering solutions to climate change issues. The balance between global and local environmental concern will be one of the defining elements of the development of electricity networks. There will be a strong perception that electricity generation sources should be environmentally friendly and energy efficiency is essential and a matter of national strategic importance. This will be delivered through markets with appropriate frameworks and bounds.

Environmental concern will shape the market place which responds to consumer demands not only for energy at attractive prices but also for environmental acceptability and the ability for consumers to play their role in their energy and electricity supplies. Government will play a role by implementing policy that addresses market structures to ensure that barriers do not prevent the market responding to the environmental challenge.

Government will be responding to increasingly tough national targets for GHG emissions set in response to strong EU and global mandates. Policy would be directed towards achieving environmental targets and protecting consumers.

There would 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 would still be regulation to oversee the operation of and to promote competition in the energy markets. The Government would 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 standardized 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 microgeneration. 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.

Attitudes to transport would change. Longer journeys and commuting would be 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. 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 would be actively looking for ways to implement energy efficiency. They would also desire that those agencies that serve and represent them also work to minimise environmental impact. Consumer demand creates diverse market opportunities 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 generation must serve.

Generation is almost exclusively low carbon due to the above influences. 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[12]. 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 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 microgeneration, 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 microgeneration. 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 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

[12] 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.

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 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.

4.4.2 Network

The self-sufficiency (renewables, CHP, energy efficiency, demand side management) concept 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 Transmission and/or Distribution.

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 a reduced role for the bulk power system.

One approach being deployed widely is the microgrid where self-sufficiency among individual and groups of customers has developed to such an extent that demand management, energy storage, power quality as well as energy production are coordinated in well defined customer groups. The role for the distribution network operator might be in operating the microgrids themselves or connecting microgrids to the wider distribution system as virtual or actual private networks. Microgrids 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 mircogrid 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.

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

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

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

The transmission system role would be to connect 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 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.

4.4.3 Modelling results

The high carbon price and elastic demand function mean that total primary energy demand ends up at the lowest level of all the runs, 5148 PJ in 2050. Perhaps the most notable aspect of this severely curtailed energy mix is that demand for natural gas remains almost unchanged from previous runs. This is because natural gas is still being used with very little change for space and water heating in buildings, as well as in industry. Despite the carbon penalty, this is still the least cost option for these services.

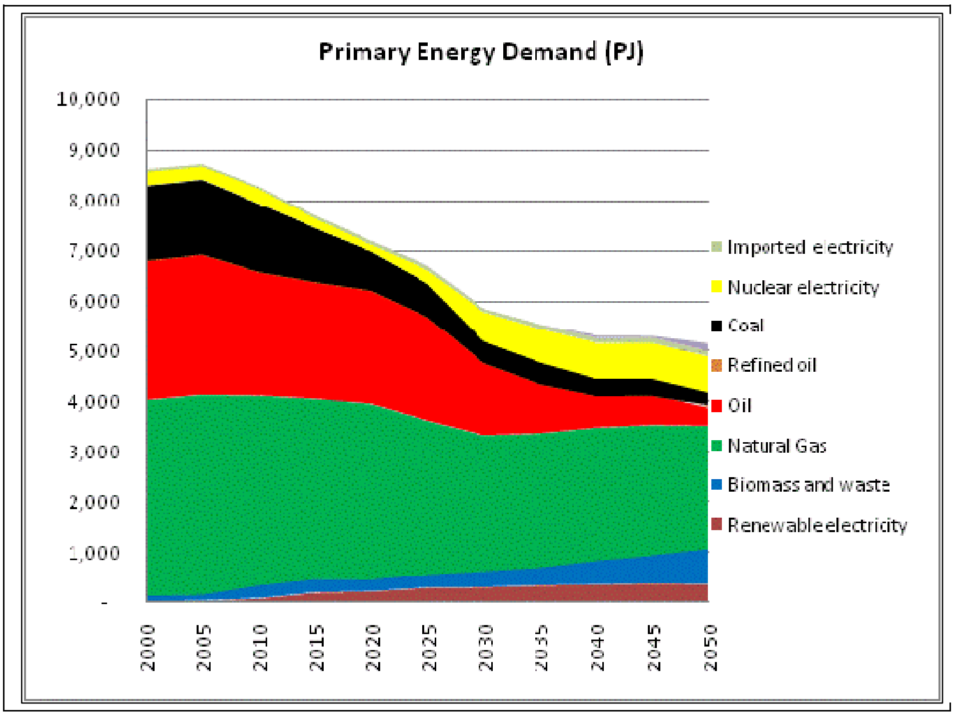


Figure 35 Microgrids primary energy demand, 2000-2050

Demand reduction is employed to a very significant extent by the model in response to the high carbon prices, particularly in industry, agriculture and service, with significant lifestyle and economic implications. Transport demand reductions are in general slightly less great. As in the DSO run, it is the only sector where one service demand shows an increase, again that for car transport, due to the availability of cost effective low carbon alternatives late on in the period.

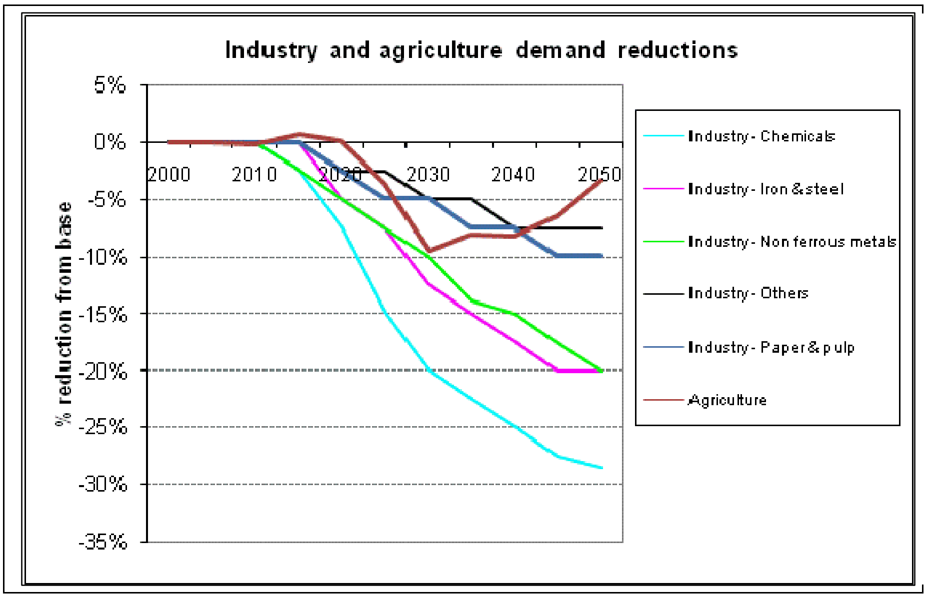


Figure 36 Microgrids industry & agriculture demand reductions.

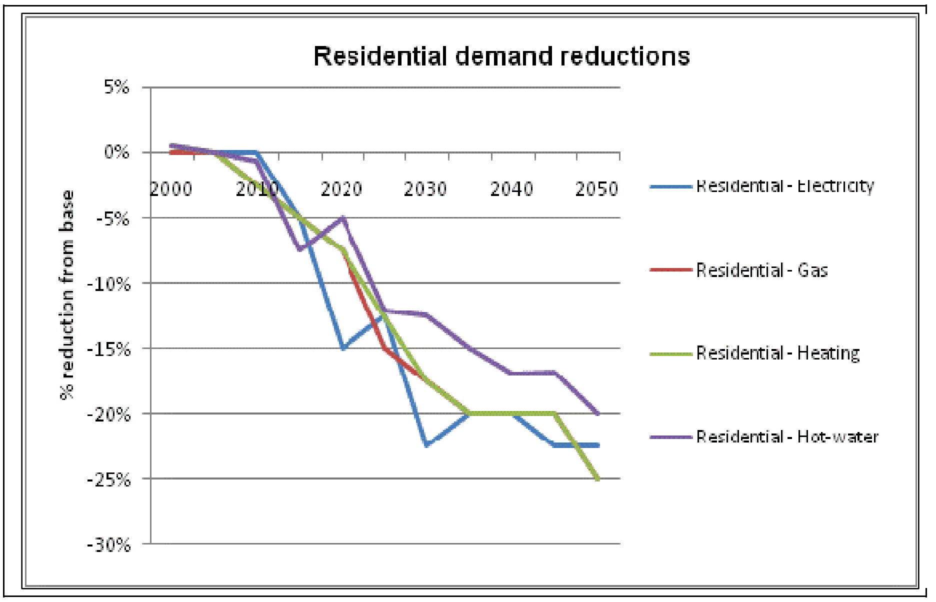


Figure 37 Microgrids residential demand reductions

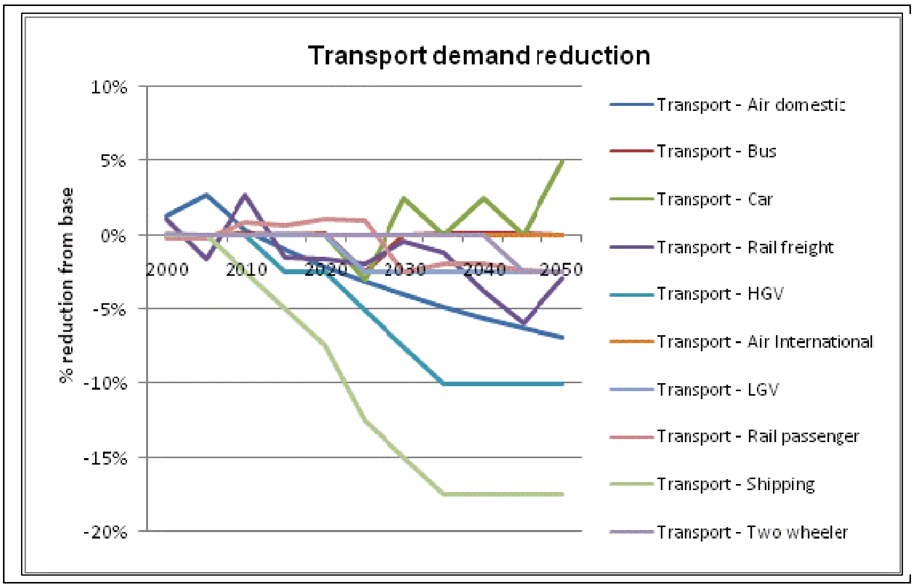


Figure 38 Microgrids transport demand reductions

A mid-period decline in electricity generation is a response to the restriction on transmission. It is reversed from 2025 onwards when the increased availability of distributed technologies to meet demand in the residential and service sectors, as well as a major increase in demand for electricity from the transport sector, both directly and indirectly through the production of hydrogen, sees a very significant overall expansion in electricity generation. The model is able to use large scale plants to meet this demand, and the response is a huge investment in nuclear from 2025 onwards.

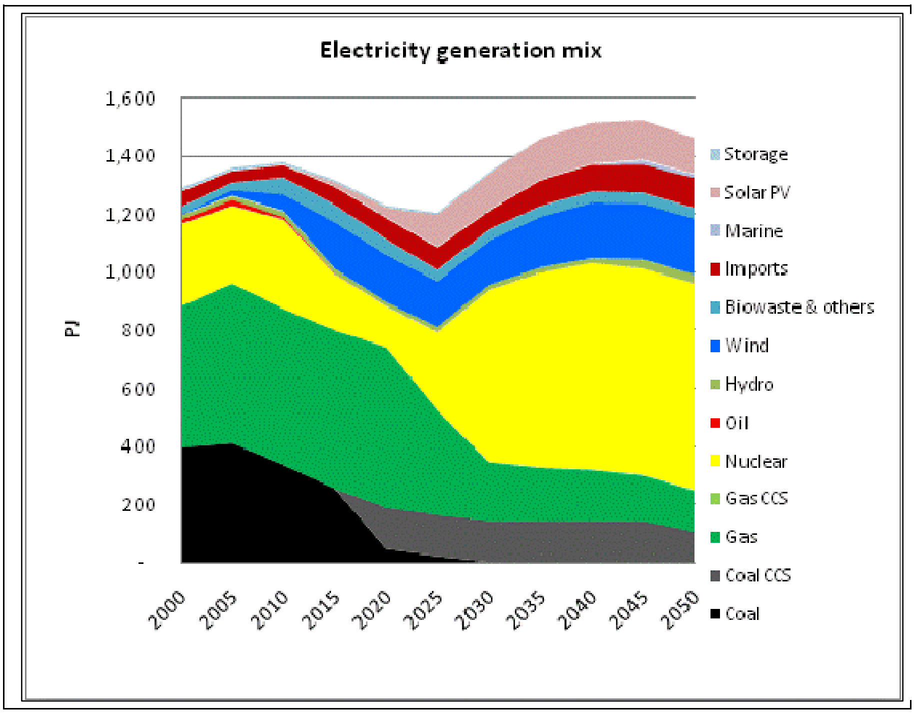


Figure 39 Microgrids electricity generation mix, 2000-2050

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.

This run also deploys greater quantities of microgeneration, and at an earlier time than in DSO. The microwind resource is once again fully deployed by 2020, and residential 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 55PJ 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).

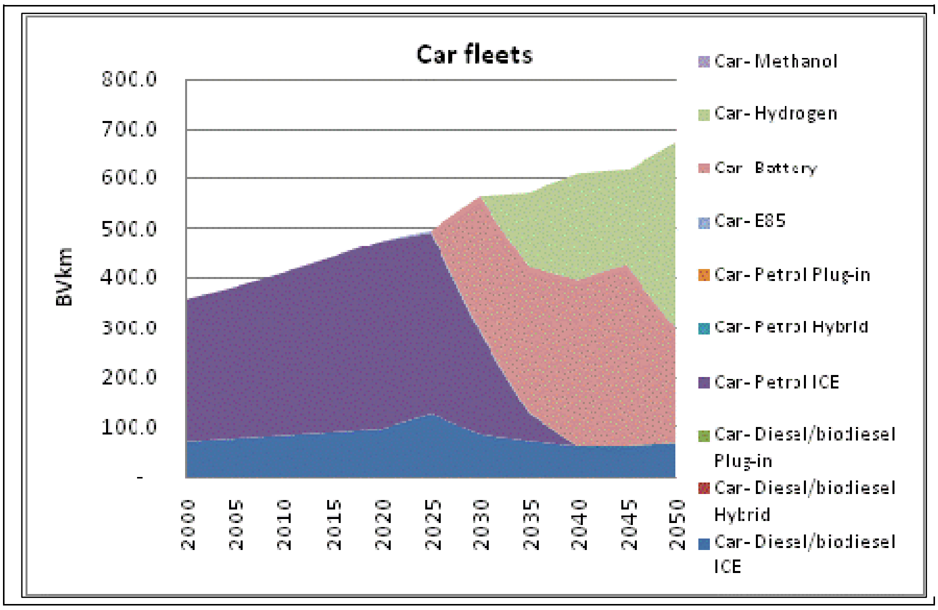


Figure 40 Microgrids car and fleet technologies, 2000-2050.

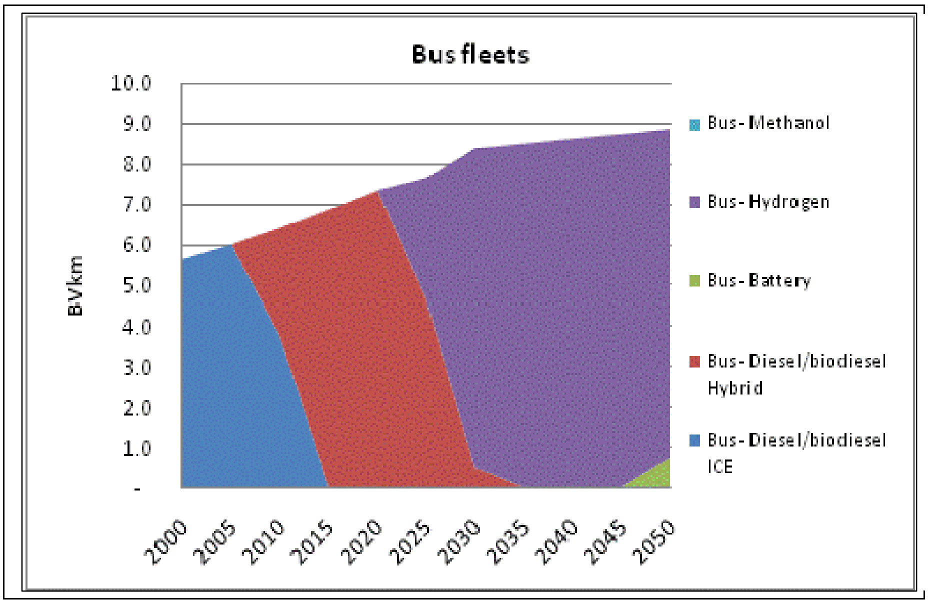


Figure 41 Microgrids bus fleet technologies, 2000-2050.

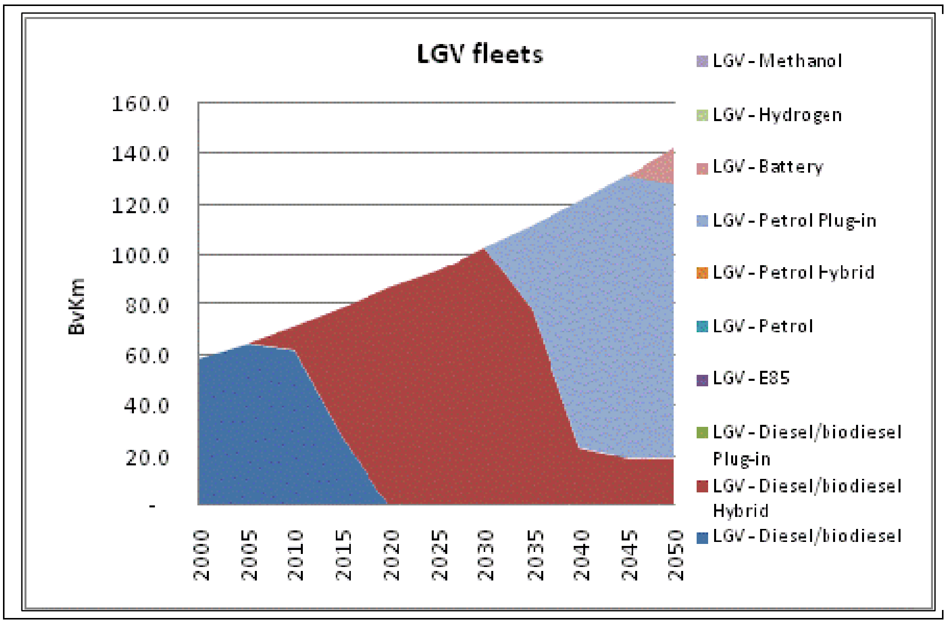


Figure 42 Microgrids LGV fleet technologies, 2000-2050

This model run incurs very significant costs both from the very high carbon price, and the constraints on transmission which reduce the potential of relatively affordable large scale low carbon options to contribute to decarbonisation. These increased costs cause some significant demand reductions, producing a similar pattern in the MED overall system welfare indicator of consumer plus producer surplus as found in the DSO run. However, whereas in DSO welfare losses were close to zero by 2050 due to the increasing benefits of low carbon energy technologies, in this run welfare losses remain highly significant compared to the base year.

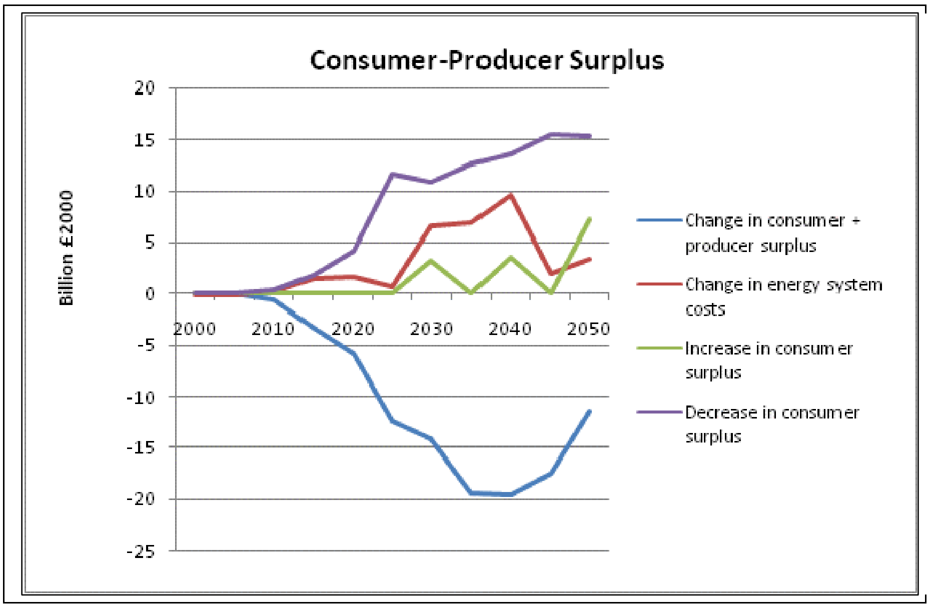


Figure 43 Microgrids consumer-producer surplus, 2000-2050

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.

Relation of model run to scenario storyline
This run certainly represents a scenario where environmental concern is strong throughout every level of society. The main environmental driver, the carbon price, applies to all sectors and becomes extremely high, causing major technology switching as well as demand response, which would be commensurate with fairly major behavioural shifts in the use of energy.

DG technologies are now widely deployed, which reflects one of the key elements of the scenario. However, the measures that were taken in this model run (major acceleration of technology development as well as significant transmission constraint) may give some indication that serious policy support would be required for these technologies to be deployed. A policy area of major importance could be low carbon housing. Distributed technologies would also require careful load management, an assumption which is also implicit in their technological characterisation in the model.

As described in the scenario, gas is still prominent, though not just in the medium term, retaining its importance in CHP applications due to the constraint on electricity transmission.

Generation type		**Network**	**Installed capacity (GW) in year:**	
			2025	**2050**
Large thermal (no CCS)		T&D	21.5	4.1
Large thermal (CCS)		T&D	5	5
Nuclear		T&D	10	27
Large wind	Offshore	T&D	0	1.5
	Onshore	T&D	5.56	8.36
Marine		T&D	0	1
Other large renewable		T&D	5	5
Storage		T&D	0	1
Imports (interconnector capacity)		T&D	4	12
CHP	Large (industrial / commercial)	T&D	2	0.5
TOTAL T&D			53.06	65.46
CHP	Small (household)	Distribution only	7.3	24.5
Microgen (inc. microwind, solar etc)		Distribution only	21.8	23.2
TOTAL DISTRIBUTION ONLY			29.1	47.7
TOTAL			82.16	113.16

Table 9 Microgrids installed capacities by network connection – Draft results

A more detailed discussion of these points is contained in Appendices A and B (sections 7 and 8).

4.4.4 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.

4.5 Multi Purpose Networks

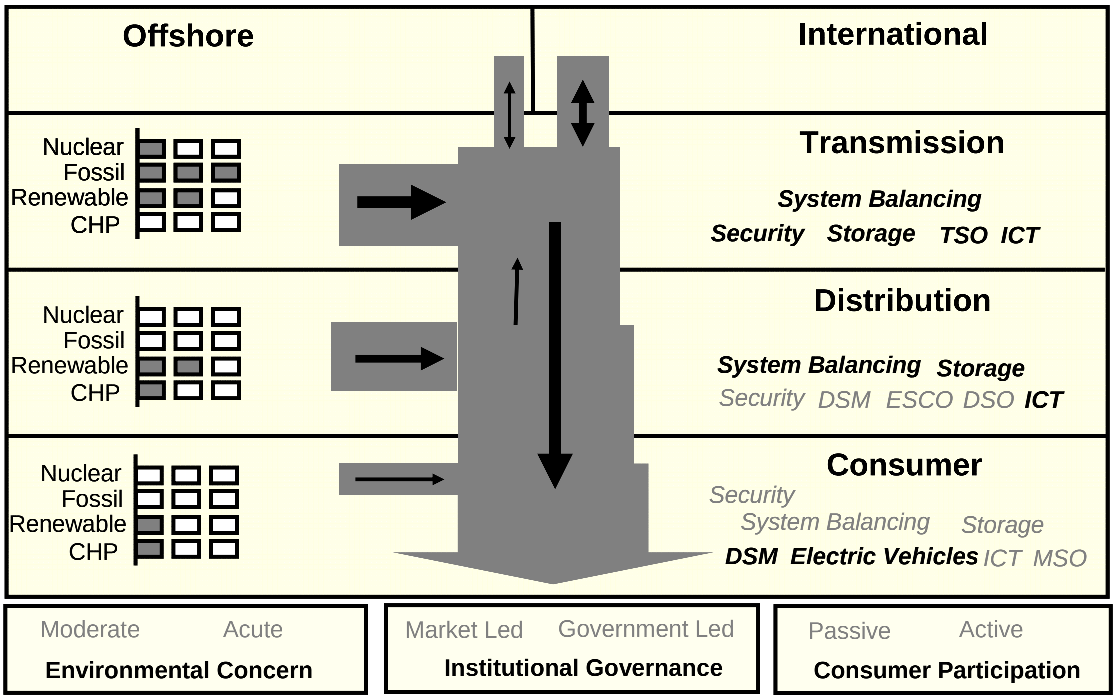


Figure 44: 'Multi-Purpose Networks' scenario schematic illustration.

Network companies at all levels respond to emerging policy and market requirements. TSOs still retain the central role in developing and managing networks but DNOs 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.

- There is a pervasive feeling of uncertainty and a resulting ambiguity within society towards environmental issues and the influence this has on energy infrastructure development. Environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental observations and reports/statistics.
- A lack of global consensus on environmental issues contributes to the uncertainty regarding environmental action.
- There are various market led and Government led approaches pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of fuel supplies and immediate economic concerns.
- Differing attitudes towards energy consumption develop among consumers resulting in varied types and levels of consumer participation depending on the geographic area, social demographics and services provided by energy companies.
- There are many types of generation in the national portfolio with centralised thermal generation and offshore renewables both prominent groupings. Combined heat and power and microgeneration are deployed in areas with the right mix of public investment, services from energy companies and demand from consumers.
- There is a strong potential for stranded assets and investment redundancy in the power sector.
- Attempts have been made to exploit many energy technologies over time and there exists a large diversity in electricity production and demand side management initiatives implemented.
- The network is characterised by diversity in network development and management approaches as a result of changing energy policies and company strategies over time.
- Substantial differences exist in network capabilities with excess capability in some areas and constraints in other areas.
- Electricity networks fulfil different roles including bulk transfer, interconnection, backup and security, and meeting renewable and demand side objectives.
- Challenges in managing diverse system architectures are accompanied by opportunities from the diversity of generation, network and demand side provision.
- The commercial implications of the lack of consistency in energy policy and the subsequent diverse network infrastructures that emerge means that the stranding of certain power system assets becomes more apparent over time.

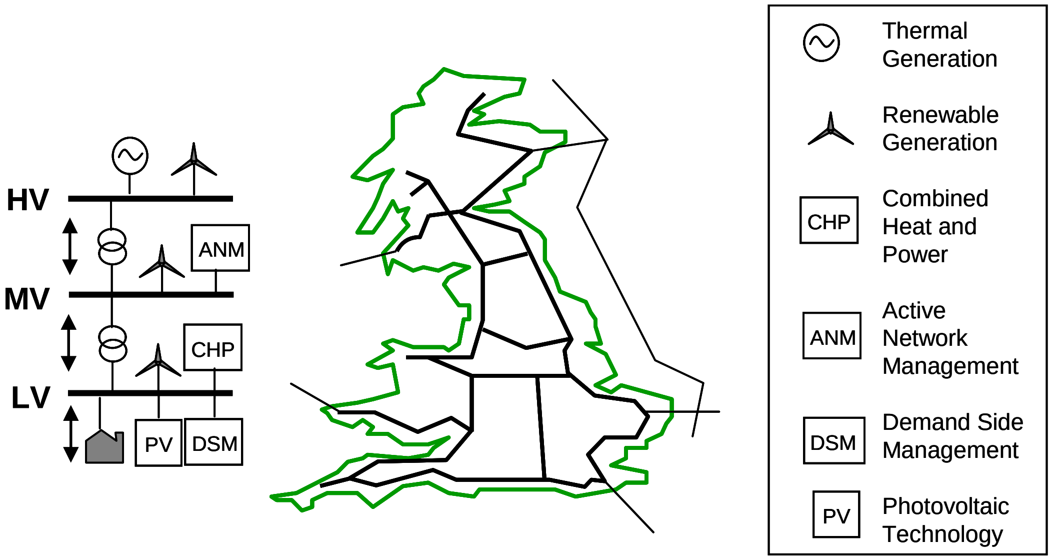


Figure 45: 'Multi-Purpose Networks' network scenario.

4.5.1 Context

The international situation will be an underlying cause of GB's inconsistent direction as increasing environmental concern does not force a consensus approach. Although all countries agree action must be taken, what form this should take will be the subject of strong debate. International treaties will be undermined by fluctuating national policies and approaches. Several OECD countries take different directions leading to a wide variety of approaches and technological solutions. In the EU, 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 will be acknowledgement that the environment is important and should be protected, however opinions on how this can best be achieved will be mixed and short term approaches in one direction often lack commitment and would quickly be replaced by another approach. The fluctuating attitudes within society will also apply to other environmental issues affecting networks. Significant infrastructure developments will be approved or opposed depending on the attitudes of society and Government at the time that proposals for developments are brought forward.

In GB the Government would be responding in a reactive manner to changeable 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.

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 and as a succession of approaches only have limited impact before they are replaced, concern over reaching targets will increase. This results in increasingly serious measures as 2050 approaches. These include, carbon limits for participants in different sectors with high penalties for breaching limits and 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 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 all over the country reflecting the varied technology and primary fuel source, i.e. centralised in the south, offshore renewables around Scotland/Irish Sea/East Anglia, windfarms in Scotland, biomass CHP in rural communities.

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). I.e. not everyone will get smart meters and from those that do, not everyone will desire/be empowered to use them or even continue to use them once the focus has gone elsewhere[13]. 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.

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

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.

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

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

Transmission, extra high-voltage distribution and lower-voltage distribution have each been developed relatively highly since at various times that was what was required to meet the energy policy objectives of the time. The transmission network has been expanded to reach the exploited sources of renewable energy in rural and offshore regions. Additional interconnection to the mainland European power networks has been developed and this provides additional capability for securing electrical supplies and also for balancing the GB system in real time. At the same time some parts of the networks have not been expanded as a result of efficiency and capacity investment deferral initiatives such as demand side management. In addition there have been periods of general under-investment as a result of different energy policies 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.

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

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

4.5.3 Modelling results

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.

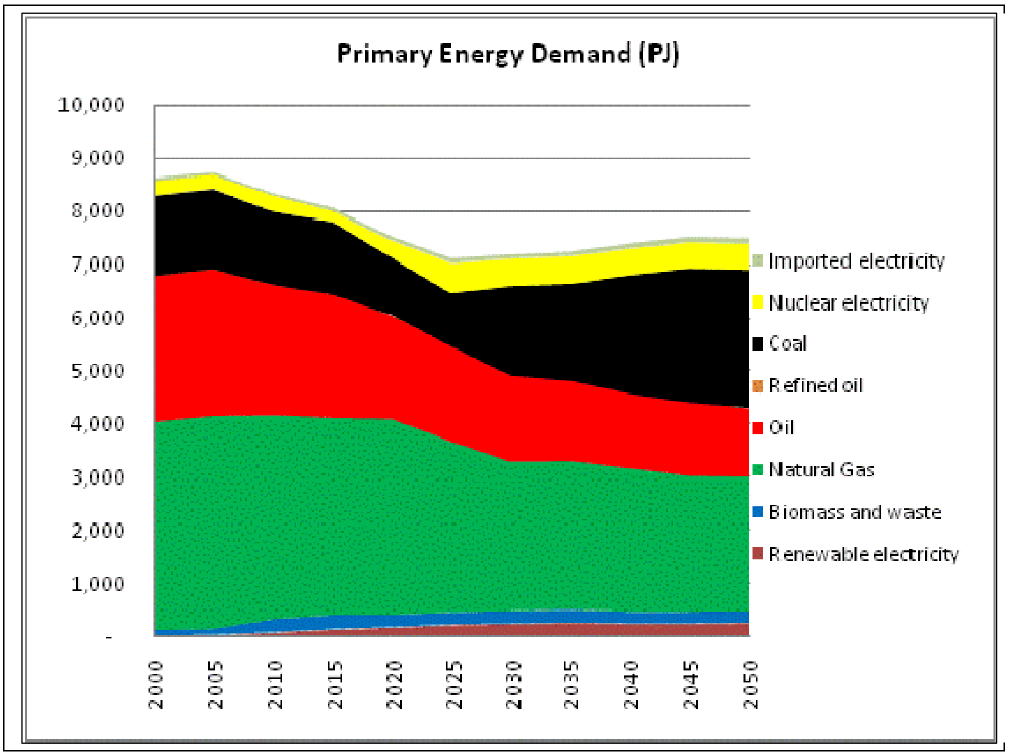

Figure 46 Multi purpose networks total primary energy demand

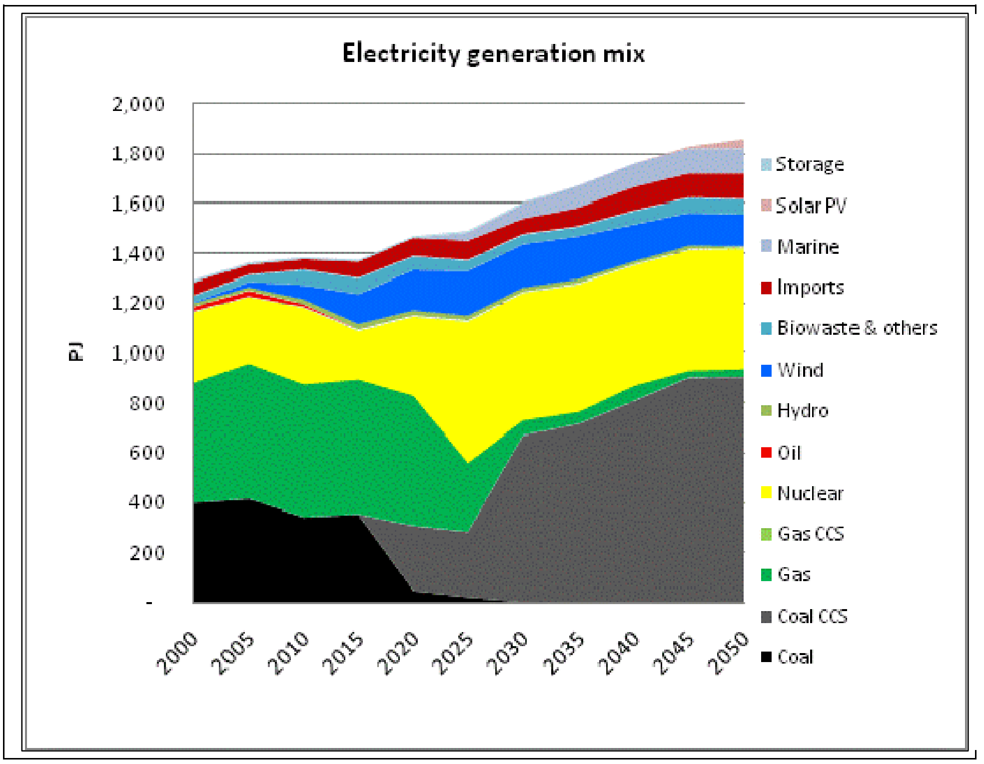

Figure 47 Multi purpose networks electricity generation mix

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 2025. This year sees microwind 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 microgeneration technologies also see residential solar PV making a small contribution towards the end of the period.

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.

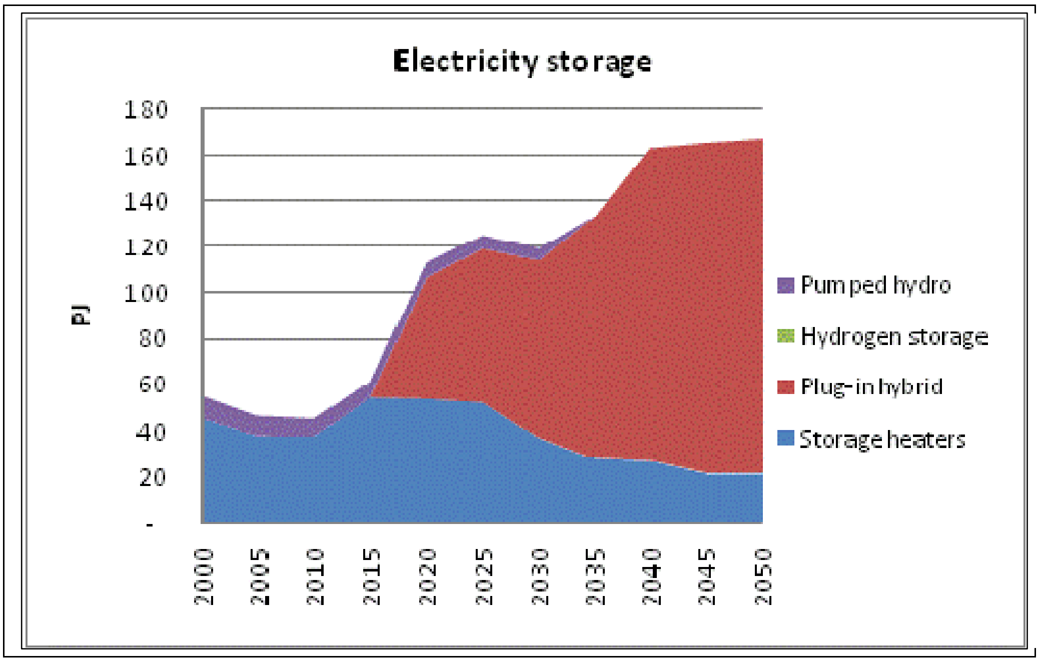

Figure 48 Multi purpose networks electricity storage activity, 2000-2050

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

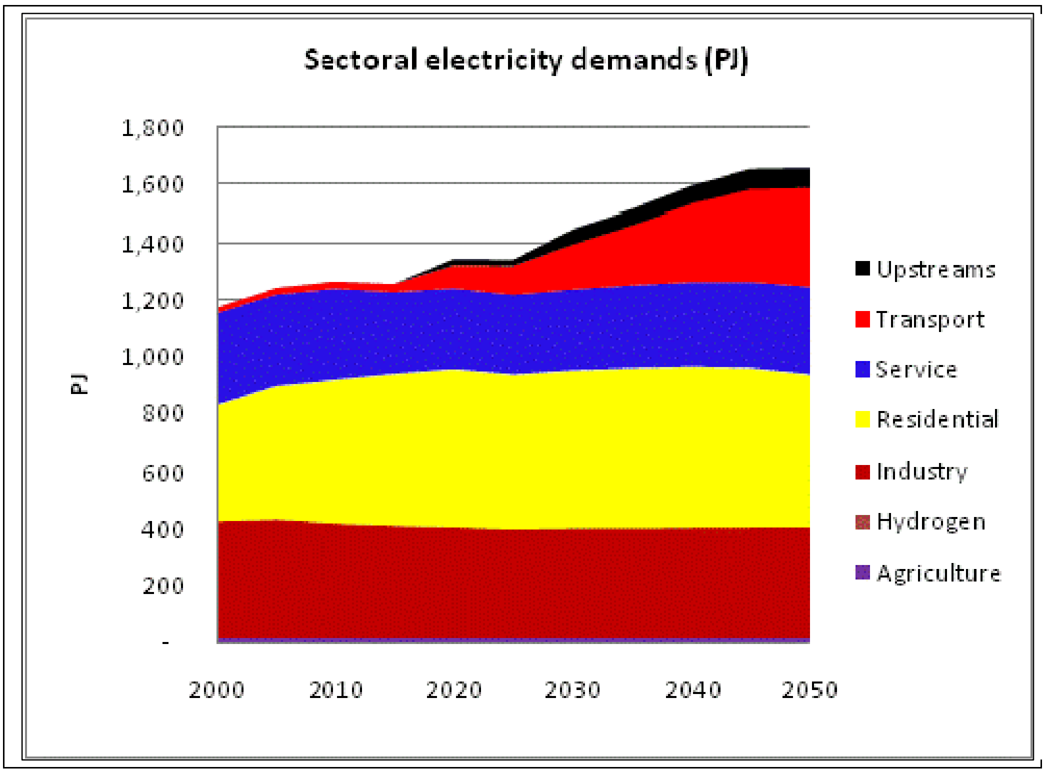

Figure 49 Multi purpose networks sectoral electricity demands, 2000-2050

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.

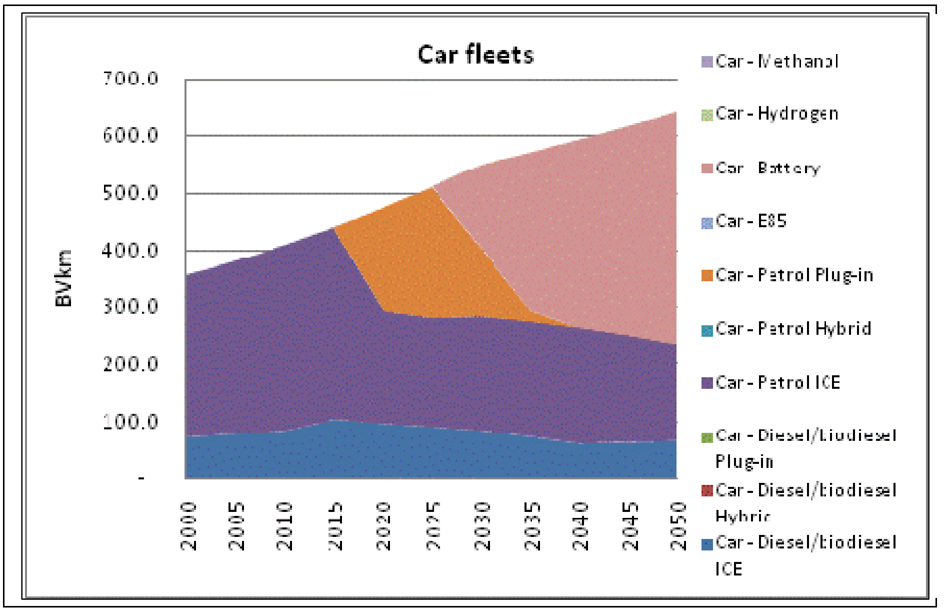

Figure 50 Multi purpose networks car fleet technologies, 2000-2050.

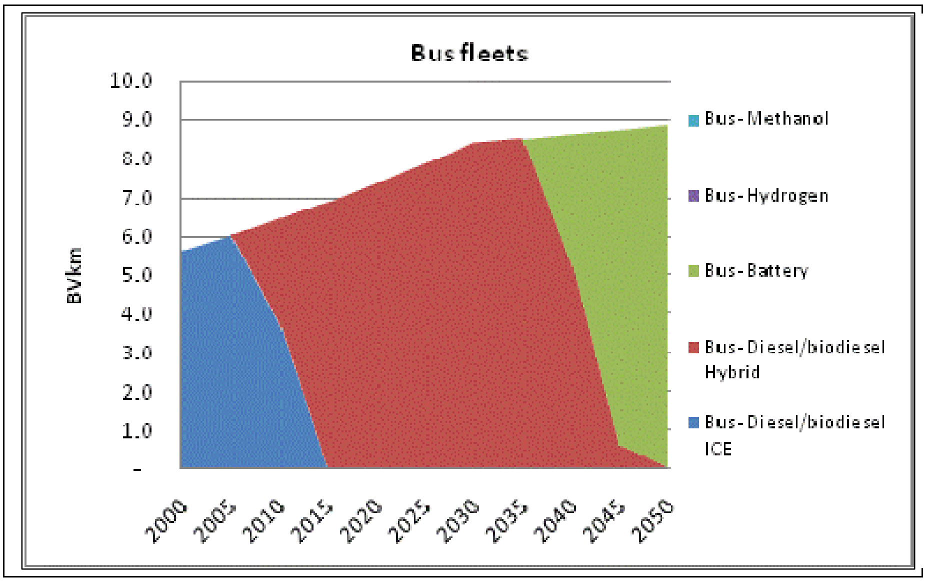

Figure 51 Multi purpose networks bus fleet technologies, 2000-2050

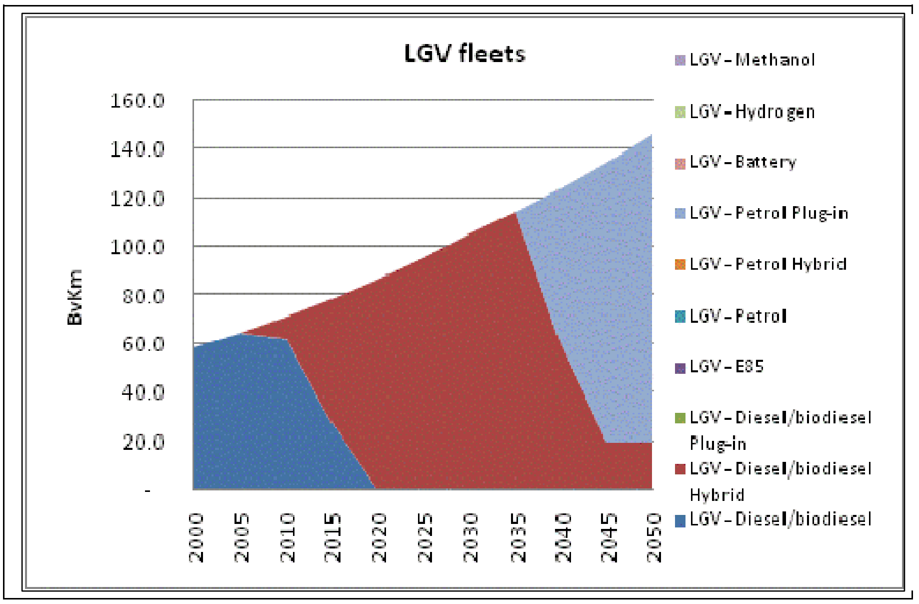

Figure 52 Multi purpose networks LGV fleet technologies, 2000-2050

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 46% reduction over the system as a whole.

Relation of model run to scenario storyline

This run supports much of the scenario storyline. There are two issues however which the model run highlights. The model run does not choose much offshore wind: this is due to the fact that so many other technologies have been forced in that it has no need for what is commonly thought of as one of the most viable sources of renewable electricity, finding the onshore wind resource sufficient. Second, there remains a significant role for electricity storage including plug in hybrids, due to the variety of technologies forced in. Although the scenario storyline does not discuss in great detail issues of 'active demand management', nevertheless if such a diverse technology mix was stimulated due to conflicting policies, it may require some careful system management.

Generation type		Network	Installed capacity (GW) in year:	
			2025	2050
Large thermal (no CCS)		T&D	20	13
Large thermal (CCS)		T&D	11	36
Nuclear		T&D	21	18
Large wind	Offshore	T&D	1.2	0
	Onshore	T&D	8.6	8.3
Marine		T&D	5	11
Other large renewable		T&D	12	5
Storage		T&D	2	2
Imports (interconnector capacity)		T&D	4	11
CHP	Large (industrial / commercial)	T&D	2	2
TOTAL T&D			86.8	106.3
CHP	Small (household)	Distribution only	0	0
Microgen (inc. microwind, solar etc)		Distribution only	3.2	7.8
TOTAL DISTRIBUTION ONLY			3.2	7.8
TOTAL			90	114.1

Table 10 Multi purpose networks installed capacity by network connection – Draft results

A more detailed discussion of these points is contained in Appendices A and B (sections 7 and 8).

4.5.4 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 power networks.

4.6 Comparison of modelling results across the five scenarios

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.

Nuclear and CCS: 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- as a greater proportion of gas turbines' overall cost is fuel cost, these technologies are more sensitive to higher fuel prices. Therefore, if the higher BERR fuel price projections of 2008 were used in the model, it is unlikely that there would be a great change in this particular aspect of the technology mix.

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.

Biomass and CHP: A potential low carbon alternative to natural gas for the residential and service sectors might be thought to be biomass, however the model does not choose this for the direct production of heat in these sectors. This is because the biomass 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 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. If higher resource prices were assumed for natural gas, this might also affect the balance between natural gas and biomass. CHP is also 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. 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.

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 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 (see row three of Table 11). 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 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.

Welfare losses: In the two runs with the elastic demand function enabled, a comparable trend emerged of deep economic and social costs in the middle of the period, as high carbon prices resulted in high energy prices and demand reductions, with resultant welfare losses. However, in both cases welfare losses began to reduce towards the end of the period, as cost effective low carbon technologies became available. This indicates the importance for the wider economy of developing low carbon technology alternatives, and that the sooner such options become cost effective the less will be the resulting welfare losses in future periods where carbon prices may be high. This underlines the economic good sense of major upfront investment in developing low carbon technologies and the systems to manage them at an early stage. The kinds of technology development possibilities that were considered as assumptions within these runs, particularly in the DSO and MG runs, would imply not just a solid R&D programme within the UK, but significant consensus at the international level as a result of which a number of other countries would be involved in developing and deploying these technologies, driving down costs through economies of scale and learning.

	2000	2050				
		Big T&D	ESCO	DSO	MG	MN
Total Primary Energy Demand (PJ)	**8,624**	**8,463**	**7,631**	**6,021**	**5,148**	**7,492**
Total Final Energy Demand (PJ)	**6,189**	**6,468**	**5,807**	**4,910**	**4,558**	**5,785**
Total Electricity Generation (PJ)	**1,288**	**1,652**	**1,874**	**1,501**	**1,462**	**1,860**
Total Electricity installed capacity (GW)	**84**	**101**	**120**	**105**	**113**	**114**
Total Final Electricity Demand (PJ)[14]	**1,176**	**1,449**	**1,665**	**1,370**	**1,376**	**1,657**
Relative size of electricity sector to whole system (%)[15]	**19**	**22**	**29**	**28**	**30**	**29**
Relative size of distributed generation to total electricity generation (%)[16]	**0**	**0**	**14**	**23**	**42**	**7**
Electricity CO2 reductions from 2000 (%)	**0**	**50**	**88**	**95**	**99**	**78**
Whole system CO_2 reductions from 2000 (%)	**0**	**24**	**54**	**61**	**71**	**46**

Table 11 Snapshot summary of the model runs in 2050 – Draft results

[14] Includes electricity used for hydrogen electrolysis as well as end use electricity
[15] Total Final Electricity Deman (PJ) / Total Final Energy Demand (PJ)*100
[16] Total distributed generation installed capacity (GW) / Total electricity installed capacity (GW)*100

5 Initial Implications for Networks and Regulation

This section sets out some of the implications of the scenarios presented in the previous section and forms the academic team's contribution to the work on implications of scenarios being undertaken by Ofgem.

The academic team have reviewed the scenarios presented in this report and offer the following initial view on implications of the scenarios. The implications are not repeated across scenarios.

5.1 Big Transmission & Distribution

- This scenario paints a picture of expanded power 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 a power network based on passive consumers given potential environmental, energy security and economic concerns does not seem logical. The implication here is that passive consumers may be undesirable from various important perspectives.

5.2 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, 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 power 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.

5.3 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 ICT. The investment in and delivery of such advanced ICTT systems is far from trivial with security, privacy and appropriate use of the information all key issues.

5.4 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 arrangements between microgrid system operators (MSOs) and DSOs/TSOs for network services is 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.

5.5 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 network 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.

6 Next Steps

This report is the latest contribution from the LENS academic team and draws to a close several months of intensive activity to produce a set of draft electricity network scenarios for Great Britain for 2050.

The next steps of the project will include the consideration of stakeholder feedback to the Ofgem consultation on this report and the production of a final scenarios report. There will also be further assessment of the implications for networks and the regulation of networks.

Further inputs from external academic peer review and from the consultation process will provide stakeholders with the ability to contribute to the final stage of the project and to have confidence in the rigour of the process to the end of the project.

More details on next steps are provided in the Ofgem consultation letter about this report.

7 Appendix A – LENS Modelling: Further discussion

The discussions of the modelling results found in section 4 were abridged from a slightly longer discussion which is reproduced in full here. Data are available in the form of the graphs reproduced in section 4, as well as in the tables reproduced in Appendix B, section 8.

7.1 Big Transmission & Distribution

There is a steadily growing demand for electricity which is significantly stronger than the overall increase in energy service demand across the system as a whole. The strongest growth for electricity demand is found in the residential sector. As well as growing service demands, this suggests that electricity is becoming increasingly cost effective through the period compared to the direct use of gas, which though it is used for residential and services space and water heating, becomes increasingly more expensive as continued use moves it up the resource supply curve.

This model run therefore shows a growing electricity generation sector, where the growth is entirely met by large scale generation plants connected to the large T&D network. The model does not invest in new nuclear, hence nuclear capacity is reduced to zero by the end of the period. For its major baseload capacity it overwhelmingly selects coal, finding it cheaper for baseload capacity than nuclear or gas plants. When the increasing carbon price encourages it to seek lower carbon options, it selects CCS on coal plants rather than gas, installing about 20 GW between 2025 and 2035.

It is important to stress that as the model seeks an economically optimal solution it is to be expected that it will strongly prefer one particular (lowest cost) option. In this case though, this is on the basis of quite small differences between the capital costs of these major base load technologies, and that modified yet still plausible cost assumptions would have yielded a different balance between these technologies.

Another aspect to the preference for coal however is due to the fact that the model prioritises gas for use in the residential and services sector, using the cheapest gas for these services. Having made this allocation, the gas which could be used for electricity generation is more expensive than the coal, being further up the resource supply curve.

By 2050 the model is effectively generating no electricity from gas for average peak and off peak demands, however it has nevertheless installed 12 GW of gas fired generation in order to meet the need for flexible generation.

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 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 technology mix represented in this model run would have particular implications for networks. It would not require significant investment in more flexible distribution networks, such as to enable the connection of distributed sources of electricity generation. In some ways it represents very little departure from the current organisation of the networks. However it does nevertheless represent some significant investment requirements for the purpose of connecting large scale plants. Though the large amounts of coal based capacity might be expected to be sited in areas where a good connection to the grid was already available, the 14 GW of large scale wind generation (of which around 8GW is offshore) may need some planning and facilitation. The carbon price however is not strong enough to stimulate a wider portfolio of low carbon technologies, and the network required to support such a mix would not be required to consider the connection of marine technologies, for example. Perhaps the biggest impact would be the upgrade in interconnectors, which are required to provide flexible balancing, and encouraged by the relaxed constraints assumed in this run. It raises the question as to whether an increased import capacity should be an important part of our generation mix, and if so how the investment to deliver this should be mobilised.

This run delivers modest decarbonisation achieving a 51% CO_2 emissions reduction in 2050 from 2000 levels within the electricity sector. Across the whole energy system, the scenario achieves a 24% CO_2 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.

Impacts of the changes in the electricity sector in the wider system are relatively small in this run. This is again because the carbon price does not affect the whole system. There is however a growth in electric vehicles towards the end of the period, driven by cost effectiveness as the technologies improve their performance, rather than a carbon incentive. Buses are beginning to electrify in 2050, and plug in hybrids are starting to show a fast growth.

This model run delivers a technology mix which compares very closely to that described in the scenario storyline, as the key drivers implemented in the model of moderate carbon policy and the favouring of the existing large transmission network lead to similar outcomes as described in the scenario. The 'initial surge' in low carbon generation in response to government carbon policies described in the scenario is reflected in the fast installation of CCS in the middle of the period, which plateaus by the final decade, reflecting a levelling off of the carbon price, implying a slowing down in policy initiatives. The model also depicts an evident, though relatively slow and niche focused, take up of electric vehicles, as described in the scenario.

The biggest differences are in the precise kinds of large scale base generation technologies which are selected. The scenario sees moderate carbon concern, though without a more stringent 'deep green' philosophy bringing on a range of large generating technologies, including gas CCGT, coal with and without CCS, and nuclear. As has been discussed above, as the model cost optimises it is likely to overwhelmingly prefer one of these broadly comparable technologies, and nuclear is the main loser in this run, though gas still maintains a role for flexible plant. The preference under higher carbon prices for coal CCS rather than gas CCS is driven by the moderately high resource prices, gas powered generation being more sensitive to higher fuel costs. It is also due to competing end uses for gas, which is used for direct heat in residential and industry sectors, the model's preference indicating that it finds this a more cost effective allocation of resources than to use gas for electricity generation. While the model run may seem to present a much more uniform supply mix than that of the scenario, in another sense it confirms the scenario's description of gas being widely used for space and water heating. This bias is the result of a system wide cost optimisation, and does not reflect policies which the government may implement to deliver a more diverse generation portfolio, for example in order to meet security of supply objectives.

The scenario describes wind and tidal generation as well as onshore and offshore wind, however the model does not select these marine technologies. With the relatively modest carbon driver it has no incentive to move beyond wind, indicating that a broader renewable generation mix would require either a much stronger carbon price signal, or technology specific deployment policies. Whether such policies would be part of the Big T&D scenario as currently described is open to question- and this therefore may be the biggest area of 'challenge' of the model to the scenario.

7.2 Energy Service Companies

Despite endogenous changes in energy service demands not being available to the model in this run, reflecting the 'passive' consumer characterisation in the ESCO scenario, this run achieves a slightly lower overall primary energy demand than Big T&D. This is because the higher carbon price is incentivising a more efficient selection of technologies, both at generation and end use level. This is particularly evident in residential demand for electricity, which grows in line with the Big T&D run until 2040, before the higher carbon price on the electricity sector at the end of the period, making electricity more expensive, encourages the selection of more efficient end use technologies, resulting in a small decline in residential electricity demand.

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, generating a total of 1,874 PJ in 2050, compared to Big T&D's 1,642 PJ. With the industry sectors reducing electricity demand due to efficiency measures, and services and agriculture remaining more or less constant, this increase is the result in a massive increase in electricity demand from the transport sector, rising from 20 PJ in 2000 to 330 PJ in 2050.

The ELC system
Due the increased environmental priority described in the ESCO scenario, this run operates with a higher carbon price than in Big T&D, of £60/tCO2, but which still only applies to electricity and industry sectors. Once again decarbonisation is driven by the availability of options in the electricity sector. The industry sector does achieve significant decarbonisation, but this is almost entirely as a result of decarbonisation in the electricity sector, with electricity it uses becoming

significantly less carbon intensive. This is also true for the service sector, although this sector also doubles the use of energy conservation options compared to Big T&D, as a result of these being made available under the assumptions of the scenario.

When applied to the electricity and industry sectors alone, a carbon price of £60/tCO2by 2050 is sufficient to almost entirely decarbonise electricity- CO2 reductions in this sector from 2000 levels are 88%. This means that whereas in Big T&D the dominating Coal CCS baseload was supplemented with advanced coal without CCS, in the ESCO run the carbon price is sufficient to completely disincentivise investment in coal power without CCS. In the ESCO run generation from coal CCS hits a ceiling slightly below that of the level in Big T&D, 937 PJ in 2050. 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). In this situation then, it becomes cost effective to fulfil the remainder of the baseload requirement by investing in nuclear (which the model considers zero carbon), a technology which had no capacity by the end of the period in the Big T&D run.

The other very significant aspect of the electricity generation mix in this run is the large amount of wind power, which is expanded steadily throughout the period. The model very quickly uses all the available onshore wind resource of 6m/s and over, around 8.4 GW. It then proceeds to the offshore resource, installing 9.4 GW by 2040 and generating 110 PJ p.a. By 2045, due to the accelerated cost and performance assumptions as part of the ESCO storyline, as well as the rising carbon price microwind has become economically attractive, and the model immediately chooses to invest in this technology to the maximum level permitted by the constraint. This results in a huge investment of 8.4 GW to generate 66 PJ p.a. By 2050 247 PJ of electricity are generated from wind, with 27% of the total coming from micro-wind.

The rising carbon price and ESCO accelerated technology assumptions stimulate a late surge in generation from solar PV, with 47 PJ being generated in small scale residential applications. Marine technologies also feature with 64 PJ by 2050- this energy is entirely from tidal stream applications. Biogas driven thermal plant, from agricultural wastes, landfill and sewage gas are also generating 39 PJ by the end of the period.

Gas powered generation is effectively absent from the average base and shoulder load generation periods, with the majority of gas being diverted for direct use in space and water heating in buildings, the model seeing this as a more cost effective use of this premium resource. However a significant 16 GW of gas fired plant remains active in 2050, to provide flexible response for demand peaks.

The transport sector sees major technology changes over the period. First, the period from 2020 to 2035 sees a large investment in plug-in hybrids. This investment is stimulated by the favourable economics of this close to market technology, but also by its extra advantage of providing electricity storage to allow greater penetrations of variable electricity generation. From 2030, full battery electric vehicles are becoming economically attractive, and become the dominant form of private car transport by 2050, as well as penetrating significantly into bus fleets. No adjustments were made to the costs or performance characteristics of these electric vehicle technologies compared to the Base or T&D data. Their improved prospects were entirely due to the reduction of the discount rate from the higher one previously applied to reflect perceived risk of these 'unknown' technologies, to a standard market discount rate. This implies that ESCOs could have a significant role in changing the prospects for such transportation technologies simply by providing them as part of an 'energy services package', reducing perceived investment risk for the consumer, even without major technological breakthroughs. It should also be noted that this could also have a sizeable impact on the size of the electricity system, with the electrification of transport being almost entirely responsible for the growth in electricity demand in the second half of the period.

It should also be noted that these changes were not driven by direct carbon policies- the carbon price did not directly apply to the transport sector. However, as described above the decarbonisation of the electricity sector does stimulate a demand for electricity storage technologies and so is likely to have indirectly stimulated demand for plug-in hybrids.

Overall decarbonisation

All major end use sectors in this scenario achieve significant decarbonisation. However, in every case this is directly related to their use of electricity which, due to the carbon price, becomes an increasingly carbon-free energy vector through the period. 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. They thus effectively achieve decarbonisation by accident. The electricity system reduces its carbon emissions between 2000 and 2050 by 88%, contributing to an overall systems CO_2 mitigation effort of 54%. This run therefore clearly demonstrates that the electricity sector is of major importance in decarbonisation efforts in the UK, and that even policy drivers aimed principally at the electricity sector will have significant effects across the whole system, particularly if technology choices in other sectors favour electricity. 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.

Relation of model run to scenario storyline

The model run provides on the whole results which confirm and support the storyline developed for the ESCO scenario. The fairly high levels of environmental concern, combined nevertheless with an absence of public appetite for major systemic and lifestyle changes, see high levels of energy service demand met in the electricity sector principally through large scale low carbon centralised generation technologies.

At a more detailed level, the success in the model results of microgeneration technologies as well as electrified transport, highlights the potentially important role identified in the scenario storyline of ESCOs in reducing the financial risk for individual consumers in new technologies, and also in overcoming barriers to information, implementation and driving down costs through economies of scale. Given that a significant part of the installation costs of microgeneration technologies is in installation, it is likely that significant cost reductions in these technologies may be expected if they are included in designs for newly built houses as opposed to retrofitted, which may be encouraged by future building regulations. The significant levels of microgeneration in the results have significant implications for networks. The model sees these technology groups as having *en masse* a relatively stable output- this implies that the model is effectively 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. This can be explained by the fact that in its current configuration the model has slightly different constraints under which it may produce electricity and provide heat. The residential sector is not itself subject to a carbon price, hence gas can be freely used in the existing network infrastructure to provide space and water heating in the conventional fashion. There is no added benefit therefore of producing small scale heat in a low carbon manner, and the electricity still has economies of scale when produced in large plants. The model results seem to suggest that given the advantages of retaining existing large scale infrastructure, small scale CHP would need specific policy support to be utilised.

7.3 Distribution System Operators

This run allows for the operation of elasticities in energy service demands, which indicates a society which due to rising environmental concern which takes root in a more fundamental way, is prepared to take measures to reduce its demand across all sectors, if encouraged to do so by carbon policies (represented in the model by the carbon price). However, it is also the case with the elastic demand option that service demands may increase, if the additional social welfare generated as a result of the service outweighs the costs of providing it. This leaves open the option for successful low carbon technologies to actually increase energy service provision, implying the increased stimulation of economic activity in some areas.

The effect of the elastic demand component is the most noticeable element of the primary energy demand mix in this run compared to Big T&D and ESCO. Total primary energy shows a very clear and steady downward trend, most evidently between 2005 and 2035. Looking at the sectoral response, all sectors have reduced their energy service demand levels- for example, residential heating and hot water demand has reduced by 17%, implying end use efficiency, but also some significant cultural and lifestyle changes in perceived domestic 'comfort' levels. The one service demand which shows a modest increase is car transport, showing a 5% increase above the base level in 2050. This has been allowed by the availability of a low carbon transportation option which escapes the carbon price and therefore stimulates increased demand.

Total levels of electricity generation show a modest growth overall, but ultimately remain somewhat less than the previous two runs, producing 1501 PJ in 2050. There are two high level factors influencing this final total. The first is that in the middle of the period the constraint on the use of the transmission system to supply residential and service electricity reduces electricity generation overall: whereas the model finds some distributed options to supplement the supply to these sectors, they are by this stage not cost effective compared with the other option of reducing service demands. Towards the end of the period two things happen to bring the total levels of electricity generation up again. First the model does start to find more cost effective distributed options to make up some of the restricted residential and services supply deficit. Second, developments in other sectors not subject to the transmission constraint, most notably transport, generate a steadily growing demand for electricity between 2030 and 2050.

The DSO scenario storyline emphasises that despite the increased importance of distribution level generation, the transmission network will still play a strong role in this scenario, not least because of the value of the investments already made in these infrastructures. The model run echoes this description with very significant levels of large scale centralised low carbon generation remaining the backbone of the electricity system. As in the ESCO run, gas powered generation is squeezed out of what becomes a highly decarbonised electricity portfolio, by 2030. CCS is again selected for coal rather than gas due to the more cost effective possibilities for the use of gas in other sectors. 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 as fully utilised as in ESCO, 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 5GW.

The higher carbon price and the constraints on transmission mean that microwind (which avoids the transmission network) is an attractive option much earlier in the period, receiving its first major investment in 2015, and reaching its maximum capacity in 2020.

For the same reasons the prospects are also increased for residential solar PV, which also feeds in directly to the distribution level, and 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 is no longer cost effective- in this run of course, the carbon price is extended to residential, transport and services sectors.

Tidal stream also shows in strong growth in the final decade of the period, stimulated by the carbon price and the growing electricity demand from the transport sector, though it does not reach the level it achieved in ESCO. The increase in variable renewable generation during this final period stimulates a greater requirement for electricity storage options. However, this is of about half the level of that required for ESCO due to the lower quantities of variable renewables. This does not account for the variability of the distributed generation technologies. It is clear that DSOs will have to take highly innovative measures to balance these at the distribution network level- this is assumed within the model assumptions and described in more detail in the scenario storyline.

Once again the transport sector undergoes major systemic changes, with significant impacts on the electricity sector. This is driven by one of the key DSO scenario storyline themes, that the UK is part of a concerted international push to develop a 'hydrogen economy'. With the advanced technology inputs to the model intended to represent this scenario, hydrogen fuel cell cars and buses become cost effective in this run from 2030. As the carbon price is extended to the transport sector, the hydrogen on which these vehicles run has to pay for any emissions associated with its production.

The model prefers small scale hydrogen generation options which avoid the requirement to build hydrogen pipelines or use hydrogen tube trailers. Rather it uses existing infrastructure- the gas and electricity networks, to move the energy over long distances, for conversion to hydrogen at the point of use using small scale steam methane reforming and electrolysis. 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 1501 PJ to 2071 PJ.

In 2050, about 80% (356 PJ) of the hydrogen produced and distributed to the transport sector comes from small scale steam methane reforming (SMR), a process which due to its distributed nature cannot be linked to CCS and therefore incurs a carbon penalty. The remaining 20% comes from small scale electrolysis- a technology which was also permitted some advanced technology development based on the most optimistic industry assumptions. This electrolytic production of hydrogen represents a significant share of the increased demand on the electricity sector towards the end of the period. It is also clear that the need to generate low carbon hydrogen has been the factor which shifted some of the hydrogen production from SMR- which would otherwise have been the preferred option- to small scale electrolysis, demonstrating how policies applied to other sectors can increase demand for electricity. As has been discussed, the relatively low carbon intensity of hydrogen vehicle transport, due to the high efficiencies and the contribution of electrolytic production, means that as this option approaches economic viability it stimulates a positive demand response, increasing car transport service demand levels. From the more specific perspective of the economics of hydrogen technologies and infrastructure, it is noticeable that the model has in this run chosen options which avoid the requirement to build hydrogen pipelines or use hydrogen tube trailers. Rather it uses existing infrastructure- the gas and electricity networks, to move the energy over long distances, for conversion to hydrogen at the point of use.

Battery electric cars and buses do not compete with the fuel cell options in this run. The lowered discount rates for electric vehicles used in ESCO do not apply in this run, and this combined with the increased progress in hydrogen technologies, means that these technologies are not selected. However, elsewhere in the transport sector electrification continues, further stimulated by the high carbon price. Rail transport is completely electrified by 2050, and plug-in hybrids dominate in the LGV fleet, also providing electricity storage options in the final decades of the period, facilitating the increased penetration of variable renewables.

The Markal Elastic Demand parameters show a sharp negative spike in the change in consumer plus producer surplus, indicating the highest impact on overall social welfare at around 2035. This correlates to a period when the carbon price is already high but the full range of low carbon technology options are not yet available or fully cost effective. The last decade and a half represents a period when a range of low carbon options are becoming cost effective allowing the system to avoid the carbon price without having to forgo energy services, as shown by the increase in consumer surplus. The change in consumer plus producer surplus compared to the base case recovers to close to zero by the end of the period.

Overall decarbonisation
All sectors contribute to decarbonisation, though once again, the electricity sector carries the majority of the burden and other sectors largely achieve their decarbonisation through their use of electricity as an energy vector. Transport achieves quite considerable emissions reductions through technology switching to electricity and hydrogen. The residential sector on the other hand does not decarbonise through switching to electricity for heating which is limited by reliance on microgeneration, or through the use of biomass, but 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.

This run has therefore demonstrated that with a representation of a 'thinner' transmission network, the model will deploy significant amounts of microgeneration for electricity services. However, natural gas remains a major energy vector for space and water heating demand. Industry and transport however continue to make full use of the transmission network to assist their decarbonisation.

Relation of model run to scenario storyline
It must be reiterated at the outset of this section that a major element of the scenario storyline was imposed on the model through an exogenous constraint-that is, the constraining of access to the transmission grid for residential and service sectors. In comparing the model results to the scenario storyline, it must be acknowledged that this is in some ways a fairly artificial constraint. However, it is also worth considering the implications of the need to resort to this technique in generating runs with a greater role for distributed technologies. MARKAL favours large scale generation and transmission because of economies of scale and the

existence of a large infrastructure in which the investment has largely already been made. Arguably these are very strong reasons to favour such a network, and that therefore the burden of proof is on the viability and desirability of an alternative one. Furthermore, it does seem clear that the establishment of greater roles for distribution networks would need planned and deliberate policy action to create the right regulatory 'enabling environment'- and in this broader sense it might be argued that an exogenous constraint on a model with a tendency to perform in a certain way is not a completely artificial construct.

Notwithstanding these issues, the effect of the constraint does deliver a need for microgeneration which becomes particularly acute as the constraint reaches its highest level in 2030. The accelerated cost and performance assumptions, assumptions which are justified as part of the strong political push for the use of microgeneration, mean that microwind is being selected in large amounts by 2015, with solar following by 2025. This is in line with the scenario storyline, in particular the waymarker indicating a breakthrough for microgeneration, in part stimulated by the desire for zero carbon housing.

The model run avidly takes up hydrogen for transportation purposes in response to the carbon price but also the advanced technology assumptions which were justified as part of the scenario storyline. However in contrast to the scenario storyline hydrogen is not utilised for stationary power in small fuel cell CHP units. The model has not taken up these options due to the availability of various other cheaper technologies for providing both heat and power, to residential and service end uses. This is despite an input assumption of 25% capital cost reduction in these technologies- hydrogen is still prioritised for the transport sector. It should be acknowledged that due to time constraints it was not possible to significantly reappraise the basic technology assumptions for stationary hydrogen applications. Nonetheless the focus of the model results on vehicles is in line with recent detailed analyses of the prospects for hydrogen as a carbon mitigation option.[17] In terms of hydrogen generation, the model overwhelmingly prefers small scale options located at the point of use, to avoid the additional costs of hydrogen distribution infrastructure. This confirms the scenario storyline.

The model confirms the scenario's description that base load generation from large scale nuclear and fossil fuel with CCS plants remains a major part of the energy mix. Indeed nuclear is becoming more prominent than in previous scenarios, as the higher carbon price is becoming increasingly punitive for the residual emissions of CCS. The scenario's indication that gas will remain an important fuel is confirmed by the model which continues to deploy gas for space and water heating in buildings. However, once again the model does not pick up any form of CHP, which contrasts greatly with the scenario description. Now that the carbon price applies directly to the residential and service sectors, CHP is not enough of a low carbon option to be economically viable.

The scenario storyline describes fairly strong economic growth overall. While MED is not a macro-econometric model, and therefore cannot comment directly on the interactions of the energy system with the wider economy, and corresponding effects on GDP, it nonetheless raises some questions about wider

[17] See: Eoin Lees et al (2004) *A strategic framework for hydrogen energy in the UK.* Available at: http://www.berr.gov.uk/files/file26737.pdf

economic impacts. Most notably it implies fairly considerable energy service demand reductions in almost all sectors. It is worth considering what the implications of such demand reductions would be for economic growth, at least as it is conventionally defined. However, as described, the MED parameter of consumer plus producer surplus, which balances the welfare delivered through energy services against the cost of delivering them, returns to very close to the base case level at the end of the period. This may be interpreted as a decade at the end of the period when the long term investment in low carbon technologies is finally paying off, as the technologies becoming competitive, delivering substantial benefits to overall welfare after a period of significant welfare losses when high carbon prices were combined with a less well equipped technology portfolio.

7.4 Microgrids

As with the DSO run, this run has the model's elastic demand function enabled. The very high carbon price is intended to represent a world of very high concern for carbon emissions, where 'climate change will be at the forefront of decision making for individuals, private companies, public institutions and the Government in the UK.' As such this priority extends to every level of society, as in the model does the carbon price. This price incentivises lower carbon technology choices, and also stimulates even greater demand responses, which within the context of the scenario are interpreted as being correlated to a very strong societal willingness to undergo social and lifestyle change.

Total primary energy demand therefore ends up at the lowest level of all the runs, 5148 PJ in 2050. Perhaps the most notable aspect of this severely curtailed energy mix is that demand for natural gas remains almost unchanged from previous runs. This is because natural gas is still being used with very little change for space and water heating in buildings. Although this use is incurring a carbon penalty, the comparatively low carbon intensity of natural gas compared to other fossil fuels means that the penalty is not sufficient to incentivise a major switch to more costly alternatives for providing residential and service heat, particularly when access to electricity for these purposes is limited due to the constraint on transmission. The model prefers instead to make the reductions in other areas where the alternatives are more economic.

Demand reduction is employed to a very significant extent by the model in response to the high carbon prices. Industry, agriculture and service demand reductions occur in the range of 3 to 30%, and residential services, including electrical appliances, heating and hot water, reduce by 20-25%. Again, the wider economic implications of such demand reductions would be significant. Transport demand reductions are in general slightly less great. As in the DSO run, it is the only sector where one service demand shows an increase, again that for car transport, due to the availability of cost effective low carbon alternatives late on in the period.

The MG electricity sector is the smallest of all the runs in actual terms as a result of the major energy service demand reductions; however, relative to the size of the whole energy system in this run, the MG electricity sector is the largest of all runs. From 2010 to 2025 total electricity generation declines significantly as demand reductions are the only available response to the steeply increasing carbon price and the constraints on the transmission network. However from 2025 onwards the increased availability of distributed technologies to meet demand in the residential and service sectors, as well as a major increase in demand for electricity from the transport sector, both directly and indirectly through the production of hydrogen, sees a very significant overall expansion in electricity generation. Due to the fact that this transport-bound electricity can be provided through the transmission network, the model is able to use large scale plants to meet this demand, and the response is a huge investment in nuclear from 2025 onwards. As discussed in previous sections, the residual emissions from CCS are a potential weak point in its economic battle with nuclear, depending on the strength of the carbon price. In this run the very high carbon price tips the balance in favour of nuclear such that it becomes completely dominant.

For the first time gas is back within the main electricity generation mix, rather than simply being held back as flexible responsive plant. This generation is from small scale gas fired CHP, at the residential and commercial scale, which are required to provide a source of distributed residential and service electricity demand as the constraint on transmission becomes more and more pressing. This transmission constraint is the main reason why this scenario is the only one to significantly deploy small scale CHP, and to use heat as an energy vector for final distribution. 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.

As would be expected, this run also deploys significant quantities of microgeneration, and begins to do so even earlier in the period than in DSO. The microwind resource is once again fully deployed by 2020, and residential 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 the assumptions on electric vehicles under ESCO and those on hydrogen vehicles under DSO were combined, under the general assumption that in this world of very high environmental concern efforts would be made by both governments and private companies to pursue a range of options, resulting in something of a 'technology battle' between competing low carbon options. This is exactly what plays out in the model run, with the transport sector made up of the most diverse technology mix of all runs. The private car fleet begins to make a major change towards electric vehicles in 2030; however by 2035 hydrogen fuel cell cars also enter the market strongly and by 2025 have an equal share with battery vehicles, with a small number of conventional diesel cars still on the roads. The bus fleet converts completely to hydrogen, whereas HGVs continue to use diesel but with hybrid technology for greater efficiency. In the LGV fleets plug-in hybrids dominate, and as before these also have a crucial role as electricity storage options to balance variable supply sources. The rail fleet is completely electrified.

The model retains a preference for small scale hydrogen production methods which avoid the problems of distribution infrastructure. In 2050, 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 55PJ 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).

It is also notable that in the transport fuel mix, the remaining vehicles running on diesel (mainly HGVs) have switched from conventional to biodiesel. This completes a multi-technology and multi fuel switching process which means that, with the exception of a small number of petrol ICE cars, the transport sector is almost completely decarbonised.

MED:
This run incurs very significant costs in a two key ways. First the very high carbon price increases costs across the system. Second, the constraints on transmission to residential and service sectors have reduced the ability of relatively affordable large scale low carbon options to contribute to decarbonisation in these areas. The constraint has encouraged the deployment of small scale renewables, however due to both their costs and physical capacity constraints they are unable to contribute fully. Residential and services space and water heating therefore achieves very little reduction in carbon intensity.

These increased costs cause some significant demand reductions, as observed above. This produces a similar pattern in the MED overall system welfare indicator of consumer plus producer surplus as found in the DSO run. However, whereas in DSO welfare losses were close to zero by 2050 due to the increasing benefits of low carbon energy technologies, in this run, though that upward trend is starting to become evident by the end of the period as the technologies improve their cost, welfare losses remain highly significant compared to the base year, at £11.4 bn (yr2000£). The costs incurred earlier in the period have been that much greater that the recovery is somewhat delayed.

Overall decarbonisation
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.

Relation of model run to scenario storyline
The comparison of this model run to the scenario storyline must be viewed with the same caveat as applied to the DSO run. A more binding constraint on the transmission system must be viewed as in some ways a slightly artificial exogenous constraint; nonetheless it is worth reiterating that a highly distributed system would be likely to be the result of some very concerted policy action to move the system in that way, as highlighted within the Microgrid scenario, which describes 'overall Government strategy supporting distributed energy'.

This run certainly represents a scenario where environment concern is strong throughout every level of society. The main environmental driver, the carbon price, applies to all sectors and becomes extremely high, causing major technology switching as well as demand response, which would be commensurate with fairly major behavioural shifts in the use of energy.

DG technologies are now widely deployed, which reflects one of the key elements of the scenario. However, the measures that were taken in this run- major acceleration of technology development as well as significant transmission constraint- may give some indication that serious policy support would be required for these technologies to be deployed. A policy area of major importance could be low carbon housing. Distributed technologies would also require careful load management, an assumption which is also implicit in their technological characterisation in the model.

As described in the scenario, gas is still prominent, though not just in the medium term, retaining its importance in CHP applications due to the constraint on electricity transmission.

Hydrogen is perhaps more prominent than is suggested by the scenario storyline. The positive technology assumptions about hydrogen were kept in the model for this run alongside those relating to electric vehicles, driven by an assumption that this scenario takes place within a context of 'global consensus' where international action drives down costs across a range of low carbon technologies.

7.5 Multi Purpose Networks

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 2025. This year sees microwind 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 microgeneration technologies also see residential solar PV making a small contribution towards the end of the period.

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 46% reduction over the system as a whole.

This run supports much of the scenario storyline. There are two issues however which the model run highlights. It does not choose much offshore wind- this is due to the fact that so many other technologies have been forced in it has no need for what is commonly thought of as one of the most viable sources of renewable electricity, finding the onshore resource sufficient. Second, there remains a significant role for electricity storage including plug in hybrids, due to the variety of technologies forced on. Although the scenario storyline does not discuss in great detail issues of 'active demand management', nevertheless if such a diverse technology mix was stimulated due to conflicting policies, it may require some careful system management.

8 Appendix B – Model output data tables

The following data tables have been generated under a range of input assumptions which have been developed as part of a scenario process, which is outlined in detail in the main body of the report.

With reference to the disclaimer included at the start of this report, between the cover page and the table of contents, these figures should not be taken as projections or predictions, and should not be quoted outside of the context within which they were developed, namely as part of the LENS project.

8.1 Big Transmission & Distribution

Primary Energy Demand (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Renewable electricity	20	35	79	152	182	194	193	196	198	204	213
Biomass and waste	121	127	265	273	232	253	261	263	256	257	253
Natural Gas	3,907	3,994	3,825	3,710	3,618	3,417	2,645	2,660	2,675	2,592	2,461
Oil	3,039	3,029	2,514	2,442	2,412	2,299	2,483	2,403	2,317	2,289	2,187
Refined oil	- 298	- 267	- 67	- 120	- 164	- 145	- 315	- 210	- 139	- 32	20
Coal	1,500	1,502	1,374	1,524	1,517	1,637	2,623	2,865	2,831	2,952	3,146
Nuclear electricity	282	266	306	193	139	85	31	31	-	-	-
Imported electricity	52	46	41	58	40	137	146	76	164	173	182
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total	**8,624**	**8,732**	**8,338**	**8,231**	**7,976**	**7,877**	**8,066**	**8,284**	**8,301**	**8,436**	**8,463**

Final Energy demand by fuel (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,176	1,249	1,278	1,307	1,325	1,337	1,359	1,377	1,392	1,398	1,449
Fuel oil	220	183	156	153	135	117	110	102	86	123	105
LPG	52	53	22	14	7	2	25	18	3	3	1
Gas	2,391	2,396	2,418	2,433	2,480	2,491	2,486	2,485	2,503	2,433	2,407
Coal	75	95	122	110	134	143	155	168	184	205	234
Petrol	872	908	881	889	921	907	942	963	982	1,028	1,041
Diesel	1,164	1,185	1,054	964	932	907	928	950	955	953	918
Jet fuel	30	35	38	39	40	40	40	39	38	37	37
Hydrogen	-	-	-	-	-	-	3	6	11	21	33
Ethanol/Methanol	-	-	29	30	31	30	31	32	33	34	32
Bio diesels	-	-	40	37	36	39	41	42	42	41	40
Manufactured fuel	75	62	58	53	61	75	3	3	3	3	3
Biomass	28	24	45	58	54	58	48	48	62	62	62
Heat	105	132	159	173	133	140	141	136	113	110	107
Others	-	-	-	-	-	-	-	-	-	-	-
Total	**6,189**	**6,323**	**6,299**	**6,259**	**6,288**	**6,287**	**6,311**	**6,368**	**6,406**	**6,452**	**6,468**

Final Energy demand by Sector (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	51	52	53	55	56	58	59	61	63	65	67
Industry	1,473	1,442	1,451	1,467	1,490	1,493	1,508	1,516	1,524	1,532	1,540
Residential	1,961	2,072	2,117	2,132	2,128	2,057	1,987	1,979	1,966	1,945	1,920
Services	850	813	793	780	764	769	771	778	789	795	801
Transport	1,855	1,943	1,884	1,825	1,850	1,911	1,985	2,034	2,065	2,116	2,142
Total	**6,189**	**6,323**	**6,299**	**6,259**	**6,288**	**6,287**	**6,311**	**6,368**	**6,406**	**6,452**	**6,468**

Electricity generation mix (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	396	413	340	392	489	434	414	414	334	44	113
Coal CCS	-	-	-	-	-	105	610	714	767	1,086	1,086
Gas	487	550	538	545	511	445	61	51	40	30	-
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	282	266	306	193	139	85	31	31	-	-	-
Oil	16	21	10	5	4	-	-	-	-	-	-
Hydro	17	15	21	23	22	21	19	18	16	16	8
Wind	3	20	58	128	160	174	175	178	182	187	167
Biowaste & others	26	27	60	61	61	51	61	60	59	58	58
Imports	52	40	41	58	40	137	146	76	164	173	182
Marine	-	-	-	-	-	-	-	-	-	-	38
Solar PV	-	-	-	-	-	-	0	-	-	-	-
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,383**	**1,413**	**1,433**	**1,456**	**1,521**	**1,542**	**1,563**	**1,596**	**1,652**

Generation by plant type (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	592	604	609	576	673	658	1,084	1,184	1,121	1,146	1,199
Non-base load	641	694	730	793	718	761	402	330	414	424	426
CHPs	45	54	36	37	35	31	29	28	27	27	27
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,383**	**1,413**	**1,433**	**1,456**	**1,521**	**1,542**	**1,563**	**1,596**	**1,652**

Electricity storage (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Storage heaters	46	38	38	55	55	53	51	52	51	50	50
Plug-in hybrid	-	-	-	-	-	-	-	-	-	-	41
Hydrogen storage	-	-	-	-	-	-	-	-	-	-	-
Pumped hydro	10	9	8	7	6	6	5	-	-	-	-
Total	**55**	**47**	**45**	**62**	**61**	**59**	**56**	**52**	**51**	**50**	**90**

Installed capacity by fuel (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	29	26	24	19	22	19	16	16	16	16	16
Coal CCS	-	-	-	-	-	4	23	27	29	41	41
Gas	24	24	25	28	28	24	13	14	15	14	13
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	12	12	12	7	5	3	1	1	-	-	-
Oil	10	10	8	7	7	-	-	-	-	-	-
Hydro	1	1	2	2	2	2	2	2	1	1	1
Wind	0	1	5	8	11	13	13	13	14	14	12
Biowaste & others	2	2	4	7	7	16	16	13	13	3	3
Imports	2	2	2	2	2	5	5	5	5	7	11
Marine	-	-	-	-	-	-	-	-	-	-	3
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	**84**	**81**	**83**	**83**	**85**	**87**	**90**	**93**	**94**	**98**	**102**

Installed capacity by plant type (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	36	34	33	26	29	28	42	46	47	58	57
Non-base load	41	41	45	52	52	55	45	43	44	37	42
CHPs	4	3	4	3	3	3	2	2	2	2	2
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	84	81	83	83	85	87	90	93	94	98	102

Sectoral electricity demands (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	16	16	16	16	16	16	16	16	16	16	16
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Industry	412	419	405	397	392	383	387	388	390	391	392
Residential	403	464	499	528	550	563	574	580	584	586	587
Service	326	323	322	329	329	332	335	342	348	354	360
Transport	20	23	26	28	27	33	36	39	44	41	85
Upstreams	-	-	-	-	-	9	47	55	59	83	83
Total	1,176	1,244	1,268	1,297	1,315	1,335	1,395	1,421	1,441	1,471	1,522

Sectoral Emissions (Million t-CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Upstream	25	23	19	15	14	13	13	15	15	14	12
Agriculture	2	2	3	3	3	3	3	3	3	3	4
Electricity	181	194	172	187	177	153	118	118	102	50	60
Hydrogen	-	-	-	-	-	-	1	1	2	4	6
Industry	63	59	57	58	59	60	59	60	60	62	63
Residential	89	90	88	86	87	80	74	73	73	72	70
Services	26	25	24	23	22	22	22	22	22	22	22
Transport	140	146	136	132	134	138	143	146	148	151	149
Total	**526**	**539**	**500**	**504**	**496**	**470**	**432**	**438**	**425**	**379**	**387**

Transport b.v.km by vehicle type

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car - Diesel/biodiesel ICE	70.1	76.2	81.9	88.1	94.8	127.5	141.0	147.4	150.8	143.1	184.2
Car - Diesel/biodiesel Hybri	-	-	-	-	-	-	-	-	-	-	-
Car - Diesel/biodiesel Plug-	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol ICE	285.8	304.6	327.7	352.5	379.2	382.4	407.4	422.5	441.4	472.2	455.2
Car - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol Plug-in	-	-	-	-	-	-	-	-	-	-	-
Car - E85	-	-	-	-	-	-	-	-	-	-	-
Car - Battery	-	-	-	-	-	-	-	-	-	-	-
Car - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Car - Methanol	-	-	-	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel ICE	5.6	6.0	3.7	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel Hybr	-	-	2.7	6.9	7.3	7.8	8.4	8.5	8.6	8.7	8.2
Bus - Battery	-	-	-	-	-	-	-	-	-	-	0.7
Bus - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Bus - Methanol	-	-	-	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel	33.1	35.2	10.3	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel Hyb	-	-	27.3	40.1	42.7	45.6	48.7	50.0	51.3	52.6	54.0
HGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Diesel/biodiesel	58.8	64.6	62.1	27.6	-	-	-	-	-	-	-
LGV - Diesel/biodiesel Hybi	-	-	9.2	51.0	86.6	95.5	105.4	114.4	124.3	134.9	70.5
LGV - Diesel/biodiesel Plug	-	-	-	-	-	-	-	-	-	-	-
LGV - E85	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Plug-in	-	-	-	-	-	-	-	-	-	-	61.4
LGV - Battery	-	-	-	-	-	-	-	-	-	-	14.7
LGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Methanol	-	-	-	-	-	-	-	-	-	-	-
TW - Petrol	4.9	5.5	6.2	6.9	7.5	7.4	7.4	7.2	7.0	6.8	6.7
TW - Electricity	-	-	-	-	-	-	-	-	-	-	-
TW - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Rail - Diesel/biodiesel	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	-	-	-
Rail - Electricity	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.8	0.9
Rail - Hydrogen	-	-	-	-	-	-	0.1	0.1	0.2	0.3	0.5
Ship - Diesel/biodiesel	28.7	27.6	26.7	27.4	28.1	28.8	29.5	30.3	31.0	31.8	32.6
Air - Jet fuel	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Air - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Jet fuel	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total -	**488**	**520**	**559**	**601**	**647**	**696**	**749**	**781**	**816**	**852**	**890**

8.2 Energy Service Companies

Primary Energy Demand (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Renewable electricity	20	35	79	149	190	205	213	223	236	299	374
Biomass and waste	121	127	265	273	224	241	243	245	225	221	234
Natural Gas	3,907	3,990	3,826	3,700	3,875	3,291	2,749	2,767	2,732	2,656	2,571
Oil	3,039	3,029	2,507	2,403	1,956	1,897	1,895	1,716	1,546	1,452	1,316
Refined oil	- 298	- 267	- 59	- 97	- 8	- 110	- 281	- 210	- 140	- 87	-
Coal	1,500	1,502	1,372	1,505	1,328	1,459	2,355	2,478	2,741	2,755	2,699
Nuclear electricity	282	266	306	193	139	397	343	343	312	334	334
Imported electricity	52	46	41	43	72	77	58	73	93	98	103
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total	**8,624**	**8,728**	**8,337**	**8,170**	**7,776**	**7,457**	**7,574**	**7,635**	**7,746**	**7,728**	**7,631**

Final Energy demand by fuel (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,176	1,249	1,277	1,285	1,352	1,376	1,455	1,521	1,593	1,637	1,665
Fuel oil	220	183	156	153	135	117	110	102	86	86	86
LPG	52	53	22	14	7	-	-	-	-	-	-
Gas	2,391	2,392	2,419	2,424	2,467	2,484	2,496	2,493	2,517	2,501	2,491
Coal	75	95	122	110	134	143	161	179	189	204	228
Petrol	872	908	881	855	659	661	570	486	545	566	526
Diesel	1,164	1,185	1,054	994	927	823	805	796	664	606	605
Jet fuel	30	35	38	39	40	40	40	39	38	37	37
Hydrogen	-	-	-	-	-	-	3	9	18	33	50
Ethanol/Methanol	-	-	29	28	22	22	19	16	15	14	12
Bio diesels	-	-	40	38	36	35	35	34	28	25	25
Manufactured fuel	75	62	58	53	61	75	3	3	3	3	3
Biomass	28	24	45	49	45	44	44	50	62	62	47
Heat	105	132	159	172	133	140	132	112	72	53	33
Others	-	-	-	-	-	-	-	-	-	-	-
Total	**6,189**	**6,319**	**6,299**	**6,216**	**6,018**	**5,961**	**5,873**	**5,840**	**5,830**	**5,828**	**5,807**

Final Energy demand by Sector (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	51	52	53	55	56	58	59	61	63	65	67
Industry	1,473	1,442	1,451	1,467	1,490	1,493	1,510	1,519	1,526	1,533	1,543
Residential	1,961	2,072	2,117	2,130	2,126	2,054	1,986	1,978	1,966	1,945	1,921
Services	850	809	794	742	718	722	721	726	733	736	735
Transport	1,855	1,943	1,884	1,822	1,629	1,635	1,597	1,556	1,542	1,549	1,542
Total	**6,189**	**6,319**	**6,299**	**6,216**	**6,018**	**5,961**	**5,873**	**5,840**	**5,830**	**5,828**	**5,807**

Electricity generation mix (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	396	413	340	385	75	20	-	-	-	-	-
Coal CCS	-	-	-	-	282	390	861	917	1,040	1,040	1,024
Gas	487	550	538	545	659	380	111	106	75	30	-
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	282	266	306	193	139	397	343	343	312	334	334
Oil	16	21	10	5	4	-	-	-	-	-	-
Hydro	17	15	21	23	22	21	19	18	16	16	16
Wind	3	20	58	125	168	184	194	205	220	269	247
Biowaste & others	26	27	60	61	61	51	59	55	51	47	39
Imports	52	40	41	43	72	77	58	73	93	98	103
Marine	-	-	-	-	-	-	-	-	-	11	64
Solar PV	-	-	-	-	-	-	0	-	-	3	47
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,382**	**1,389**	**1,488**	**1,526**	**1,649**	**1,719**	**1,807**	**1,849**	**1,874**

Generation by plant type (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	592	604	609	570	541	842	1,234	1,285	1,373	1,389	1,358
Non-base load	641	694	729	775	906	647	382	410	416	444	508
CHPs	45	54	36	37	35	31	28	23	19	16	8
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,382**	**1,389**	**1,488**	**1,526**	**1,649**	**1,719**	**1,807**	**1,849**	**1,874**

Electricity storage (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Storage heaters	46	38	38	54	54	52	36	25	7	2	-
Plug-in hybrid	-	-	-	-	54	67	125	161	172	166	130
Hydrogen storage	-	-	-	-	-	-	-	-	-	-	-
Pumped hydro	10	9	8	7	6	6	5	-	-	-	-
Total	**55**	**47**	**45**	**62**	**115**	**126**	**166**	**186**	**179**	**167**	**130**

Installed capacity by fuel (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	29	26	24	19	6	3	-	-	-	-	-
Coal CCS	-	-	-	-	11	15	33	35	40	40	40
Gas	24	24	25	28	34	25	15	16	16	17	16
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	12	12	12	7	5	15	13	13	12	13	13
Oil	10	10	8	7	7	-	-	-	-	-	-
Hydro	1	1	2	2	2	2	2	2	1	1	1
Wind	0	1	5	9	13	14	16	17	18	25	23
Biowaste & others	2	2	4	6	5	9	9	7	6	4	3
Imports	2	2	2	2	2	4	5	7	9	10	10
Marine	-	-	-	-	-	-	-	-	-	1	5
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	**84**	**81**	**83**	**82**	**86**	**88**	**93**	**97**	**103**	**112**	**112**

Installed capacity by plant type (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	36	34	33	26	24	35	48	50	53	54	53
Non-base load	41	41	45	52	58	50	42	44	47	56	66
CHPs	4	3	4	3	3	3	2	2	1	1	1
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	84	81	83	82	86	88	93	97	103	112	121

Sectoral electricity demands (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	16	16	16	16	16	16	16	16	16	16	16
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Industry	412	419	405	397	392	383	387	388	390	391	392
Residential	403	464	499	528	550	563	574	580	584	517	473
Service	326	323	321	307	301	304	307	314	319	325	331
Transport	20	23	26	28	82	100	161	212	274	309	330
Upstreams	-	-	-	-	24	33	69	73	82	82	81
Total	1,176	1,244	1,267	1,275	1,365	1,399	1,513	1,583	1,665	1,641	1,623

Sectoral Emissions (Million t-CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Upstream	25	23	19	15	13	12	11	12	11	11	10
Agriculture	2	2	3	3	3	3	3	3	3	3	4
Electricity	181	194	172	185	116	72	46	43	40	32	22
Hydrogen	-	-	-	-	-	-	1	2	3	6	10
Industry	63	59	57	58	59	60	59	61	62	64	67
Residential	89	90	88	86	86	79	74	73	73	72	70
Services	26	24	24	22	21	21	21	21	20	20	20
Transport	140	146	136	132	114	113	105	98	92	89	86
Total	**526**	**539**	**500**	**500**	**412**	**361**	**319**	**313**	**305**	**298**	**289**

Transport b.v.km by vehicle type

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car - Diesel/biodiesel ICE	70.1	76.2	81.9	102.2	91.1	85.5	80.8	71.2	59.2	61.5	63.9
Car - Diesel/biodiesel Hybri	-	-	-	-	-	-	-	-	-	-	-
Car - Diesel/biodiesel Plug-	-	-	-	-	3.7	3.7	1.5	-	-	-	-
Car - Petrol ICE	285.8	304.6	327.7	338.5	199.4	197.1	204.4	204.8	206.6	190.4	172.6
Car - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol Plug-in	-	-	-	-	179.8	223.6	115.7	17.5	-	-	-
Car - E85	-	-	-	-	-	-	-	-	-	-	-
Car - Battery	-	-	-	-	-	-	146.1	276.4	326.4	363.4	402.8
Car - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Car - Methanol	-	-	-	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel ICE	5.6	6.0	3.7	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel Hybr	-	-	2.7	6.9	7.3	7.8	8.4	8.5	5.8	5.9	5.3
Bus - Battery	-	-	-	-	-	-	-	-	2.9	2.9	3.6
Bus - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Bus - Methanol	-	-	-	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel	33.1	35.2	10.3	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel Hyb	-	-	27.3	40.1	42.7	45.6	48.7	50.0	51.3	52.6	54.0
HGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Diesel/biodiesel	58.8	64.6	62.1	27.6	-	-	-	-	-	-	-
LGV - Diesel/biodiesel Hybi	-	-	9.2	51.0	86.6	95.5	105.4	114.4	59.8	19.7	19.7
LGV - Diesel/biodiesel Plug	-	-	-	-	-	-	-	-	-	-	-
LGV - E85	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Plug-in	-	-	-	-	-	-	-	-	64.4	115.2	126.8
LGV - Battery	-	-	-	-	-	-	-	-	-	-	-
LGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Methanol	-	-	-	-	-	-	-	-	-	-	-
TW - Petrol	4.9	5.5	6.2	6.9	7.5	7.4	7.4	7.2	7.0	6.8	6.7
TW - Electricity	-	-	-	-	-	-	-	-	-	-	-
TW - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Rail - Diesel/biodiesel	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	-	-	-
Rail - Electricity	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.7	0.6
Rail - Hydrogen	-	-	-	-	-	-	0.1	0.1	0.3	0.5	0.7
Ship - Diesel/biodiesel	28.7	27.6	26.7	27.4	28.1	28.8	29.5	30.3	31.0	31.8	32.6
Air - Jet fuel	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Air - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Jet fuel	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total -	**488**	**520**	**559**	**601**	**647**	**696**	**749**	**781**	**816**	**852**	**890**

8.3 Distribution System Operators

Primary Energy Demand (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Renewable electricity	20	35	79	169	221	231	228	240	313	346	393
Biomass and waste	121	127	266	274	250	295	299	305	360	359	456
Natural Gas	3,907	3,993	3,786	3,596	3,477	2,893	2,743	2,772	2,888	2,853	2,745
Oil	3,043	3,029	2,509	2,407	2,376	2,212	1,714	1,217	926	797	629
Refined oil	- 298	- 267	- 70	- 111	- 146	- 145	- 267	- 210	- 184	- 61	-
Coal	1,500	1,499	1,357	1,229	780	701	1,202	1,191	1,197	1,210	1,192
Nuclear electricity	282	266	306	193	270	488	434	533	502	502	502
Imported electricity	52	46	41	65	72	77	82	88	93	98	103
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total	**8,628**	**8,729**	**8,275**	**7,823**	**7,299**	**6,753**	**6,435**	**6,135**	**6,095**	**6,105**	**6,021**

Final Energy demand by fuel (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,176	1,247	1,272	1,250	1,212	1,186	1,154	1,189	1,224	1,252	1,270
Fuel oil	220	180	156	154	132	115	105	97	82	82	81
LPG	56	56	22	14	7	8	-	-	-	-	2
Gas	2,391	2,395	2,381	2,326	2,349	2,275	2,290	2,226	2,237	2,201	2,132
Coal	75	97	127	117	112	132	129	122	128	141	131
Petrol	872	908	881	889	921	869	527	225	133	145	141
Diesel	1,164	1,185	1,054	953	921	869	695	592	450	438	345
Jet fuel	30	35	38	38	39	38	38	37	36	35	36
Hydrogen	-	-	-	-	-	-	211	348	439	437	470
Ethanol/Methanol	-	-	29	30	31	49	40	14	4	5	5
Bio diesels	-	-	40	36	36	38	30	53	122	123	208
Manufactured fuel	71	58	51	45	62	52	3	3	3	3	1
Biomass	28	24	40	46	45	60	78	86	86	86	77
Heat	105	132	155	157	109	85	32	30	11	12	12
Others	-	-	-	-	-	-	-	-	-	-	-
Total	**6,189**	**6,318**	**6,246**	**6,056**	**5,976**	**5,775**	**5,331**	**5,021**	**4,956**	**4,961**	**4,910**

Final Energy demand by Sector (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	51	52	53	55	55	55	56	56	57	59	60
Industry	1,472	1,442	1,451	1,441	1,417	1,413	1,385	1,374	1,377	1,371	1,355
Residential	1,961	2,071	2,077	2,029	2,008	1,807	1,714	1,682	1,682	1,689	1,625
Services	850	809	781	718	658	648	615	597	594	591	578
Transport	1,855	1,943	1,884	1,814	1,837	1,853	1,562	1,311	1,246	1,252	1,292
Total	**6,188**	**6,318**	**6,246**	**6,056**	**5,976**	**5,775**	**5,331**	**5,021**	**4,956**	**4,961**	**4,910**

Electricity generation mix (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	396	411	335	306	45	20	-	-	-	-	-
Coal CCS	-	-	-	-	143	143	467	467	467	467	463
Gas	487	550	538	545	507	278	61	50	40	30	-
Gas CCS	-	-	-	-	-	-	-	-	-	-	1
Nuclear	282	266	306	193	270	488	434	533	502	502	502
Oil	16	21	10	2	-	-	-	-	-	-	-
Hydro	17	15	21	23	22	21	19	18	16	20	20
Wind	3	20	58	145	198	192	185	185	245	230	230
Biowaste & others	26	27	60	61	54	44	40	40	40	38	38
Imports	52	40	41	65	72	77	82	88	93	98	103
Marine	-	-	-	-	-	-	-	-	-	22	57
Solar PV	-	-	-	-	-	19	23	37	52	74	87
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,359**	**1,377**	**1,348**	**1,318**	**1,287**	**1,317**	**1,417**	**1,454**	**1,480**	**1,501**

Generation by plant type (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	592	603	603	491	498	686	931	1,024	989	984	966
Non-base load	641	694	731	813	780	571	370	382	455	490	528
CHPs	45	54	35	36	34	24	11	11	10	6	7
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,359**	**1,377**	**1,348**	**1,318**	**1,287**	**1,317**	**1,417**	**1,454**	**1,480**	**1,501**

Electricity storage (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Storage heaters	46	38	39	52	51	46	45	43	42	42	38
Plug-in hybrid	-	-	-	-	-	-	17	33	47	52	50
Hydrogen storage	-	-	-	-	-	-	-	-	-	-	-
Pumped hydro	10	9	8	7	6	6	5	-	-	-	-
Total	**55**	**47**	**47**	**59**	**57**	**52**	**67**	**76**	**89**	**93**	**88**

Installed capacity by fuel (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	29	26	24	19	6	3	-	-	-	-	-
Coal CCS	-	-	-	-	5	5	18	18	18	18	18
Gas	24	24	25	27	28	18	11	10	8	11	10
Gas CCS	-	-	-	-	-	-	-	-	-	-	0
Nuclear	12	12	12	7	10	19	17	20	19	19	19
Oil	10	10	8	7	7	-	-	-	-	-	-
Hydro	1	1	2	2	2	2	2	2	1	2	2
Wind	0	1	5	12	18	18	18	18	23	21	21
Biowaste & others	2	2	4	4	3	10	9	8	8	3	3
Imports	2	2	2	2	2	4	5	6	8	11	10
Marine	-	-	-	-	-	-	-	-	-	2	5
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	**84**	**81**	**83**	**82**	**84**	**80**	**79**	**83**	**87**	**88**	**89**

Installed capacity by plant type (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	36	34	33	26	23	29	39	42	41	40	40
Non-base load	41	41	45	52	56	51	42	45	53	59	63
CHPs	4	3	3	3	2	2	1	1	1	0	0
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	84	81	83	82	84	83	84	90	96	101	105

Sectoral electricity demands (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	16	16	16	16	15	15	15	15	15	14	15
Hydrogen	-	-	-	-	-	-	35	100	100	97	100
Industry	412	419	405	391	375	364	356	354	355	353	348
Residential	403	464	496	473	445	418	390	390	390	390	378
Service	326	322	320	304	274	261	240	240	240	240	240
Transport	20	23	26	27	27	33	54	77	97	105	126
Upstreams	-	-	-	-	12	12	37	37	37	37	36
Total	1,176	1,243	1,262	1,210	1,148	1,102	1,126	1,212	1,232	1,236	1,243

Sectoral Emissions (Million t-CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Upstream	25	23	19	15	14	13	12	10	8	8	7
Agriculture	2	2	3	3	3	3	3	3	3	3	3
Electricity	181	193	170	160	83	47	16	15	14	13	10
Hydrogen	-	-	-	-	-	-	14	20	27	27	29
Industry	63	59	58	58	57	60	58	57	57	58	57
Residential	89	90	86	81	82	68	64	61	61	60	57
Services	26	25	23	21	19	19	17	16	16	16	15
Transport	140	146	136	131	133	132	94	63	45	44	37
Total	**526**	**538**	**496**	**468**	**391**	**342**	**277**	**244**	**231**	**228**	**215**

Transport b.v.km by vehicle type

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car - Diesel/biodiesel ICE	70.1	76.2	81.9	88.1	94.8	122.9	82.3	69.5	60.7	61.5	67.1
Car - Diesel/biodiesel Hybri	-	-	-	-	-	-	-	-	-	-	-
Car - Diesel/biodiesel Plug-	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol ICE	285.8	304.6	327.7	352.5	379.2	371.6	210.2	57.6	-	-	-
Car - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol Plug-in	-	-	-	-	-	-	-	-	-	-	-
Car - E85	-	-	-	-	-	2.6	2.6	1.0	-	-	-
Car - Battery	-	-	-	-	-	-	-	-	-	-	-
Car - Hydrogen	-	-	-	-	-	-	253.4	427.6	546.3	553.8	604.2
Car - Methanol	-	-	-	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel ICE	5.6	6.0	3.7	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel Hybr	-	-	2.7	6.9	7.3	7.7	3.5	3.0	-	-	-
Bus - Battery	-	-	-	-	-	-	-	-	-	-	-
Bus - Hydrogen	-	-	-	-	-	-	4.9	5.5	8.6	8.7	8.9
Bus - Methanol	-	-	-	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel	33.1	35.2	10.3	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel Hyb	-	-	27.3	39.0	41.7	43.3	45.0	46.2	47.2	47.4	46.6
HGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	2.0
LGV - Diesel/biodiesel	58.8	64.6	61.3	26.8	-	-	-	-	-	-	-
LGV - Diesel/biodiesel Hybi	-	-	9.9	51.8	86.6	93.2	67.3	42.9	23.9	19.2	19.2
LGV - Diesel/biodiesel Plug	-	-	-	-	-	-	-	-	-	-	-
LGV - E85	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Plug-in	-	-	-	-	-	-	35.4	68.7	100.4	112.3	112.6
LGV - Battery	-	-	-	-	-	-	-	-	-	-	14.7
LGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Methanol	-	-	-	-	-	-	-	-	-	-	-
TW - Petrol	4.9	5.5	6.2	6.9	7.5	7.4	7.4	7.2	7.0	6.8	6.7
TW - Electricity	-	-	-	-	-	-	-	-	-	-	-
TW - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Rail - Diesel/biodiesel	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	-	-	-
Rail - Electricity	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3
Rail - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Ship - Diesel/biodiesel	28.7	27.6	26.0	26.0	26.0	25.2	25.8	25.7	26.4	27.0	26.9
Air - Jet fuel	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Air - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Jet fuel	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total -	**488**	**520**	**558**	**599**	**644**	**675**	**739**	**756**	**822**	**838**	**910**

Demand Reductions (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0%	0%	0%	0%	-1%	-5%	-6%	-8%	-10%	-9%	-10%
Industry - Chemicals	-	-	-	-7%	-10%	-12%	-17%	-20%	-20%	-23%	-22%
Industry - Iron & steel	-	0%	0%	-3%	-8%	-8%	-10%	-13%	-13%	-15%	-15%
Industry - Non ferrous meta	-	0%	0%	-2%	-7%	-8%	-7%	-11%	-12%	-13%	-15%
Industry - Others	-	0%	0%	0%	-3%	-2%	-5%	-5%	-5%	-5%	-7%
Industry - Paper & pulp	-	-	-	-3%	-2%	-3%	-5%	-5%	-7%	-8%	-7%
Residential - Electricity	0%	0%	0%	-5%	-8%	-10%	-17%	-15%	-12%	-8%	-7%
Residential - Gas	0%	0%	-2%	-5%	-8%	-13%	-13%	-18%	-18%	-15%	-23%
Residential - Heating	1%	0%	-2%	-5%	-5%	-13%	-13%	-15%	-15%	-15%	-17%
Residential - Hot-water	1%	0%	-3%	-5%	-5%	-12%	-12%	-14%	-15%	-14%	-17%
Services - Cooking	-	-	-3%	-3%	-3%	-5%	-5%	-5%	-7%	-7%	-7%
Services - Cooling	-	-	-	-	-3%	-	-	-	-	-	-
Services - Other electrical	-	-	-	-	-5%	-3%	-13%	-15%	-15%	-17%	-19%
Services - Heating	0%	-	-3%	-5%	-8%	-8%	-10%	-13%	-13%	-13%	-15%
Services - Hot-water	0%	-	-2%	-5%	-8%	-8%	-10%	-13%	-12%	-12%	-12%
Services - Lighting	-	-	-	-	-2%	-3%	-10%	-10%	-12%	-12%	-13%
Services - Refrigeration	-	-	-	-	-	-	-2%	-2%	-2%	-2%	-2%
Transport - Air domestic	1%	3%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-6%	-4%
Transport - Bus	0%	0%	0%	0%	0%	-2%	0%	0%	0%	0%	0%
Transport - Car	0%	0%	0%	0%	0%	-2%	0%	-3%	2%	0%	5%
Transport - Rail freight	1%	-2%	3%	-2%	-2%	-2%	0%	-1%	-4%	-3%	-3%
Transport - HGV	0%	0%	0%	-2%	-3%	-5%	-7%	-8%	-8%	-10%	-10%
Transport - Air Internationa	-	-	-	-	-	-	-	-	-	-	-
Transport - LGV	0%	0%	0%	0%	0%	-2%	-3%	-2%	0%	-2%	0%
Transport - Rail passenger	0%	0%	1%	1%	1%	1%	-3%	0%	-2%	-2%	-3%
Transport - Shipping	0%	0%	-2%	-5%	-7%	-13%	-12%	-15%	-15%	-15%	-17%
Transport - Two wheeler	0%	0%	0%	0%	0%	-	0%	0%	0%	0%	0%

MED parameters (B £2000)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Change in consumer + prod	0.0018	0.0459	-0.6431	-2.6495	-3.932	-9.0344	-12.1805	-17.1899	-12.3689	-7.9771	-0.8032
Change in energy system c	-0.0018	-0.0459	0.2892	0.9079	1.5118	0.4017	4.6869	5.3073	8.541	-1.42	-0.2952
Increase in consumer surpl	0	0	0	0	0	0	0	0	3.54	0	7.2774
Decrease in consumer surp	0	0	0.3539	1.7415	2.4203	8.6328	7.4936	11.8826	7.3679	9.3971	8.3758

8.4 Microgrids

Primary Energy Demand (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Renewable electricity	20	35	79	194	214	289	299	336	350	372	359
Biomass and waste	121	127	266	274	247	286	342	379	505	585	728
Natural Gas	3,907	3,993	3,792	3,605	3,511	3,067	2,711	2,678	2,649	2,598	2,449
Oil	3,043	3,029	2,514	2,429	2,397	2,180	1,678	1,212	763	600	346
Refined oil	- 298	- 267	- 75	- 131	- 166	- 145	- 281	- 274	- 172	- 55	32
Coal	1,500	1,500	1,360	1,075	778	675	451	448	362	359	267
Nuclear electricity	282	266	306	193	139	267	592	671	713	713	713
Imported electricity	52	46	41	61	72	77	63	88	93	98	103
Hydrogen	-	-	-	-	-	9	-	-	48	28	151
Total	**8,628**	**8,729**	**8,284**	**7,700**	**7,193**	**6,706**	**5,854**	**5,537**	**5,310**	**5,298**	**5,148**

Final Energy demand by fuel (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,176	1,247	1,273	1,224	1,134	1,122	1,230	1,272	1,320	1,327	1,276
Fuel oil	220	180	156	154	132	114	105	97	80	80	80
LPG	56	56	22	14	7	-	-	-	-	-	-
Gas	2,391	2,395	2,386	2,334	2,201	2,118	1,982	1,915	1,899	1,860	1,678
Coal	75	97	127	119	113	128	95	91	6	3	2
Petrol	872	908	881	889	920	858	468	175	130	145	137
Diesel	1,164	1,185	1,054	954	921	862	706	573	312	260	116
Jet fuel	30	35	38	38	39	38	38	37	36	35	34
Hydrogen	-	-	-	-	-	9	24	141	187	168	289
Ethanol/Methanol	-	-	29	30	31	48	40	13	4	5	4
Bio diesels	-	-	40	36	36	37	64	111	251	303	454
Manufactured fuel	71	58	51	45	62	52	3	1	1	1	1
Biomass	28	24	39	46	45	61	95	100	77	89	77
Heat	105	132	155	155	202	194	235	242	323	328	408
Others	-	-	-	-	-	-	-	-	-	-	-
Total	**6,189**	**6,318**	**6,252**	**6,039**	**5,843**	**5,641**	**5,083**	**4,768**	**4,628**	**4,604**	**4,558**

Final Energy demand by Sector (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	51	52	53	55	56	56	54	56	58	61	65
Industry	1,472	1,442	1,451	1,460	1,430	1,402	1,368	1,357	1,327	1,317	1,318
Residential	1,961	2,071	2,081	2,023	1,933	1,780	1,611	1,577	1,558	1,531	1,431
Services	850	809	783	686	586	563	538	522	504	500	489
Transport	1,855	1,943	1,884	1,814	1,838	1,842	1,513	1,256	1,181	1,195	1,255
Total	**6,188**	**6,318**	**6,252**	**6,039**	**5,843**	**5,641**	**5,083**	**4,768**	**4,628**	**4,604**	**4,558**

Electricity generation mix (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	396	412	336	254	45	20	-	-	-	-	-
Coal CCS	-	-	-	-	144	144	144	144	144	144	107
Gas	487	550	538	545	554	361	202	183	175	157	142
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	282	266	306	193	139	267	592	671	713	713	713
Oil	16	21	10	2	-	-	-	-	-	-	-
Hydro	17	15	21	19	17	21	19	18	16	31	31
Wind	3	20	58	160	164	157	153	176	193	193	193
Biowaste & others	26	27	60	60	54	39	38	38	38	38	38
Imports	52	40	41	61	72	77	63	88	93	98	103
Marine	-	-	-	-	-	-	-	-	-	12	12
Solar PV	-	-	-	15	33	111	127	142	140	136	123
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,359**	**1,377**	**1,317**	**1,227**	**1,203**	**1,343**	**1,460**	**1,512**	**1,522**	**1,462**

Generation by plant type (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	592	603	603	475	373	466	765	840	876	871	819
Non-base load	641	694	731	799	772	630	423	478	493	517	493
CHPs	45	54	35	36	76	102	150	141	143	134	149
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,359**	**1,377**	**1,317**	**1,227**	**1,203**	**1,343**	**1,460**	**1,512**	**1,522**	**1,462**

Electricity storage (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Storage heaters	46	38	30	23	42	45	11	11	11	2	-
Plug-in hybrid	-	-	-	-	-	-	49	54	26	58	85
Hydrogen storage	-	-	-	-	-	-	-	-	-	-	-
Pumped hydro	10	9	8	7	6	6	5	-	-	-	-
Total	**55**	**47**	**38**	**30**	**49**	**51**	**65**	**65**	**36**	**60**	**85**

Installed capacity by fuel (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	29	26	24	19	6	3	-	-	-	-	-
Coal CCS	-	-	-	-	5	5	5	5	5	5	5
Gas	24	24	25	26	31	26	23	24	29	26	29
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	12	12	12	7	5	10	23	26	27	27	27
Oil	10	10	8	7	7	-	-	-	-	-	-
Hydro	1	1	2	2	1	2	2	2	1	3	3
Wind	0	1	5	14	14	14	14	17	18	18	18
Biowaste & others	2	2	4	4	3	3	3	3	2	2	2
Imports	2	2	2	2	2	4	5	7	8	10	12
Marine	-	-	-	-	-	-	-	-	-	1	1
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	**84**	**81**	**83**	**83**	**77**	**69**	**76**	**84**	**93**	**95**	**98**

Installed capacity by plant type (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	36	34	33	26	18	20	30	33	34	33	33
Non-base load	41	41	45	54	54	51	46	52	54	57	54
CHPs	4	3	3	3	8	10	15	15	20	20	25
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	84	81	83	84	81	83	91	101	110	111	113

Sectoral electricity demands (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	16	16	16	16	16	15	15	15	15	14	15
Hydrogen	-	-	-	-	-	-	28	100	100	100	100
Industry	412	419	405	395	377	361	353	351	343	340	342
Residential	403	464	496	424	348	271	195	195	195	195	195
Service	326	322	320	274	223	171	120	120	120	120	120
Transport	20	23	26	28	27	33	205	240	296	319	263
Upstreams	-	-	-	-	12	12	12	12	12	12	9
Total	1,176	1,243	1,263	1,136	1,003	864	927	1,032	1,080	1,100	1,044

Sectoral Emissions (Million t-CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Upstream	25	23	19	15	14	13	12	9	7	6	5
Agriculture	2	2	3	3	3	3	3	3	3	3	4
Electricity	181	193	171	146	85	47	13	11	10	8	2
Hydrogen	-	-	-	-	-	-	-	4	4	4	4
Industry	63	59	58	59	57	60	56	55	51	50	50
Residential	89	90	86	81	82	70	62	60	60	59	57
Services	26	25	23	21	19	24	27	24	20	20	20
Transport	140	146	136	131	133	131	90	57	34	31	19
Total	**526**	**538**	**496**	**455**	**393**	**346**	**262**	**225**	**189**	**181**	**160**

Transport b.v.km by vehicle type

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car - Diesel/biodiesel ICE	70.1	76.2	81.9	88.1	94.8	125.0	84.3	71.2	60.7	61.5	67.1
Car - Diesel/biodiesel Hybri	-	-	-	-	-	-	-	-	-	-	-
Car - Diesel/biodiesel Plug-	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol ICE	285.8	304.6	327.7	352.5	379.2	365.6	204.2	55.2	-	-	-
Car - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol Plug-in	-	-	-	-	-	-	-	-	-	-	-
Car - E85	-	-	-	-	-	3.8	3.8	1.5	-	-	-
Car - Battery	-	-	-	-	-	-	269.8	293.9	334.5	363.4	232.2
Car - Hydrogen	-	-	-	-	-	-	-	148.1	211.8	190.4	372.0
Car - Methanol	-	-	-	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel ICE	5.6	6.0	3.7	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel Hybr	-	-	2.7	6.9	7.3	4.7	0.5	-	-	-	-
Bus - Battery	-	-	-	-	-	-	-	-	-	-	0.7
Bus - Hydrogen	-	-	-	-	-	3.0	7.9	8.5	8.6	8.7	8.2
Bus - Methanol	-	-	-	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel	33.1	35.2	10.3	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel Hyb	-	-	27.3	39.0	41.7	43.3	45.0	45.0	46.2	47.4	48.6
HGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Diesel/biodiesel	58.8	64.6	62.1	27.6	-	-	-	-	-	-	-
LGV - Diesel/biodiesel Hybi	-	-	9.2	51.0	86.6	93.2	102.8	77.7	23.3	19.2	19.2
LGV - Diesel/biodiesel Plug	-	-	-	-	-	-	-	-	-	-	-
LGV - E85	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Plug-in	-	-	-	-	-	-	-	33.9	97.8	112.3	109.3
LGV - Battery	-	-	-	-	-	-	-	-	-	-	14.3
LGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Methanol	-	-	-	-	-	-	-	-	-	-	-
TW - Petrol	4.9	5.5	6.2	6.9	7.5	7.4	7.4	7.2	7.0	6.7	6.5
TW - Electricity	-	-	-	-	-	-	-	-	-	-	-
TW - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Rail - Diesel/biodiesel	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	-	-	-
Rail - Electricity	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3
Rail - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Ship - Diesel/biodiesel	28.7	27.6	26.0	26.0	26.0	25.2	25.1	25.0	25.6	26.2	26.9
Air - Jet fuel	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Air - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Jet fuel	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total -	**488**	**520**	**558**	**599**	**644**	**672**	**752**	**768**	**817**	**837**	**907**

Demand Reductions (%)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0%	0%	0%	1%	0%	-4%	-9%	-8%	-8%	-6%	-3%
Industry - Chemicals	-	-	-	-2%	-8%	-15%	-20%	-22%	-25%	-27%	-29%
Industry - Iron & steel	-	0%	0%	0%	-5%	-8%	-13%	-15%	-17%	-20%	-20%
Industry - Non ferrous meta	-	0%	0%	-2%	-5%	-8%	-10%	-14%	-15%	-18%	-20%
Industry - Others	-	0%	0%	0%	-3%	-2%	-5%	-5%	-7%	-7%	-7%
Industry - Paper & pulp	-	-	-	-	-2%	-5%	-5%	-8%	-7%	-10%	-10%
Residential - Electricity	0%	0%	0%	-5%	-15%	-13%	-23%	-20%	-20%	-23%	-22%
Residential - Gas	0%	0%	-2%	-5%	-8%	-15%	-18%	-20%	-20%	-20%	-25%
Residential - Heating	1%	0%	-2%	-5%	-8%	-13%	-17%	-20%	-20%	-20%	-25%
Residential - Hot-water	1%	0%	-1%	-7%	-5%	-12%	-12%	-15%	-17%	-17%	-20%
Services - Cooking	-	-	-3%	-3%	-3%	-5%	-5%	-7%	-7%	-7%	-10%
Services - Cooling	-	-	-	3%	-3%	-2%	-5%	-7%	-8%	-10%	-8%
Services - Other electrical	-	-	-	-5%	-20%	-28%	-33%	-33%	-35%	-37%	-35%
Services - Heating	0%	-	-3%	-5%	-13%	-15%	-18%	-20%	-20%	-20%	-23%
Services - Hot-water	0%	-	-	-7%	-13%	-8%	-13%	-13%	-12%	-12%	-15%
Services - Lighting	-	-	-	-3%	-15%	-20%	-25%	-27%	-29%	-30%	-28%
Services - Refrigeration	-	-	-	-	-5%	-7%	-8%	-10%	-10%	-10%	-10%
Transport - Air domestic	1%	3%	0%	-1%	-2%	-3%	-4%	-5%	-6%	-6%	-7%
Transport - Bus	0%	0%	0%	0%	0%	-2%	0%	0%	0%	0%	0%
Transport - Car	0%	0%	0%	0%	0%	-3%	3%	0%	2%	0%	5%
Transport - Rail freight	1%	-2%	3%	-2%	-2%	-2%	0%	-1%	-4%	-6%	-3%
Transport - HGV	0%	0%	0%	-2%	-3%	-5%	-7%	-10%	-10%	-10%	-10%
Transport - Air International	-	-	-	-	-	-	-	-	-	-	-
Transport - LGV	0%	0%	0%	0%	0%	-2%	-3%	-2%	-3%	-2%	-3%
Transport - Rail passenger	0%	0%	1%	1%	1%	1%	-3%	-2%	-2%	-2%	-3%
Transport - Shipping	0%	0%	-2%	-5%	-7%	-13%	-15%	-17%	-17%	-18%	-17%
Transport - Two wheeler	0%	0%	0%	0%	0%	-	0%	0%	0%	-3%	-3%

MED parameters (B £2000)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Change in consumer + proc	0.0018	0.0459	-0.5796	-3.2528	-5.8007	-12.3502	-14.1798	-19.5088	-19.6262	-17.4775	-11.4108
Change in energy system c	-0.0018	-0.0459	0.2674	1.5549	1.6903	0.7242	6.6273	6.9615	9.6142	2.0162	3.3824
Increase in consumer surpl	0	0	0	0.0795	0.0002	0	3.2951	0	3.54	0	7.2774
Decrease in consumer surp	0	0	0.3122	1.7773	4.1106	11.626	10.8476	12.5473	13.552	15.4613	15.3057

8.5 Multi Purpose Networks

Primary Energy Demand (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Renewable electricity	20	35	79	146	186	235	253	280	259	259	278
Biomass and waste	121	127	265	273	235	241	243	240	225	227	218
Natural Gas	3,907	3,992	3,828	3,702	3,682	3,206	2,807	2,797	2,692	2,550	2,514
Oil	3,043	3,029	2,507	2,403	1,947	1,891	1,897	1,717	1,545	1,431	1,295
Refined oil	- 298	- 267	- 59	- 92	15	- 105	- 281	- 210	- 140	- 50	19
Coal	1,500	1,503	1,374	1,376	1,070	998	1,683	1,819	2,234	2,523	2,584
Nuclear electricity	282	266	306	193	317	567	513	513	482	482	482
Imported electricity	52	46	41	65	72	77	63	75	93	98	103
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total	**8,628**	**8,732**	**8,341**	**8,067**	**7,522**	**7,110**	**7,177**	**7,231**	**7,389**	**7,519**	**7,492**

Final Energy demand by fuel (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,176	1,249	1,277	1,268	1,334	1,355	1,431	1,498	1,571	1,629	1,657
Fuel oil	220	180	156	154	135	117	110	102	86	104	105
LPG	56	56	22	14	7	-	-	-	-	18	-
Gas	2,391	2,394	2,421	2,427	2,499	2,576	2,638	2,619	2,498	2,401	2,378
Coal	75	97	124	119	104	131	123	143	188	209	236
Petrol	872	908	881	855	659	655	569	487	545	566	526
Diesel	1,164	1,185	1,054	994	932	828	807	796	663	587	585
Jet fuel	30	35	38	39	40	40	40	39	38	37	37
Hydrogen	-	-	-	-	-	-	7	12	21	37	53
Ethanol/Methanol	-	-	29	28	22	22	19	16	15	14	12
Bio diesels	-	-	40	38	36	36	35	34	28	24	24
Manufactured fuel	71	58	56	52	64	52	3	3	3	3	3
Biomass	28	24	43	47	37	44	44	44	62	69	62
Heat	105	132	158	165	127	84	28	26	91	106	107
Others	-	-	-	-	-	-	-	-	-	-	-
Total	**6,189**	**6,318**	**6,299**	**6,200**	**5,997**	**5,939**	**5,853**	**5,819**	**5,808**	**5,803**	**5,785**

Final Energy demand by Sector (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	51	52	53	55	56	58	59	61	63	65	67
Industry	1,472	1,442	1,451	1,469	1,483	1,491	1,509	1,518	1,525	1,532	1,543
Residential	1,961	2,071	2,117	2,130	2,124	2,054	1,986	1,978	1,966	1,945	1,920
Services	850	809	794	725	701	700	700	704	712	716	717
Transport	1,855	1,943	1,884	1,822	1,633	1,635	1,599	1,557	1,543	1,545	1,538
Total	**6,188**	**6,318**	**6,299**	**6,200**	**5,997**	**5,939**	**5,853**	**5,819**	**5,808**	**5,803**	**5,785**

Electricity generation mix (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	396	413	340	352	45	20	-	-	-	-	-
Coal CCS	-	-	-	-	261	261	669	716	808	903	906
Gas	487	550	538	545	525	280	63	51	64	30	33
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	282	266	306	193	317	567	513	513	482	482	482
Oil	16	21	10	-	-	-	-	-	-	-	-
Hydro	17	15	21	23	22	21	19	18	16	16	8
Wind	3	20	58	123	164	181	174	174	149	134	130
Biowaste & others	26	27	59	62	54	42	38	38	55	58	58
Imports	52	40	41	65	72	77	63	75	93	98	103
Marine	-	-	-	-	-	34	60	88	95	101	103
Solar PV	-	-	-	-	-	-	0	-	-	8	36
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,382**	**1,371**	**1,466**	**1,488**	**1,604**	**1,673**	**1,761**	**1,830**	**1,860**

Generation by plant type (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	592	604	609	537	668	883	1,212	1,254	1,310	1,401	1,388
Non-base load	641	694	729	789	750	576	376	410	425	404	445
CHPs	45	54	35	38	41	24	11	9	26	26	27
Storage	10	9	8	7	6	6	5	-	-	-	-
Total	**1,288**	**1,360**	**1,382**	**1,371**	**1,466**	**1,488**	**1,604**	**1,673**	**1,761**	**1,830**	**1,860**

Electricity storage (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Storage heaters	46	38	38	54	54	52	37	28	27	21	21
Plug-in hybrid	-	-	-	-	53	67	78	106	137	145	146
Hydrogen storage	-	-	-	-	-	-	-	-	-	-	-
Pumped hydro	10	9	8	7	6	6	5	-	-	-	-
Total	**55**	**47**	**46**	**62**	**114**	**126**	**120**	**134**	**164**	**166**	**168**

Installed capacity by fuel (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	29	26	24	19	6	3	-	-	-	-	-
Coal CCS	-	-	-	-	10	10	25	27	31	35	36
Gas	24	24	25	28	28	19	13	13	14	16	15
Gas CCS	-	-	-	-	-	-	-	-	-	-	-
Nuclear	12	12	12	7	12	22	20	20	18	18	18
Oil	10	10	8	7	7	-	-	-	-	-	-
Hydro	1	1	2	2	2	2	2	2	1	1	1
Wind	0	1	5	9	12	15	15	15	12	11	11
Biowaste & others	2	2	4	5	4	10	9	8	9	5	4
Imports	2	2	2	2	2	4	5	7	8	11	11
Marine	-	-	-	-	-	3	6	10	10	11	11
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	**84**	**81**	**83**	**81**	**85**	**88**	**96**	**102**	**105**	**109**	**108**

Installed capacity by plant type (GW)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base load	36	34	33	26	30	36	47	49	51	55	55
Non-base load	41	41	45	51	51	49	46	51	50	53	56
CHPs	4	3	3	3	3	2	1	1	2	2	2
Storage	3	2	2	2	1	1	1	1	1	1	1
Total	84	81	83	81	85	88	96	102	105	110	114

Sectoral electricity demands (PJ)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	16	16	16	16	16	16	16	16	16	16	16
Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Industry	412	419	405	397	392	383	387	389	390	391	392
Residential	403	464	499	528	550	539	550	557	561	555	531
Service	326	323	321	290	284	283	286	292	298	304	309
Transport	20	23	26	28	81	100	158	210	273	322	343
Upstreams	-	-	-	-	22	22	53	57	63	71	71
Total	1,176	1,244	1,267	1,258	1,345	1,343	1,450	1,520	1,601	1,658	1,662

Sectoral Emissions (Million t-CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Upstream	25	23	19	15	13	12	11	12	11	11	10
Agriculture	2	2	3	3	3	3	3	3	3	3	4
Electricity	181	194	172	173	88	51	20	20	37	38	38
Hydrogen	-	-	-	-	-	-	1	2	4	7	10
Industry	63	59	57	58	58	61	63	64	61	63	64
Residential	89	90	88	86	86	80	74	73	73	72	70
Services	26	24	24	22	21	21	21	21	20	20	20
Transport	140	146	136	132	114	113	105	98	92	88	84
Total	**526**	**538**	**500**	**488**	**384**	**340**	**299**	**294**	**302**	**300**	**299**

Transport b.v.km by vehicle type

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car - Diesel/biodiesel ICE	70.1	76.2	81.9	102.2	94.8	89.2	82.3	71.2	59.2	61.5	63.9
Car - Diesel/biodiesel Hybri	-	-	-	-	-	-	-	-	-	-	-
Car - Diesel/biodiesel Plug-	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol ICE	285.8	304.6	327.7	338.5	199.4	193.4	202.9	204.8	206.6	190.4	172.6
Car - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
Car - Petrol Plug-in	-	-	-	-	179.8	227.3	119.4	19.0	-	-	-
Car - E85	-	-	-	-	-	-	-	-	-	-	-
Car - Battery	-	-	-	-	-	-	143.9	274.9	326.4	363.4	402.8
Car - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Car - Methanol	-	-	-	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel ICE	5.6	6.0	3.7	-	-	-	-	-	-	-	-
Bus - Diesel/biodiesel Hybr	-	-	2.7	6.9	7.3	7.8	8.4	8.5	5.3	0.6	-
Bus - Battery	-	-	-	-	-	-	-	-	3.3	8.2	8.9
Bus - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Bus - Methanol	-	-	-	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel	33.1	35.2	10.3	-	-	-	-	-	-	-	-
HGV - Diesel/biodiesel Hyb	-	-	27.3	40.1	42.7	45.6	48.7	50.0	51.3	52.6	54.0
HGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Diesel/biodiesel	58.8	64.6	62.1	27.6	-	-	-	-	-	-	-
LGV - Diesel/biodiesel Hybr	-	-	9.2	51.0	86.6	95.5	105.4	114.4	59.8	19.7	19.7
LGV - Diesel/biodiesel Plug	-	-	-	-	-	-	-	-	-	-	-
LGV - E85	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Hybrid	-	-	-	-	-	-	-	-	-	-	-
LGV - Petrol Plug-in	-	-	-	-	-	-	-	-	64.4	115.2	126.8
LGV - Battery	-	-	-	-	-	-	-	-	-	-	-
LGV - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
LGV - Methanol	-	-	-	-	-	-	-	-	-	-	-
TW - Petrol	4.9	5.5	6.2	6.9	7.5	7.4	7.4	7.2	7.0	6.8	6.7
TW - Electricity	-	-	-	-	-	-	-	-	-	-	-
TW - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Rail - Diesel/biodiesel	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	-	-	-
Rail - Electricity	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.6	0.6
Rail - Hydrogen	-	-	-	-	-	-	0.1	0.2	0.3	0.5	0.8
Ship - Diesel/biodiesel	28.7	27.6	26.7	27.4	28.1	28.8	29.5	30.3	31.0	31.8	32.6
Air - Jet fuel	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Air - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Jet fuel	-	-	-	-	-	-	-	-	-	-	-
Air (int) - Hydrogen	-	-	-	-	-	-	-	-	-	-	-
Total -	**488**	**520**	**559**	**601**	**647**	**696**	**749**	**781**	**816**	**852**	**890**

Notes:

1. In 'Sectoral Emissions' the 'Upstream' category accounts for emissions from refineries
2. In 'Sectoral Electricity Demands' the 'Upstream' category accounts for electricity required to transport and store CO2 for CCS
3. 'Sectoral Electricity Demands' do not account for locally generated electricity- hence runs with high levels of distributed generation appear to have significantly lower electricity demands in this table

9 Appendix C – Bibliography

This bibliography lists the details of the major reference sources used throughout the LENS project.

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10 Appendix D – List of Abbreviations

ANM	Active Network Management
BVkm	Billion Vehicle Kilometers
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCTV	Closed Circuit Television
CHP	Combined Heat and Power
CO2	Carbon Dioxide
CSR	Corporate Social Responsibility
DG	Distributed Generation
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSM	Demand Side Management
DTI	(GB) Department of Trade and Industry
EU	European Union
EPRI	Electric Power Research Institute (US)
ESCO	Energy Supply Company
FACTS	Flexible AC Transmission Systems
GB	Great Britain
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
H2	Hydrogen
HVDC	High Voltage Direct Current
ICT	Information and Communications Technology
kW	Kilowatt
LENS	Long-term Electricity Network Scenarios
MARKAL	Market Allocation (model)
MSO	Micro Grid System Operator
MW	Megawatt
OECD	Organisation for Economic Cooperation and Development
PIU	Performance and Innovation Unit (of the GB Government)
PJ	Peta Joule (10^15 Joules)
p/therm	Pence per therm
PPP	Public Private Partnership
R&D	Research and Development
RCEP	Royal Commission on Environmental Pollution
SO	System Operator

T&D	Transmission and Distribution
TNO	Transmission Network Operator
UK	United Kingdom
UPS	Uninterruptible Power Supply
$/bbl	Dollars per Billions of Barrels
$/GJ	Dollars per Giga Joule

11 Appendix E – References

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