Electricity Network Scenarios for Great Britain in 2050

Technical Appendices to Final Report for Ofgem's LENS Project

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7 Appendix A – Scenario Development Process

This appendix to the final report for the LENS project (Ref. No. 157a/08) provides an overview of the methodology followed in the development of the network scenarios for Great Britain in 2050 and the accompanying quantitative modelling of the scenarios. Much of this description of the process for the development of the scenarios was set out in more detail in prior project reports. The summary of the full process contained in this appendix forms an essential supporting part of the final report.

It should be noted at the outset that the detailed (scenario-specific) inputs and results of the modeling activities undertaken in the LENS project using the MARKAL-MED model are presented in appendix B. The model itself, the fit with the scenarios development process, the common model input assumptions applying across scenarios, and the interpretation of the modeling outcomes are discussed in this appendix A.

7.1 Methodology

The LENS project commenced with the open letter of June 2007 (Ofgem, 2007c), initial workshop and consultation (Ofgem, 2007d).

The project methodology was then defined and published in November 2007 (Ofgem, 2007a). At this time, the approach for the LENS scenario development was clearly laid out and explained in terms of eight 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 (Shell, 2003) and Pierre Wack (Wack, 1985). A more recent study of the California energy crisis as recorded by Ghanadan and Koomey (Ghanadan, 2005) was also noted as an important influence.

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 network 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?’

The methodology also provided further detail on the intended approach for each of the other key stages and set out milestones for the project.

7.2 Scenarios Inputs Report

On completion of the information gathering stage (Dec 2007) a report on LENS inputs was published (Ofgem, 2007b) 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 the GB energy sector 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.

7.3 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.

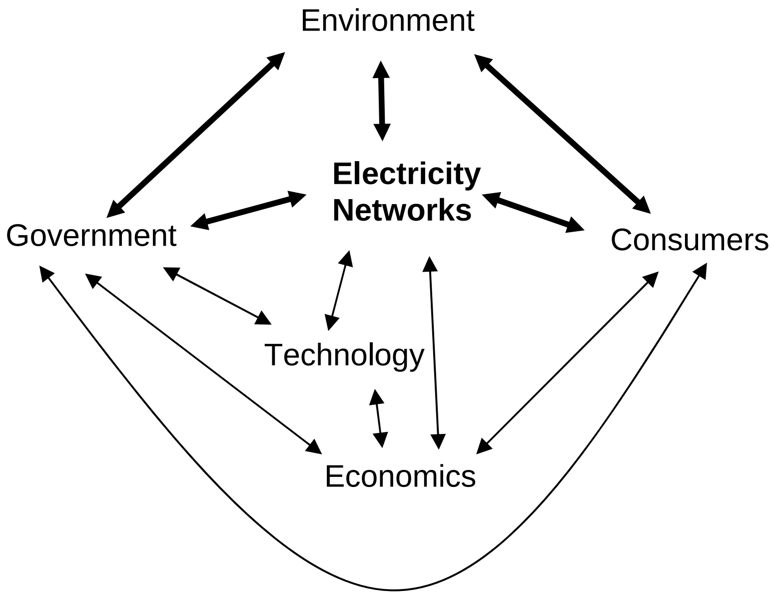

Figure 1 : LENS themes influence diagram

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 (Ofgem, 2008b).

- **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 arose 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 initial scenarios as illustrated in Figure 3.

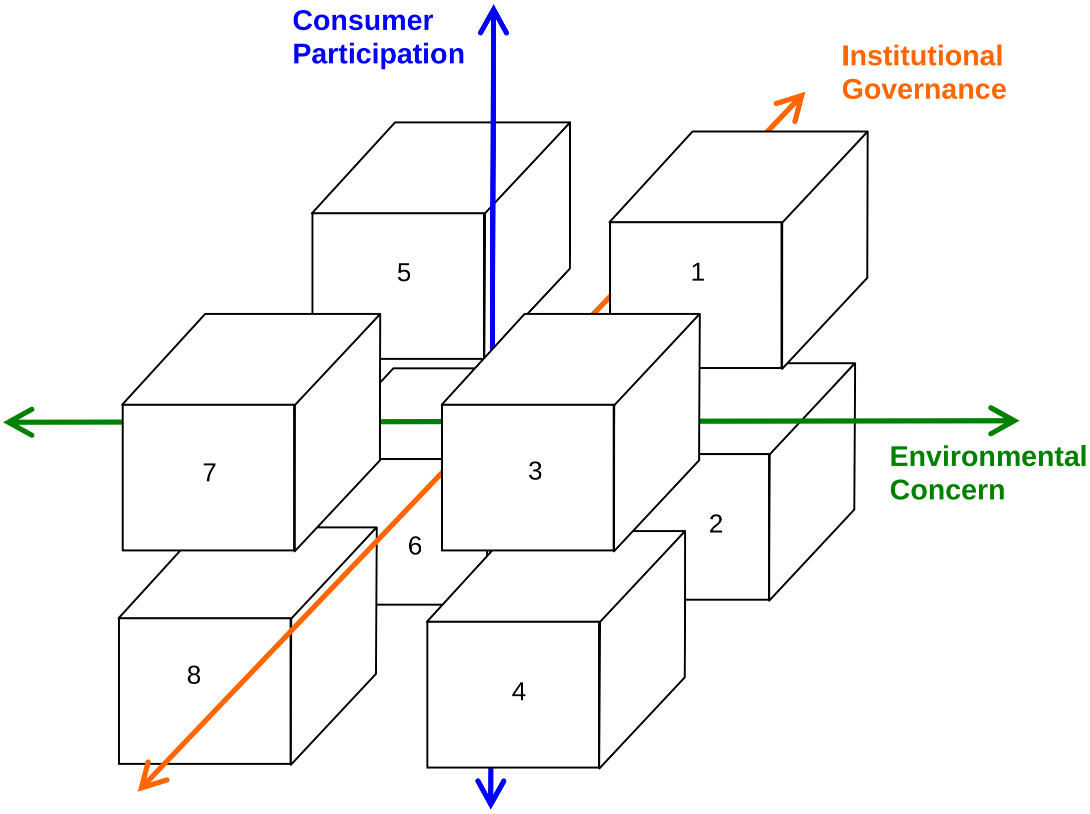

Figure 2: Interaction of three LENS themes.

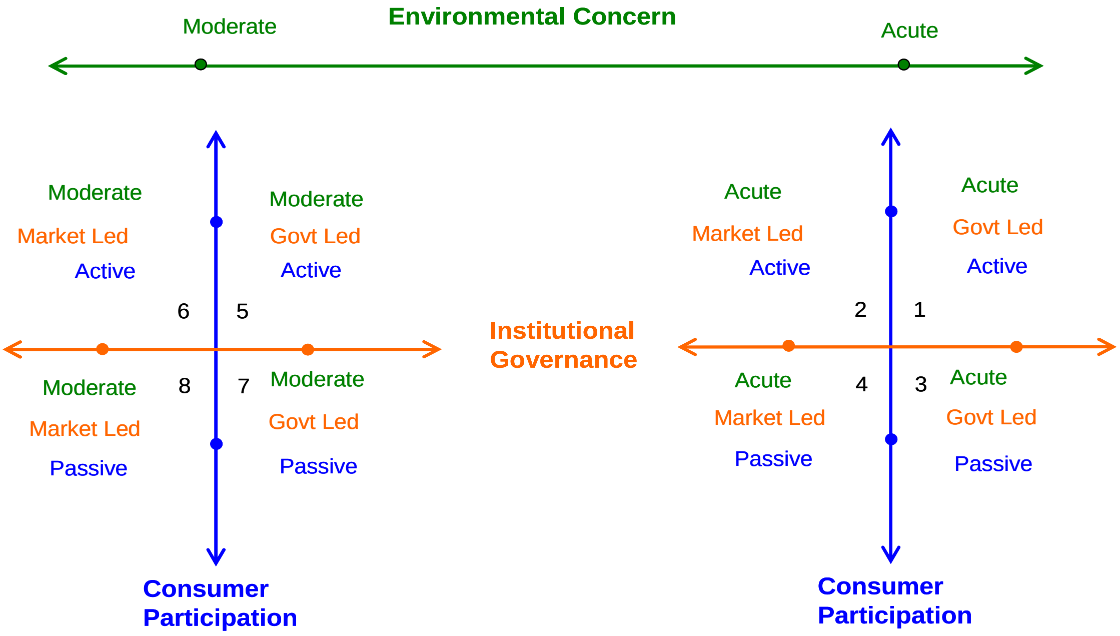

Figure 3: Eight possible initial scenarios identified from themes.

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

7.4 Interim Report

The interim report of May 2008 (Ofgem, 2008b) 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 2007 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 and are summarised below.

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

- Consumers demand abundant supplies of electricity that require minimum participation on their part resulting in consumer attitudes towards energy being passive.
- 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 fuel supplies and reserves.
- Centralised larger scale power generation (fossil, nuclear and/or renewable) dominates electricity production.

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

- Consumers remain relatively passive towards their energy supply and while the majority of people are concerned about the environment they strongly believe that it is the duty of others to sort it out through market mechanisms.
- Although 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, 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.
- Centralised electricity generation persists but with a relatively strong development of on-site and local/community scale energy developments in demand side participation and smaller scale generation (e.g. combined heat and power) through the energy service companies.

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

- The belief develops that stronger Government intervention is required in the energy sector to meet consumer demands for energy services and to make a full contribution to the global action to reduce fossil fuel emissions. This move from more market delivery oriented policies is due to perceived market failures in areas such as energy prices, energy security matters and delivery of climate change policies and targets.
- 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 with consumer moves towards energy self sufficiency.

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

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

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

- There is a pervasive feeling of uncertainty and a resulting ambiguity within society towards environmental issues and the influence this has on energy infrastructure development. Environmental concern never reaches a point that could be called acute for any consistent length of time but rather cycles through phases of acute concern in response to the latest environmental observations and reports/statistics.
- A lack of Global consensus on environmental issues contributes to the uncertainty regarding environmental action.
- There are various market led and Government led approaches pursued over time, primarily in relation to the perceived degree of environmental concern but also in response to other key matters such as security of fuel supplies and the 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 supply 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.

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**[1]
  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

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[1] 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.

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.

The energy to network scenario mapping exercise had 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. The resulting range of networks was consolidated into a smaller set of potential network types and these were reported in the Interim Report. One drawback of this process was the potential to break the link between the energy background context and the resulting network, so a process of reflection on the processes of mapping energy to network scenarios and the network consolidation process was undertaken. The outcome of this was that for each of the network scenarios, the dominant energy context scenario was identified, and this dominant energy scenario formed the context of a merged network and energy scenario (this process is described further in the next section). The outcomes from this process were checked iteratively with refinements made to ensure that the five network scenarios had a consistent and discrete energy context.

Other key steps in the development of the draft scenarios were identifying 2025 way-markers and using the results of MARKAL-MED modelling, both of which are discussed in detail in the following sections. The full scenario development process is illustrated in Figure 4 below which also shows the steps described in the sections following this.

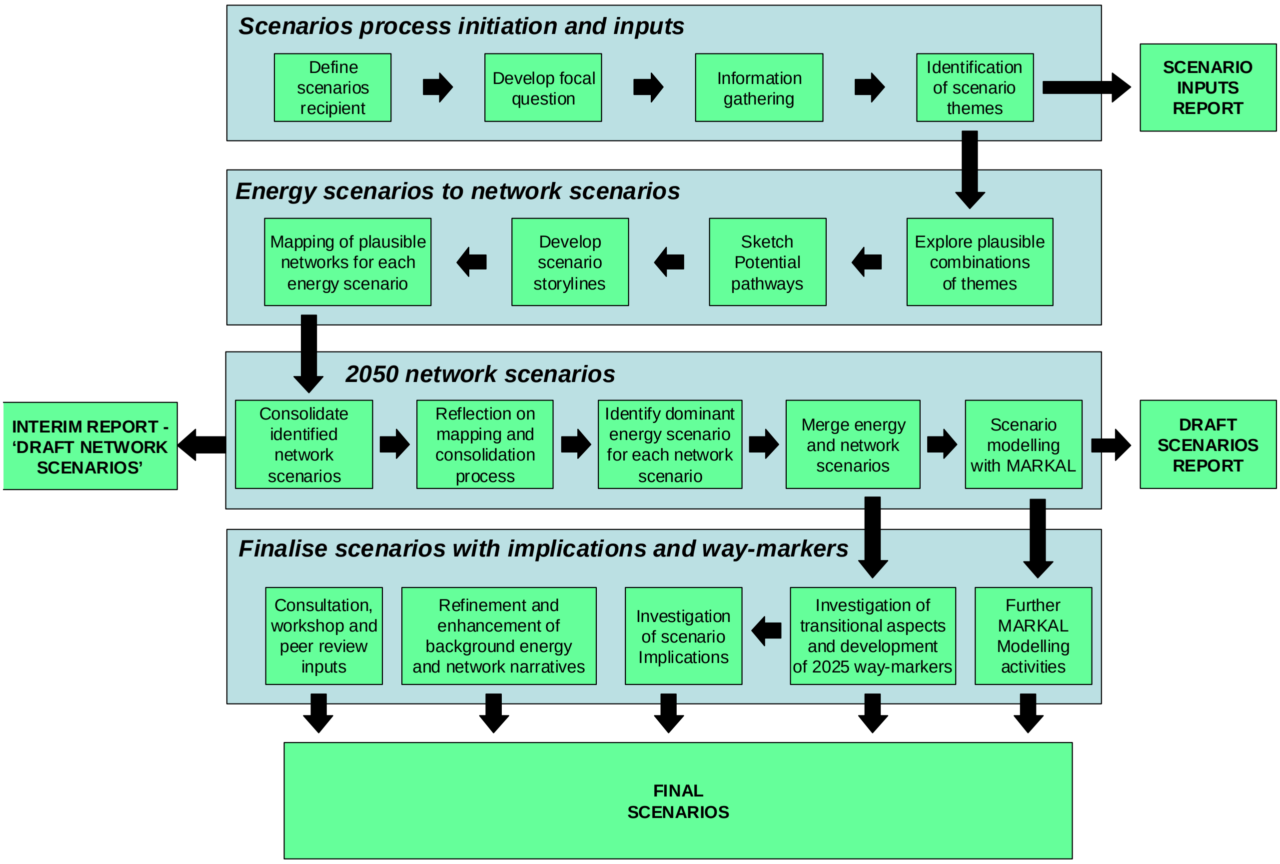

Figure 4: Development process of draft scenarios

7.5 *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 took place.

The focus of the LENS project remained 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 and 2 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

Table 2 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.

When we looked for relationships between the two sets of scenarios at a high level, we could see that ‘Big T&D’ logically fitted within a context of high demand, centralised generation and attitudes and behaviour not greatly different from today. This pointed to a close link to the ‘Switch Me On’ scenario.

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

Energy Service Companies must have a context that promoted 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 fitted well with these high level requirements.

The ‘DSO’ scenario required a context that promoted large amounts of renewable generation connected to the distribution network, significant overall demand reduction and DSM schemes that placed a significant onus on the management of these networks. The ‘Government Green Agenda’ scenario contained strong themes of demand reductions (hydrogen economy and efficiency) and a drive towards renewable generation that fitted 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 summarised 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
Micrograids (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 the Dynamic Green Markets narrative.

In summary then, a dominant energy narrative was assigned to a network scenario as shown in Table 3. 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 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 focusing 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 results of this stage of the project were reported in the Interim Report which contained draft versions of the network scenarios.

7.6 Quantifying the LENS Scenarios

7.6.1 MARKAL-MED and its application to the LENS project

7.6.1.1 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)[2]. It is an energy-economic-environment model, providing a bottom-up technology rich depiction of a whole energy system, matching resources, energy supply technologies and energy service demands to provide a solution which is optimised on the basis of discounted least energy system cost. Amongst other emissions, the model tracks CO_2 emissions resulting from energy use. 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

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[2] See: http://www.etsap.org/markal/main.html

from which the model can choose in meeting the system's energy service demands over the whole time period, within any constraints which are imposed upon it. The database includes resources, refining and processing technologies, power generation technologies, infrastructure, and end use technologies. Each technology is defined by capital, operation and maintenance costs, as well as by a number of other operational parameters, including efficiency and availability. It is on the basis of these input data that the model trades off one technology with another to find the overall cost-optimal solution. By changing such input parameters in a systematic fashion, different optimised solutions are generated, and the cross-comparison of these different results permits analysis of the most significant factors and uncertainties that will act on the energy system in the future.

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

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

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[3] Documentation on recent UK MARKAL databases, as well as research reports detailing the results they have generated, is available at: http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM2007/ESM.aspx

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

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 annualised 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 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.

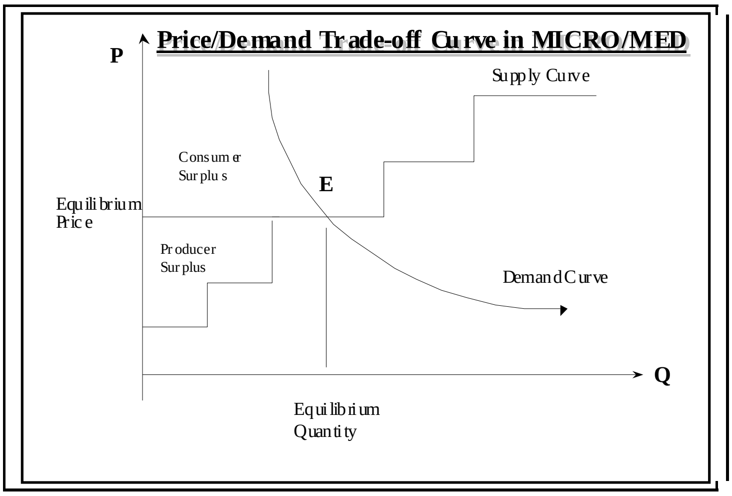

Figure 5 Representation of supply-demand equilibrium in MARKAL Elastic Demand

7.6.1.2 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.[5]
- 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.

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

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.

7.6.1.3 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.[6] 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.

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

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 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.

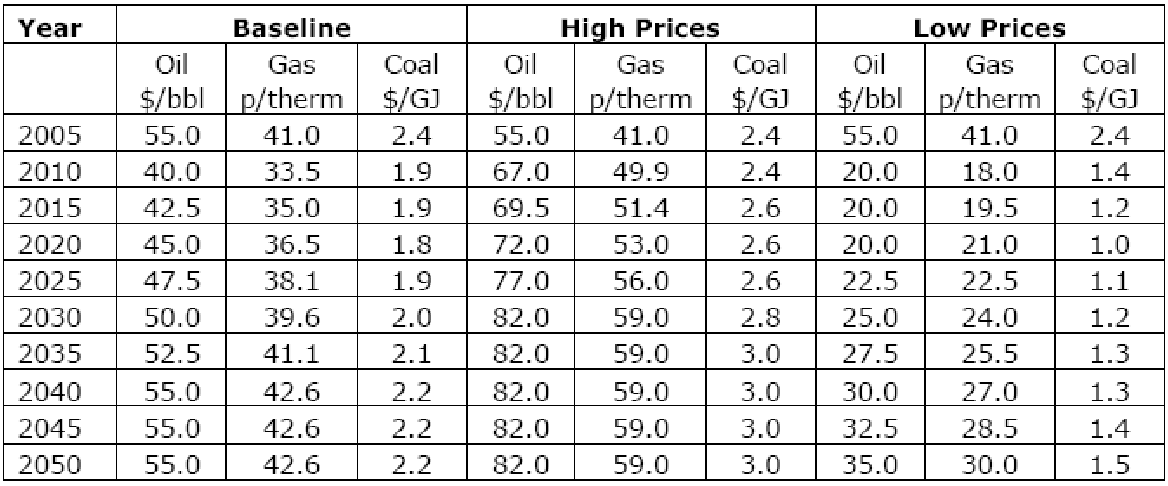
Now the input assumptions which lie behind the various MED runs for the LENS project will be explained.

7.6.2 Common model input assumptions for MARKAL-MED model runs

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[7]. 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).

Energy service demands

Standard energy service demands (before demand elasticities) are based on BERR and DfT projections (BERR, 2006 and DfT, 2005). These demands already account for

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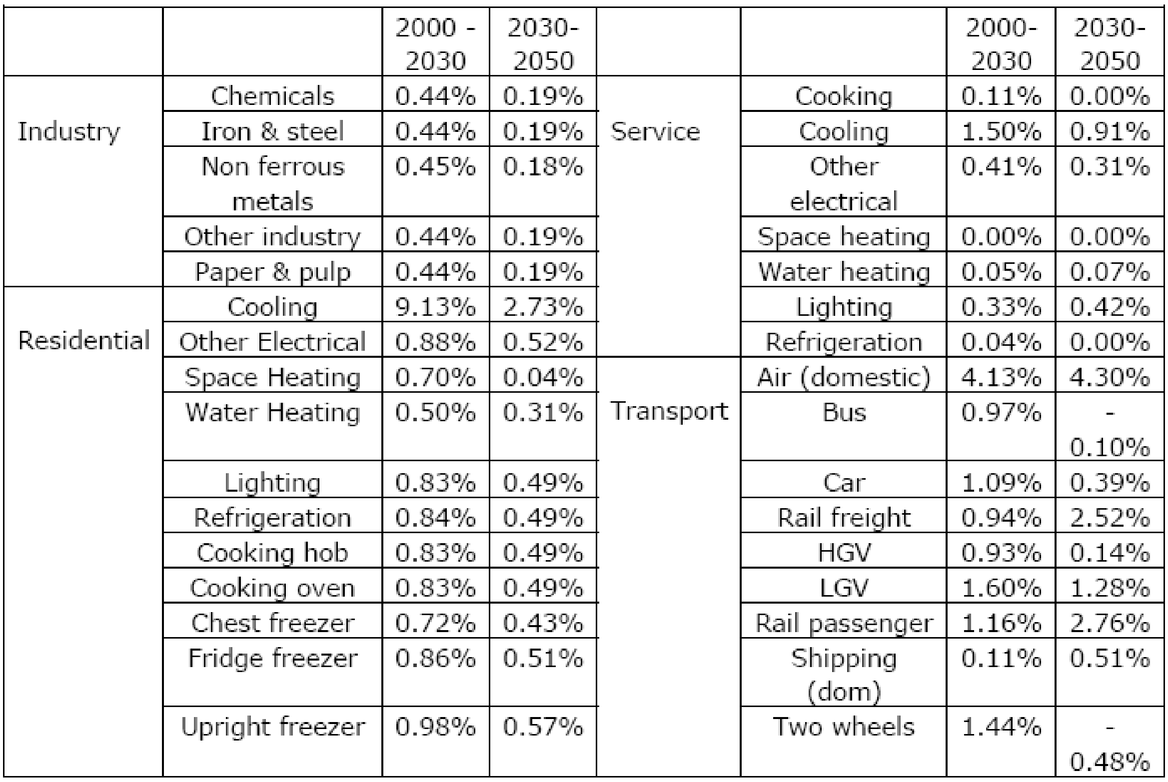
[7] See: http://www.berr.gov.uk/files/file46071.pdf

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) and Kannan et al (2007).



		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.

7.7 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.

7.8 Finalising the Scenarios

Previous sub-sections have described the scenarios development process up to the points of merged energy and network scenarios, quantitative modeling and investigating transitional issues through the 2025 way-markers. These are the key ingredients in the scenarios but a final stage of the project drew these elements together and refined and enhanced the scenarios through careful consideration of further inputs to the process.

The further inputs at the final stage of the scenario development process were illustrated in Figure 4 and included:

- ***Academic peer review***. Each of the previous deliverables from the LENS project was studied in depth by an external peer reviewer (Dr. Jim Watson at SPRU, University of Sussex). The probing analysis of the scenarios and the feedback given tailored the development of the scenarios through the development process but these inputs were reviewed again towards the close of the project to ensure that the key inputs were captured and addressed.
- ***Consultation responses***: The consultation responses from industry stakeholders were reviewed and addressed once more in several areas including removing any bias in the content or even tone of the scenarios, plausibility, consistency and inclusion of recent thinking and publication in related areas.
- ***Workshop inputs***. A good deal of valuable input was captured at the final workshop and this was used to refine and enhance the scenarios alongside the consultation responses. (The workshops were attended by a broader set of stakeholders than responded in writing to the consultation so these inputs were particularly useful in capturing broader issues and considerations for the scenarios.)

In addition to the inputs described above, the modeling results, 2025 way-markers, energy context and outlines of the networks at 2050 were reviewed, refined and enhanced to address issues of consistency and plausibility. At this final stage the illustrations were improved to take account of feedback received. In addition, comparisons were drawn by looking across the scenarios.

Implications of the scenarios were developed by a process of inspection of the finalised scenarios and consideration of technical, economic, commercial and regulatory impacts of each. The implications for each scenario were then studied broadly to develop a set of general implications of the scenarios and a set of high-level conclusions. The outcomes of each of these final steps is presented in the main body of the final report.

8 Appendix B – Modelling Inputs & Results

This appendix contains a more detailed discussion of the modelling inputs and results for each of the five scenarios contained in the main body of the report. The figures it contains represent primary model output data, and underlie the summarised data shown in the main body of the report.

The data tables in this appendix have been generated under a range of input assumptions, which have been developed as part of a scenario process that is outlined in the main body of the report and in appendix A. With reference to the disclaimer included at the start of this report, the data should not be regarded as projections or predictions.

8.1 Big Transmission & Distribution

8.1.1 Model input assumptions

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.

8.1.2 Model results: overview

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.

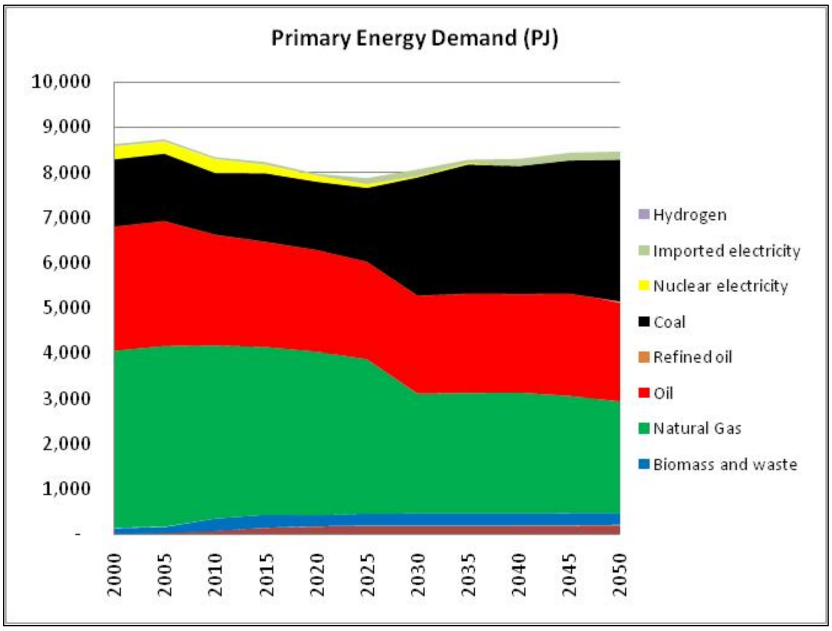


Figure 6 Big T&D Total Primary Energy Demand, 2000-2050

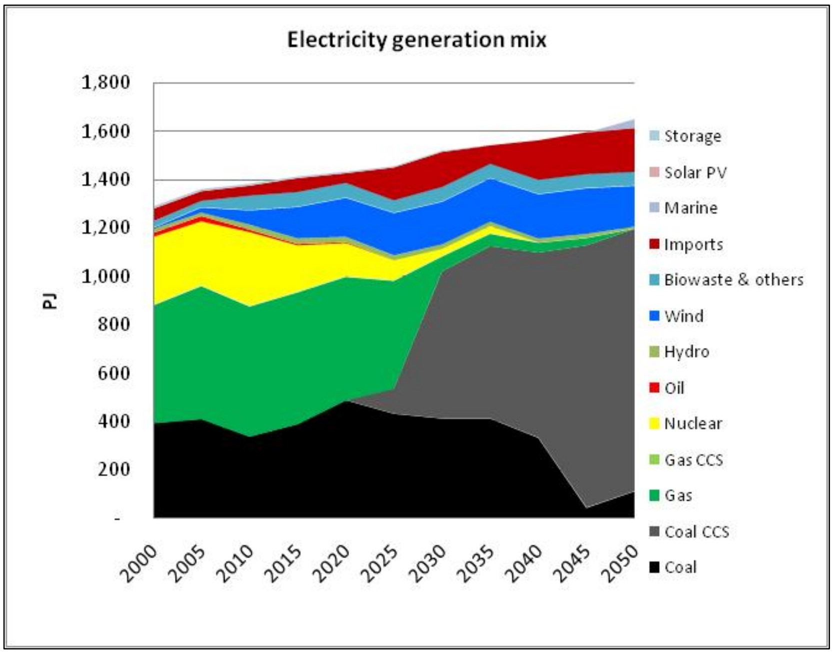


Figure 7 Big T&D Electricity Generation Mix, 2000-2050

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.

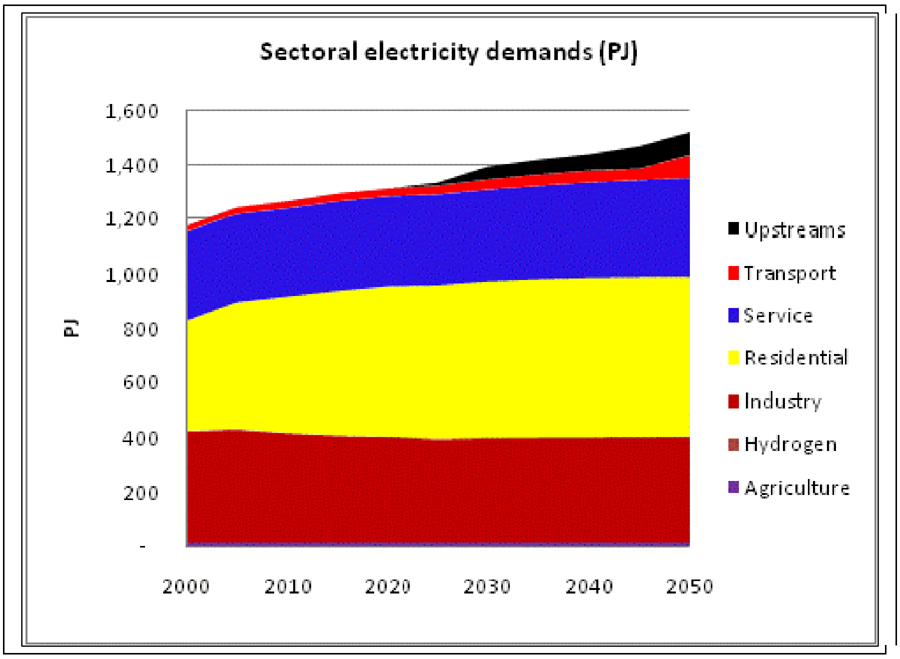


Figure 8 Big T&D Sectoral Electricity Demands, 2000-2050

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

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.

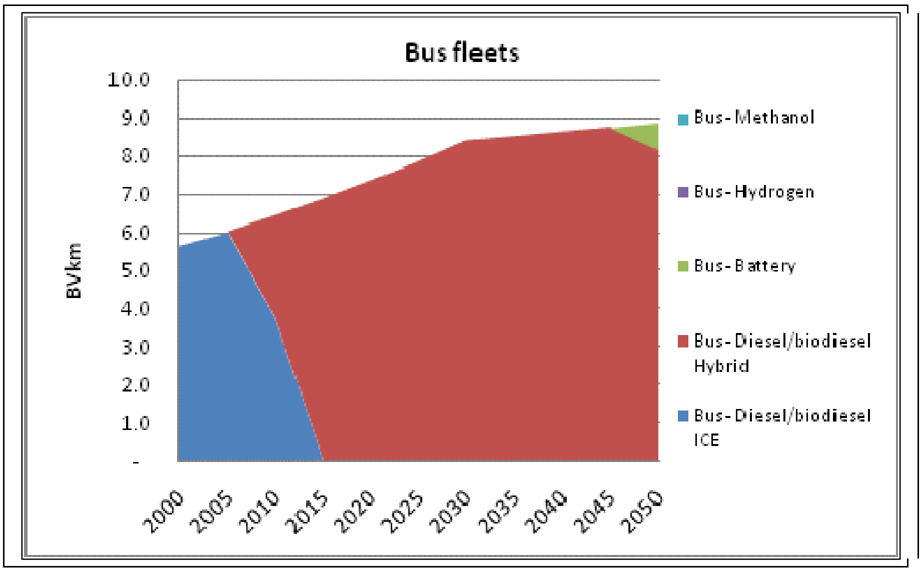


Figure 9 Big T&D Bus fleet technologies 2000-2050

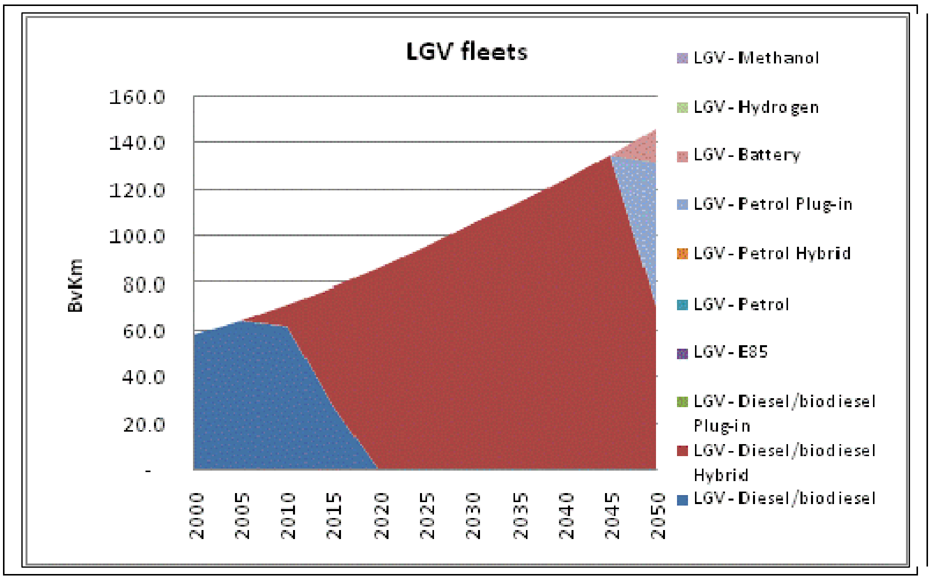


Figure 10 Big T&D LGV fleet technologies 2000-2050

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.

8.1.3 Model results: details

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 Hybr	-	-	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**

Total emissions (Million t- CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	548,824.00	555,414.85	511,867.47	511,409.62	502,328.91	473,896.04	432,434.38	438,103.54	424,918.49	378,519.67	386,583.80
Electricity sector	181,236.66	193,650.26	172,155.97	187,235.75	176,765.28	152,860.80	117,926.74	118,239.48	102,152.02	50,474.32	60,439.35

% emissions reductions from year 2000 levels

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	0	-1.2	6.7	6.8	8.5	13.7	21.2	20.2	22.6	31.0	29.6
Electricity sector	0	-6.8	5.0	-3.3	2.5	15.7	34.9	34.8	43.6	72.2	66.7

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
4. ‘Sectoral Emissions’ are incomplete before 2030 as imports and exports of fossil fuels are not completely captured in these metrics before this time period, due to model calibration. Thus summing of sectoral emissions in time periods prior to 2030 does not produce the true total. For accurate total emissions in all time periods, see tables 'Total emissions' and '% emissions reductions from year 2000 levels'.

8.2 Energy Service Companies

8.2.1 Model input assumptions

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 / tCO2 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. Thus this technology

characterisation assumes a more aggregated level of management than would currently be available for individual microwind installations.

- A maximum activity constraint was also imposed upon microwind, to ensure realistic deployment levels accounting for geographical constraints. Research for the Energy Saving Trust[8] 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).

8.2.2 Model results: overview

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.

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

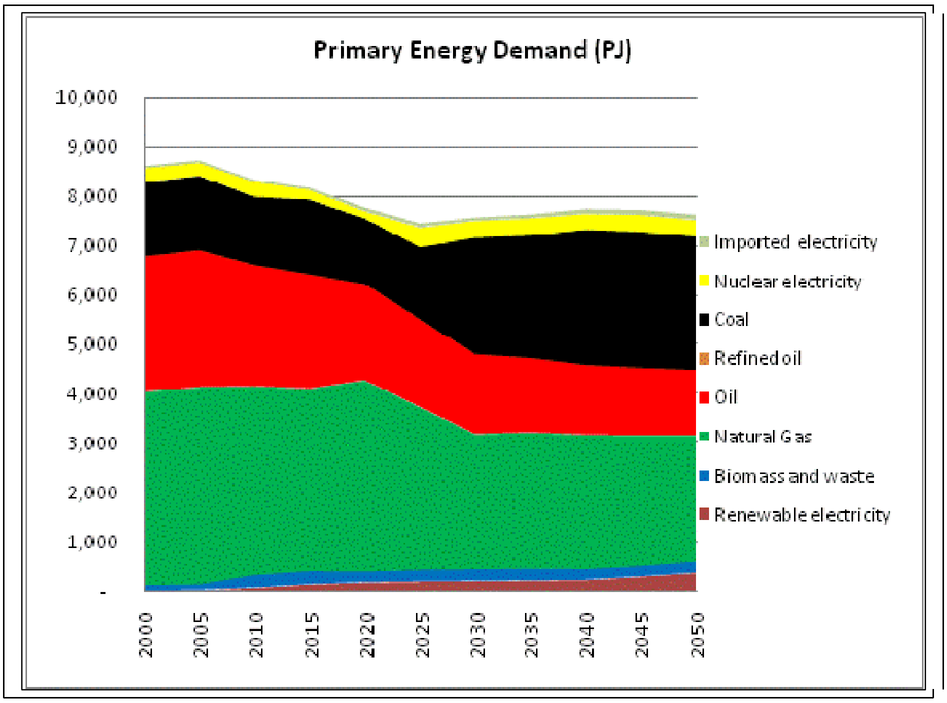


Figure 11 Energy Service Companies Total Primary Energy Demand, 2000-2050

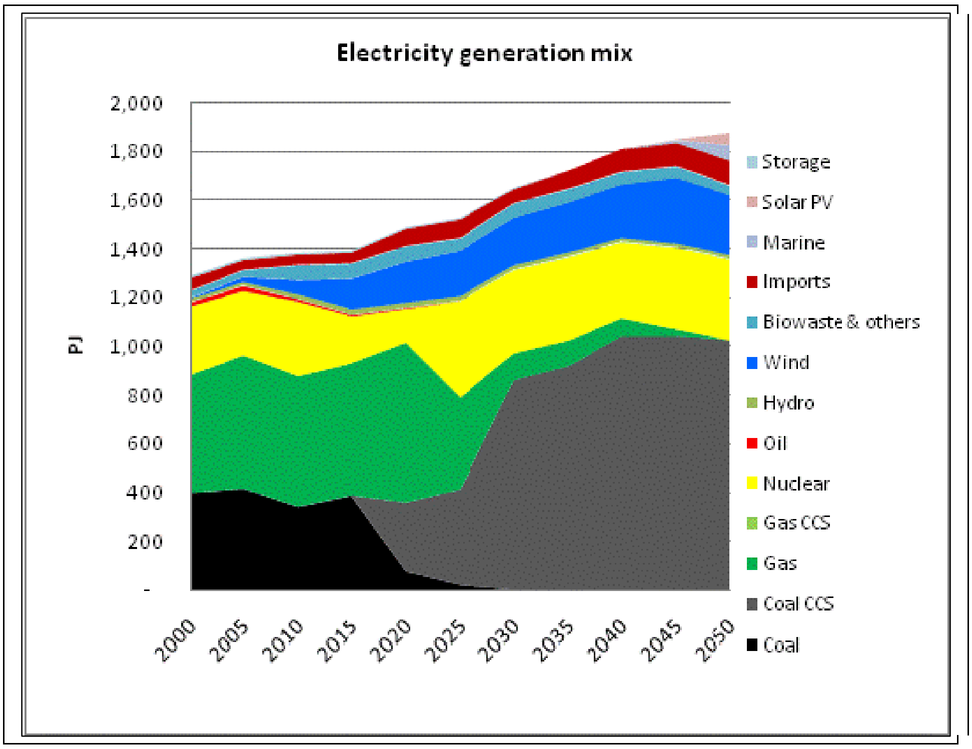


Figure 12 Energy Service Companies Electricity Generation mix, 2000-2050

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.

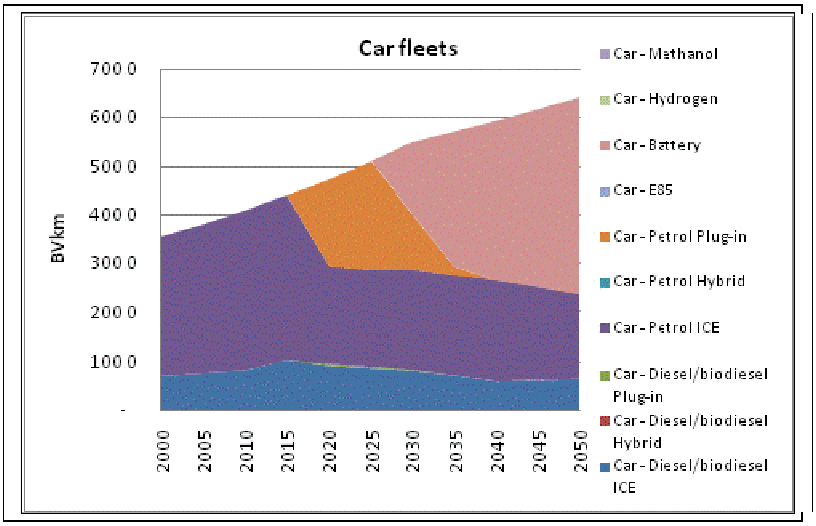
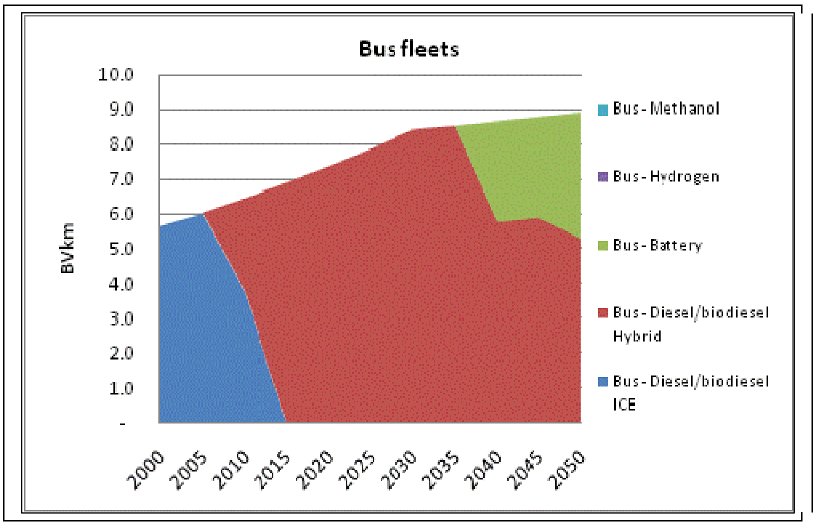


Figure 13 Energy Service Companies car fleet technologies, 2000-2050



,**Figure 14** Energy service companies bus fleet technologies, 2000-2050

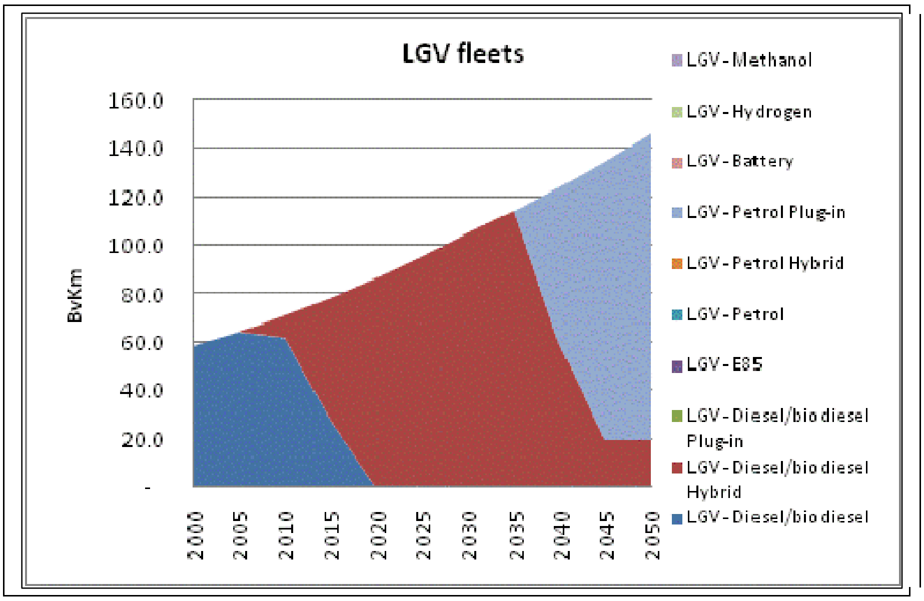


Figure 15 Energy Service Companies LGV fleet technologies, 2000-2050

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 CO2 mitigation effort of 47%. 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.

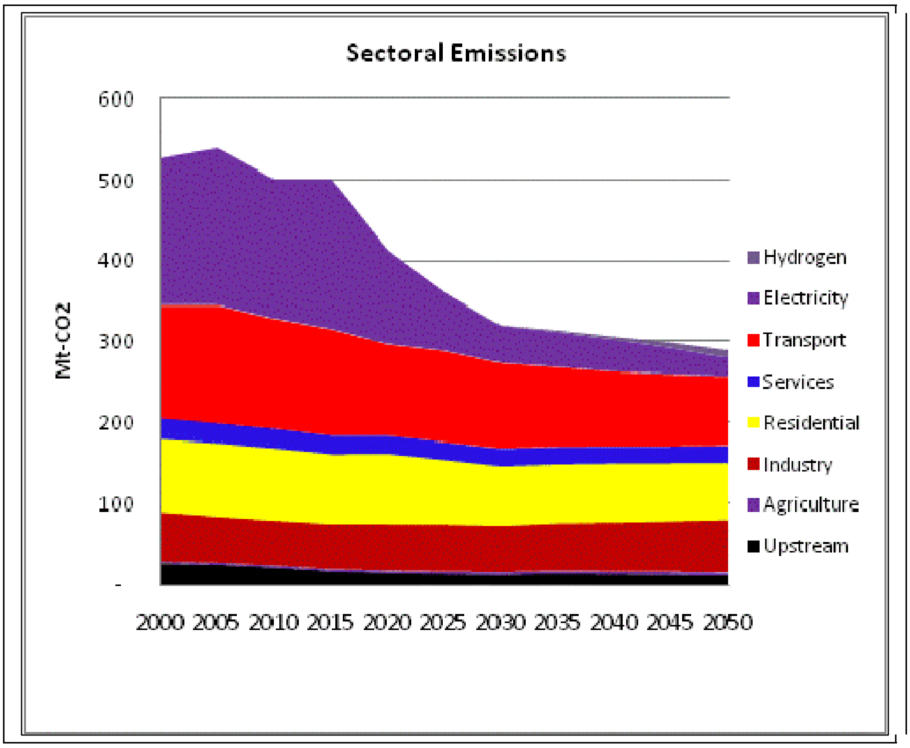


Figure 16 Energy Service Companies sectoral emissions, 2000-2050

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.

8.2.3 Model results: details

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 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	0.8	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**

Total emissions (Million t- CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole System	548,824.00	555,211.78	511,723.85	508,013.26	418,346.88	364,861.59	319,322.67	312,785.33	305,153.66	298,097.06	288,781.36
Electricity sector	181,236.66	193,650.22	171,961.38	185,423.82	115,977.18	72,402.76	45,899.21	43,378.91	39,579.33	32,448.72	22,306.68

% emissions reductions from year 2000 levels

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	0	-1.2	6.8	7.4	23.8	33.5	41.8	43.0	44.4	45.7	47.4
Electricity sector	0	-6.8	5.1	-2.3	36.0	60.1	74.7	76.1	78.2	82.1	87.7

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
4. ‘Sectoral Emissions’ are incomplete before 2030 as imports and exports of fossil fuels are not completely captured in these metrics before this time period, due to model calibration. Thus summing of sectoral emissions in time periods prior to 2030 does not produce the true total. For accurate total emissions in all time periods, see tables 'Total emissions' and '% emissions reductions from year 2000 levels'.

8.3 Distribution System Operators

8.3.1 Model input assumptions

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 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.

8.3.2 Model results: overview

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.

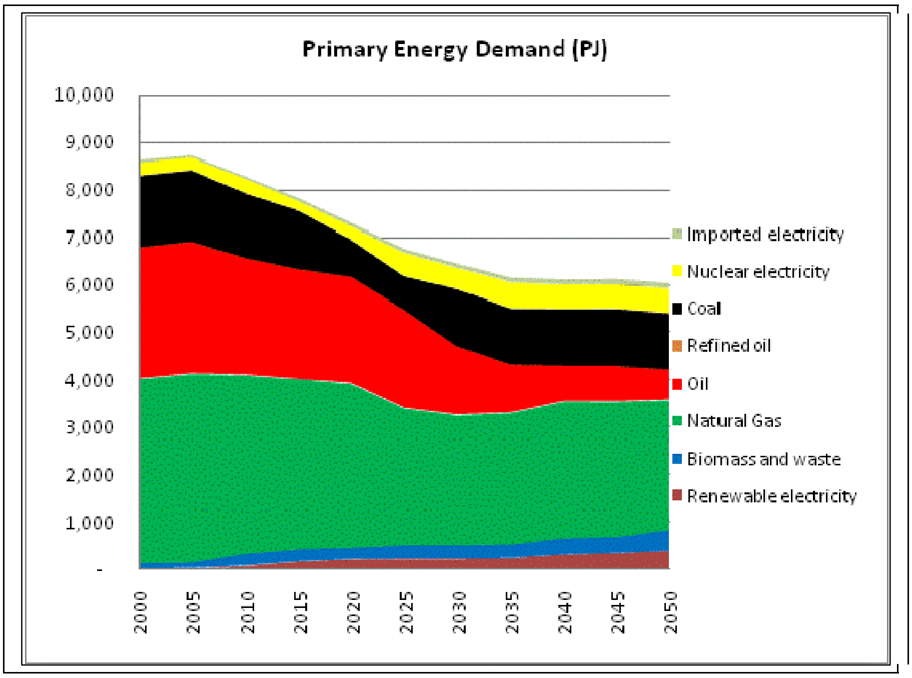


Figure 17 Distribution System Operators total primary energy demand, 2000-2050

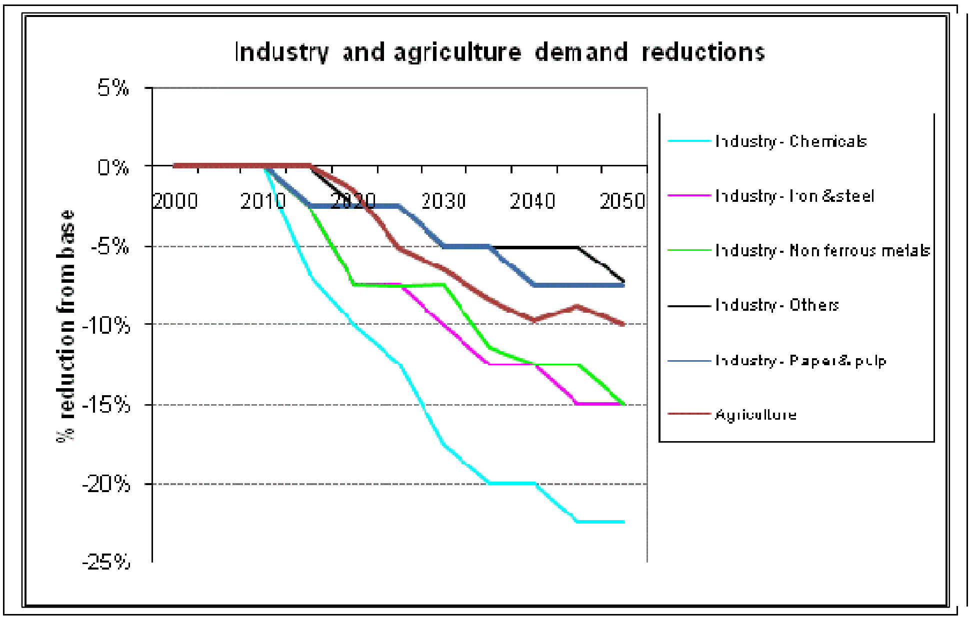


Figure 18 Distribution System Operators industry & agriculture,

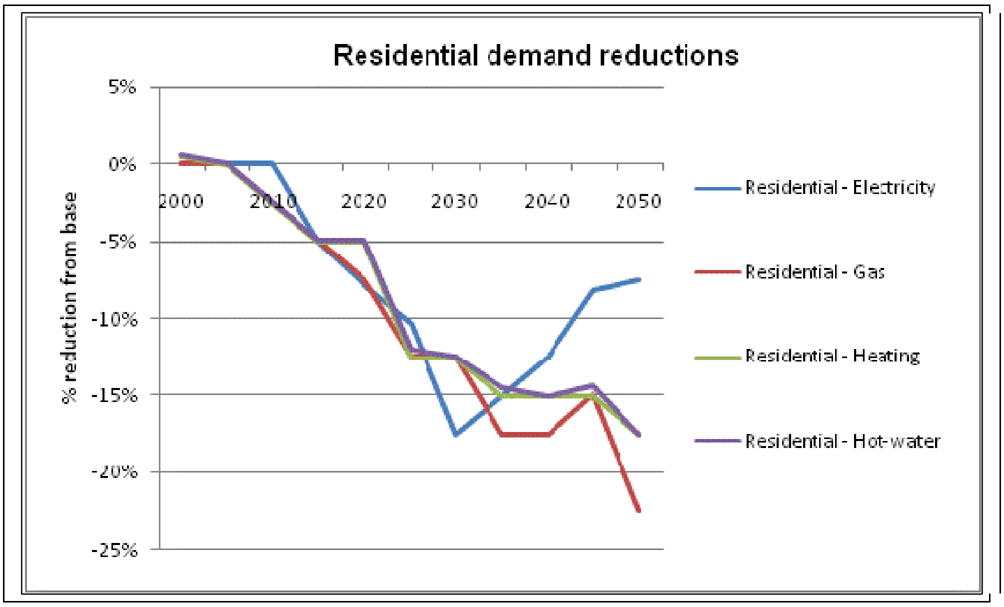


Figure 19 residential demand reductions

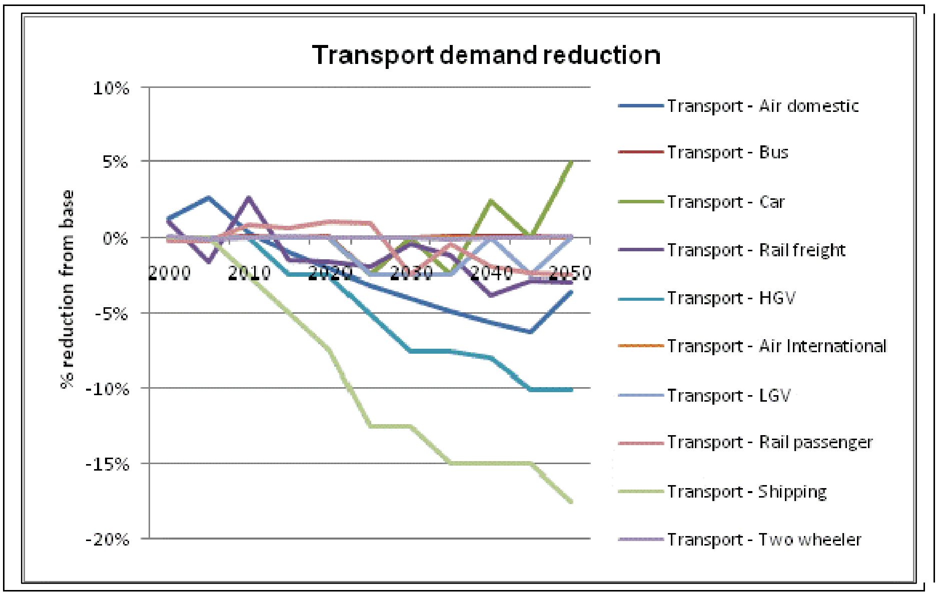


Figure 20 Distribution System Operators transport demand reductions

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.

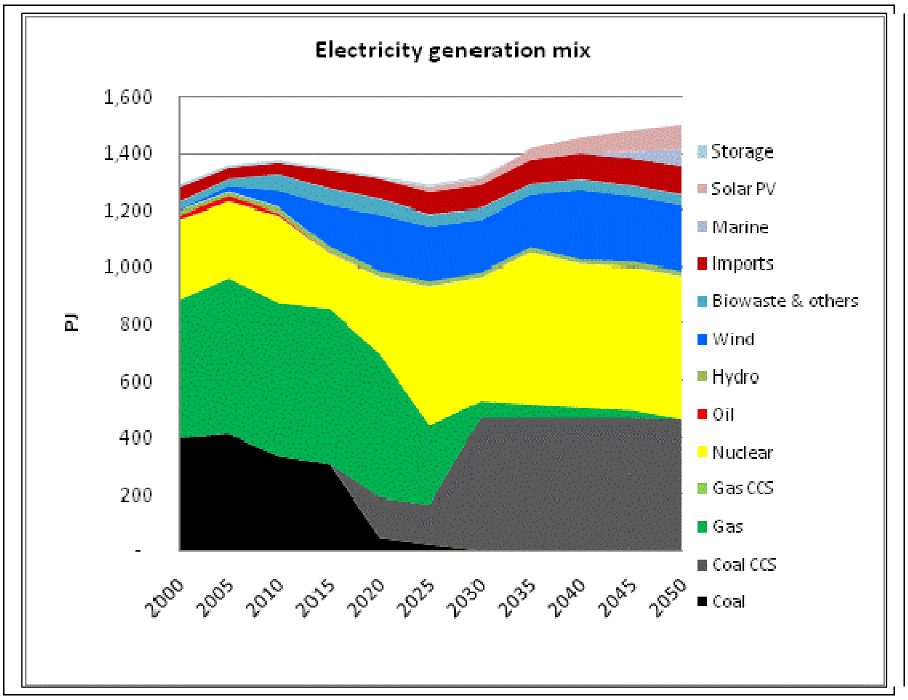


Figure 21 Distribution System Operators electricity generation mix, 2000-2050

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.

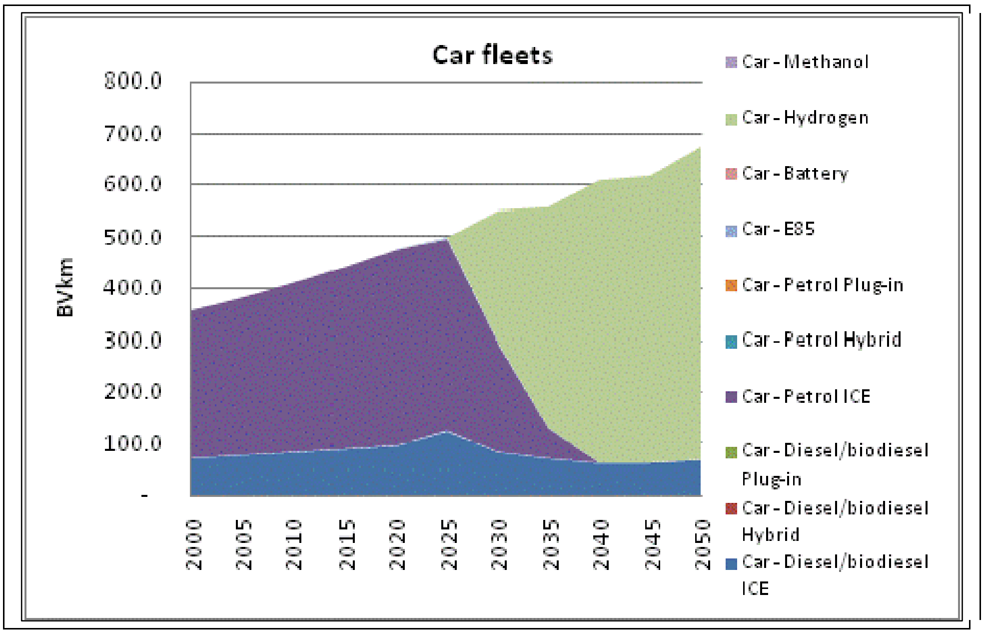


Figure 22 Distribution System Operators car fleet technologies, 2000-2050

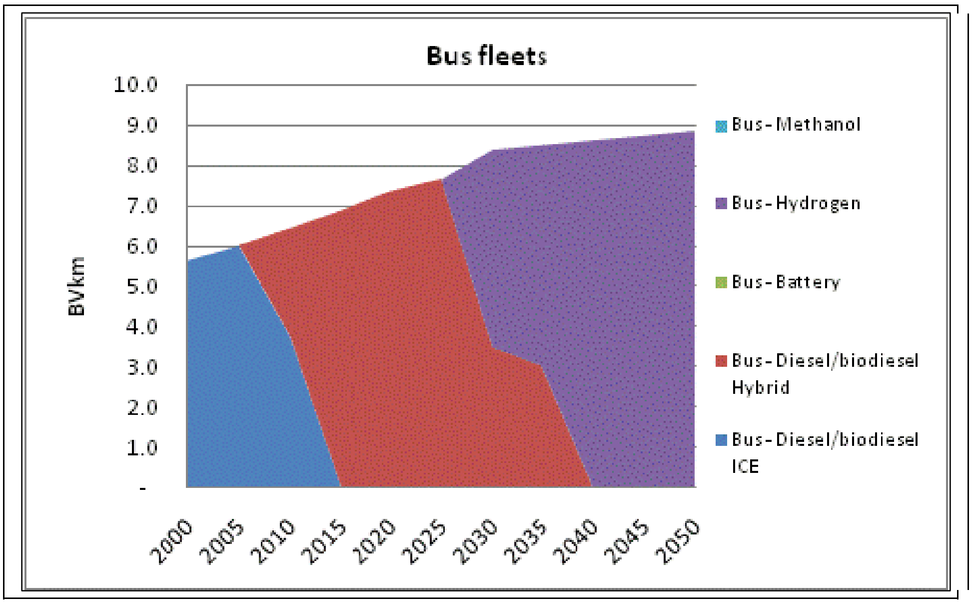


Figure 23 Distribution System Operators bus fleet technologies, 2000-2050

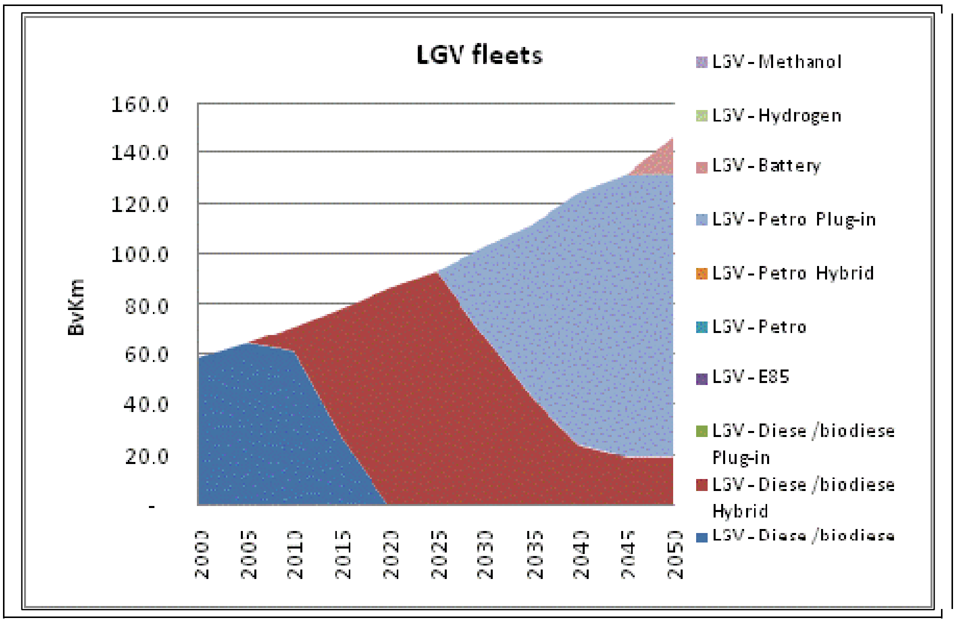


Figure 24 Distribution System Operators LGV fleet technologies, 2000-2050

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.

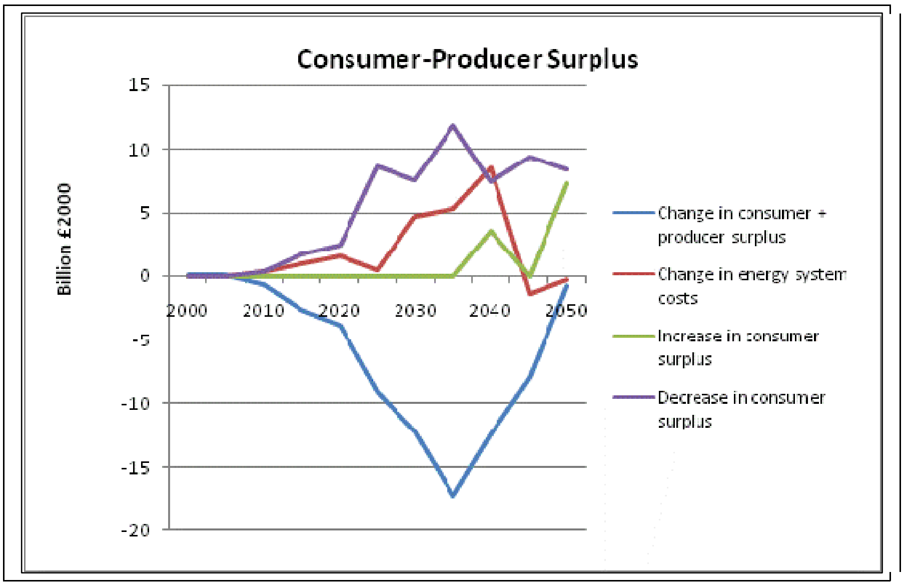


Figure 25 Distribution System Operators change in consumer-producer surplus, 2000-2050

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.

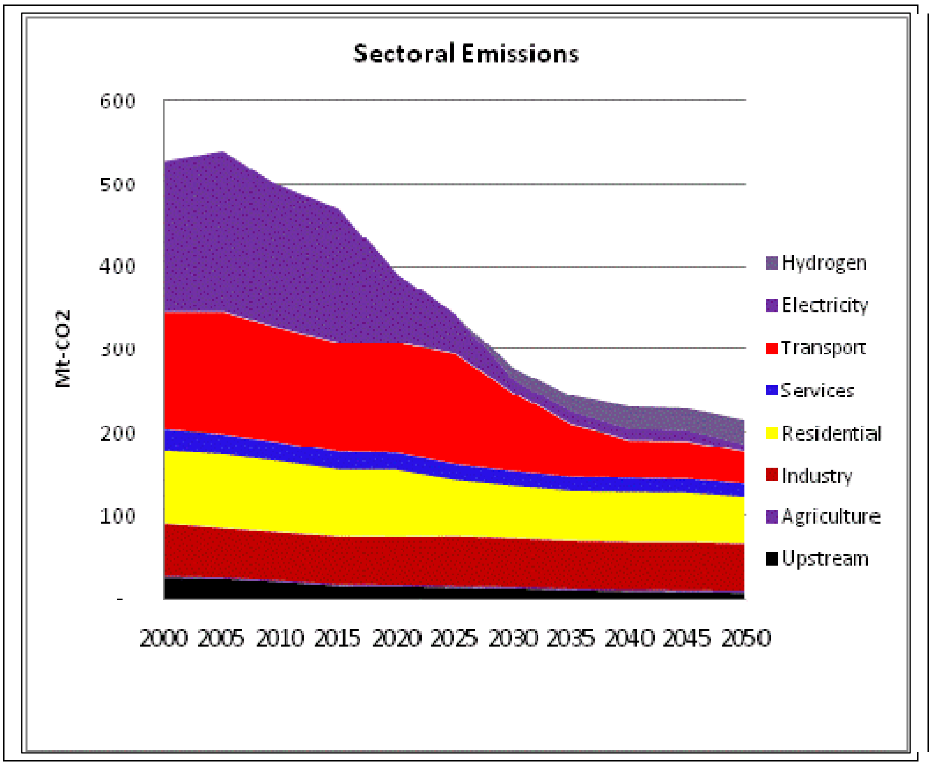


Figure 26 Distribution System Operators sectoral emissions, 2000-2050

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.[9] 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

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[9] 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

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 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.

8.3.3 Model results: details

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 Hybr	-	-	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

Total emissions (Million t- CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	548,824.00	555,118.99	507,752.82	476,562.75	396,891.31	346,227.23	277,437.53	244,384.78	230,749.12	228,474.62	214,709.71
Electricity sector	181,236.66	193,226.34	170,439.12	160,083.05	82,800.28	47,480.65	16,038.43	14,599.85	13,636.14	12,672.42	9,716.90

% emissions reductions from year 2000 levels

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	0	-1.1	7.5	13.2	27.7	36.9	49.4	55.5	58.0	58.4	60.9
Electricity sector	0	-6.6	6.0	11.7	54.3	73.8	91.2	91.9	92.5	93.0	94.6

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
4. ‘Sectoral Emissions’ are incomplete before 2030 as imports and exports of fossil fuels are not completely captured in these metrics before this time period, due to model calibration. Thus summing of sectoral emissions in time periods prior to 2030 does not produce the true total. For accurate total emissions in all time periods, see tables 'Total emissions' and '% emissions reductions from year 2000 levels'.

8.4 Microgrids

8.4.1 Model input assumptions

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.

8.4.2 Model results: overview

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.

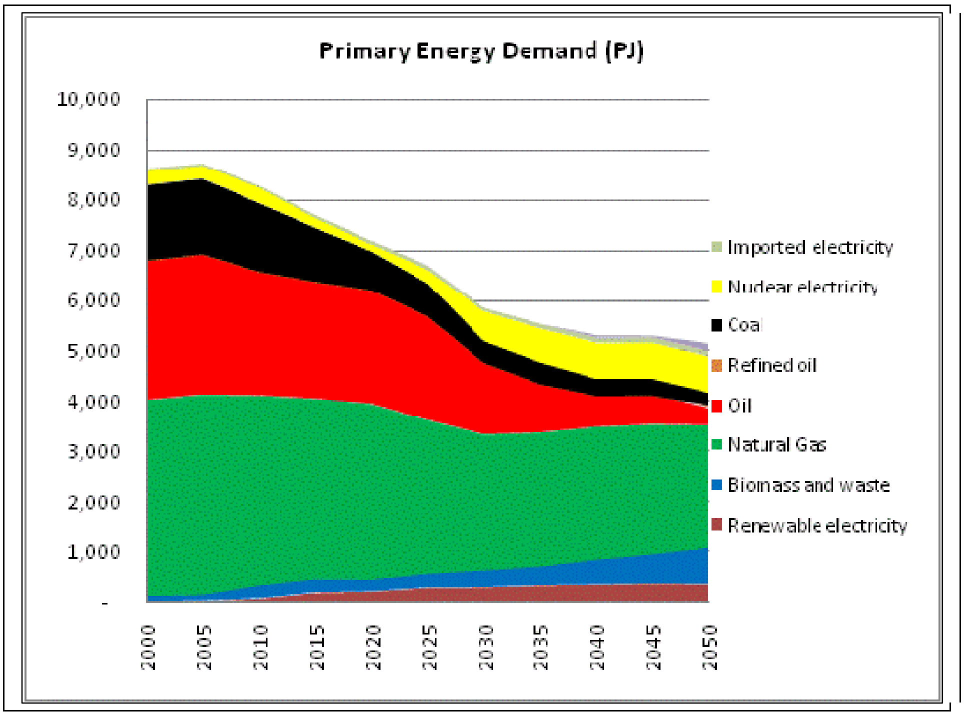

Figure 27 Microgrids primary energy demand, 2000-2050

Demand reduction is employed to a very significant extent by the model in response to the high carbon prices. 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.

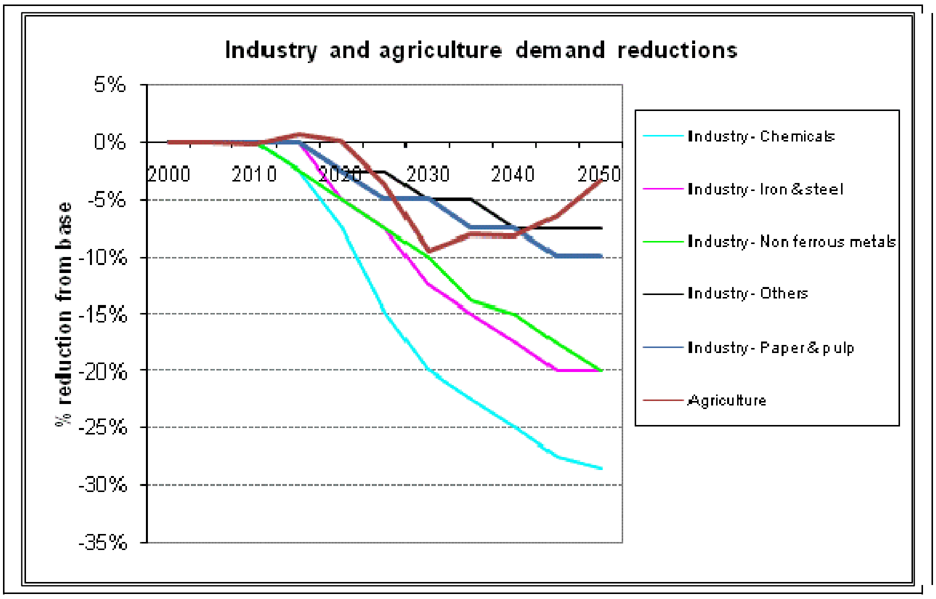

Figure 28 Micrografts industry & agriculture demand reductions.

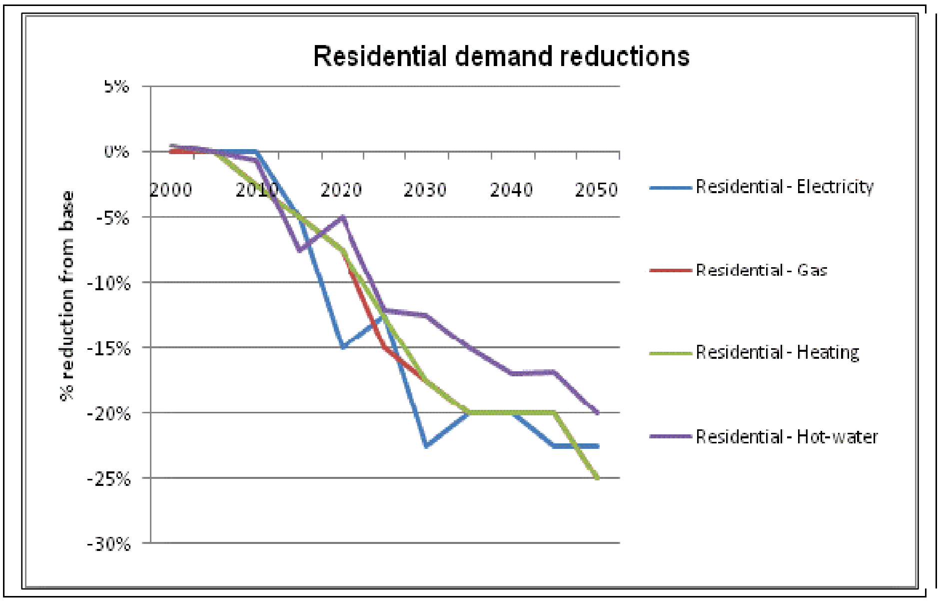

Figure 29 Microgrids residential demand reductions

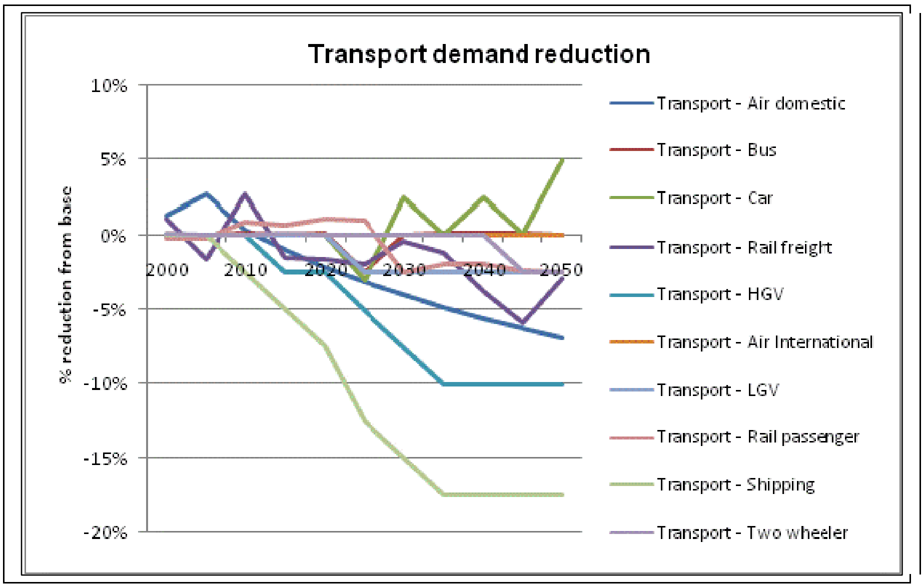

Figure 30 Microgrids transport demand reductions

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.

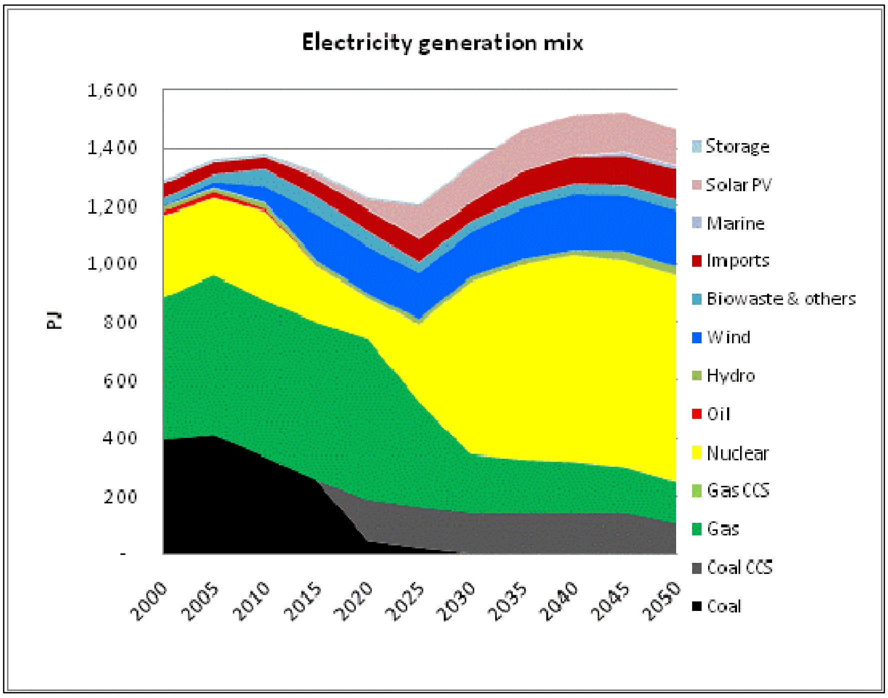

Figure 31 Microgrids electricity generation mix, 2000-2050

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.

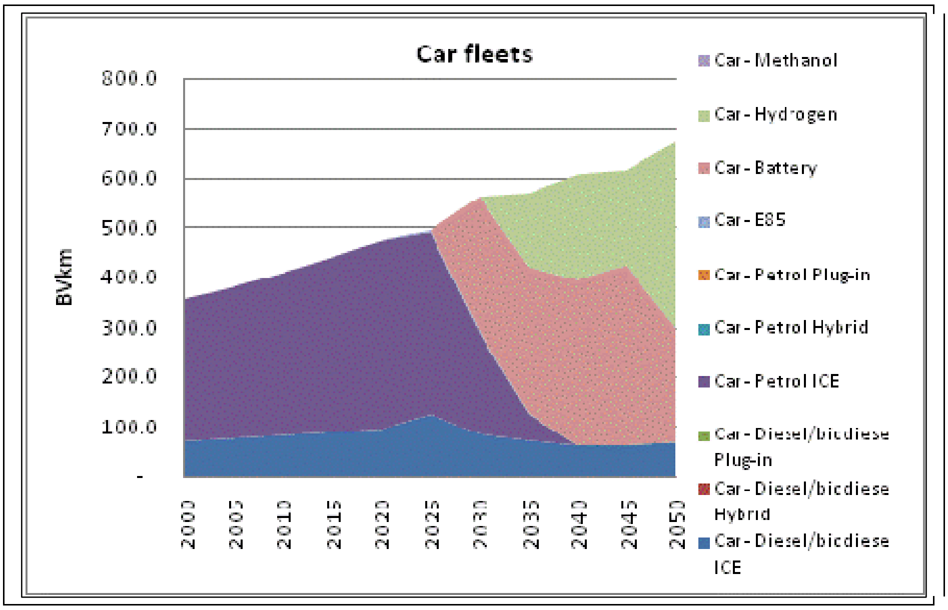

Figure 32 Microgrids car and fleet technologies, 2000-2050.

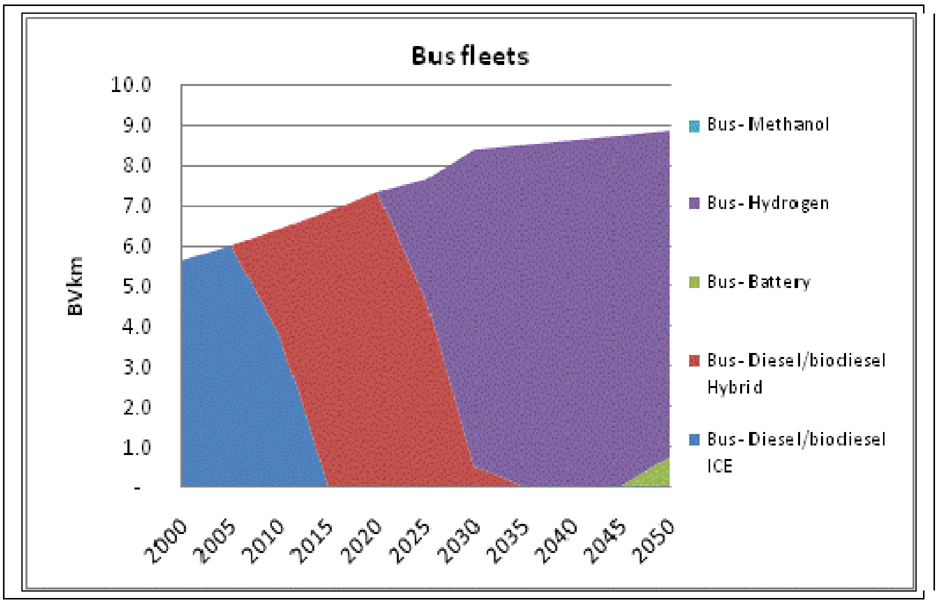

Figure 33 Microgrids bus fleet technologies, 2000-2050.

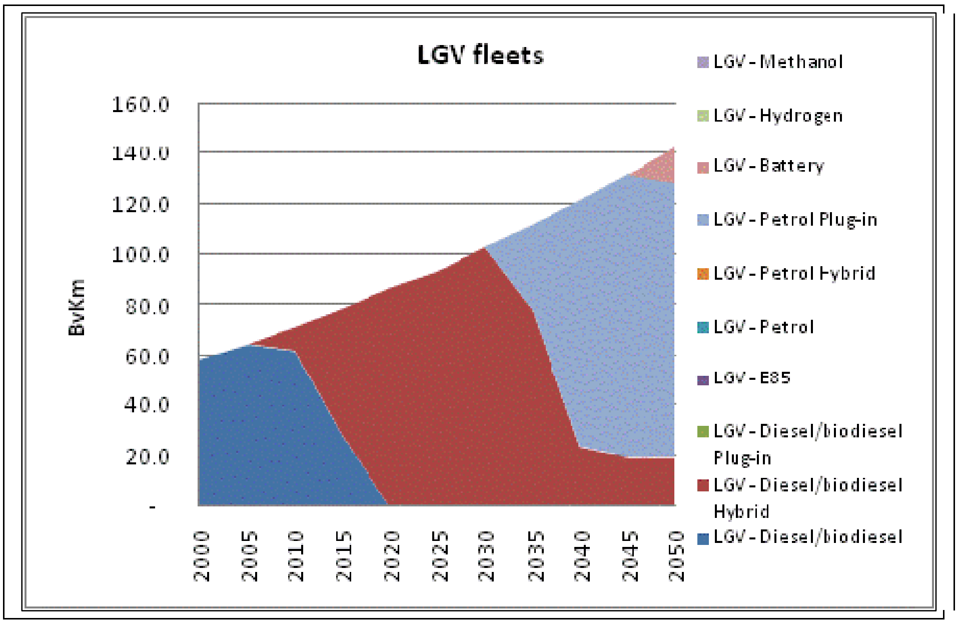

Figure 34 Microgrids LGV fleet technologies, 2000-2050

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.

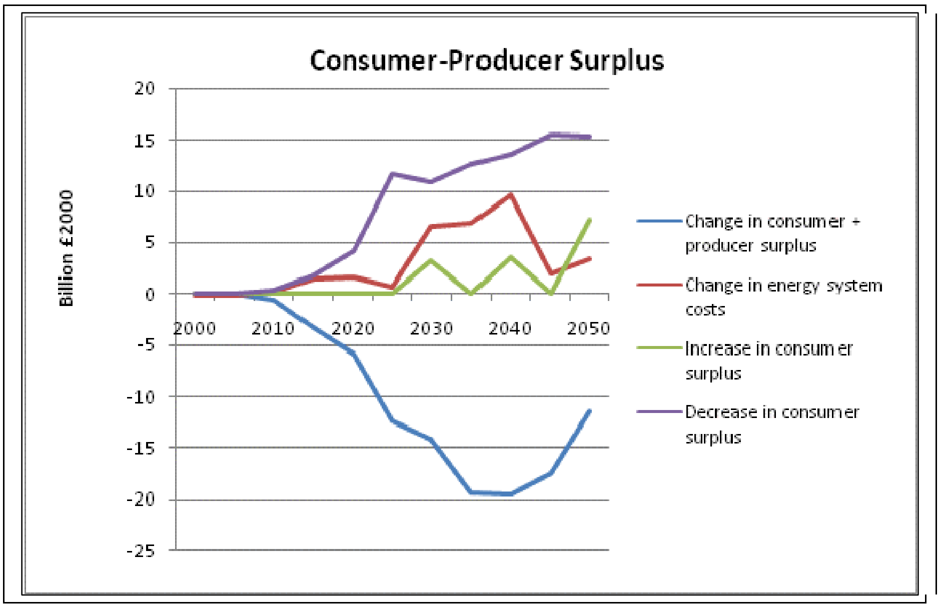

Figure 35 Microgrids consumer-producer surplus, 2000-2050

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.

8.4.3 Model results: details

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 Hybr	-	-	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 Internationa	-	-	-	-	-	-	-	-	-	-	-
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

Total emissions (Million t- CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	548,824.00	555,179.17	508,302.70	463,040.99	398,510.24	350,542.67	261,911.34	224,923.51	189,094.79	181,419.82	160,543.70
Electricity sector	181,236.66	193,294.73	170,666.75	145,757.76	85,079.20	46,713.07	12,848.90	10,836.14	9,560.24	7,686.11	2,408.09

% emissions reductions from year 2000 levels

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	0	-1.2	7.4	15.6	27.4	36.1	52.3	59.0	65.5	66.9	70.7
Electricity sector	0	-6.7	5.8	19.6	53.1	74.2	92.9	94.0	94.7	95.8	98.7

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
4. ‘Sectoral Emissions’ are incomplete before 2030 as imports and exports of fossil fuels are not completely captured in these metrics before this time period, due to model calibration. Thus summing of sectoral emissions in time periods prior to 2030 does not produce the true total. For accurate total emissions in all time periods, see tables 'Total emissions' and '% emissions reductions from year 2000 levels'.

8.5 Multi Purpose Networks

8.5.1 Model input assumptions

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.

8.5.2 Model results: overview

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.

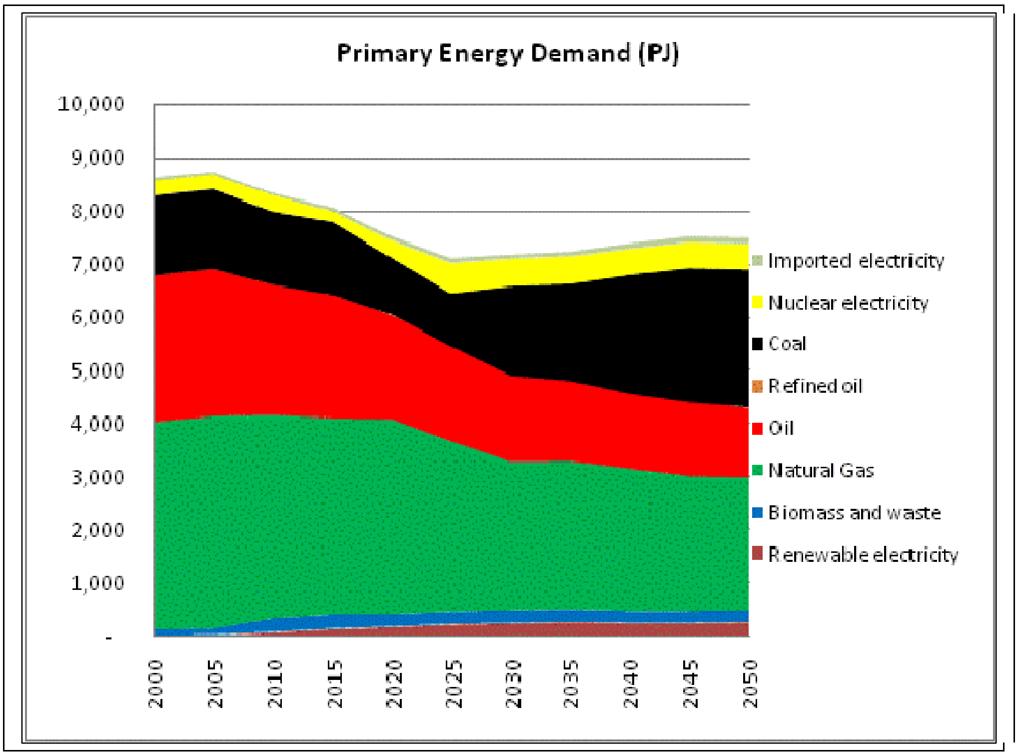

Figure 36 Multi purpose networks total primary energy demand

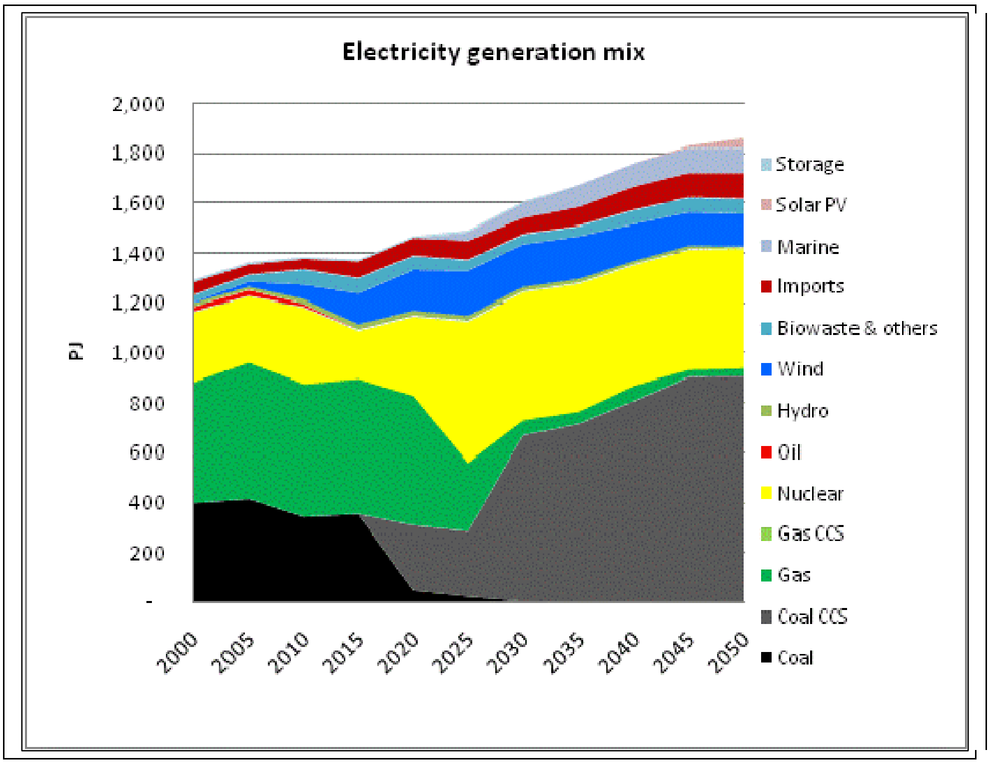

Figure 37 Multi purpose networks electricity generation mix

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.

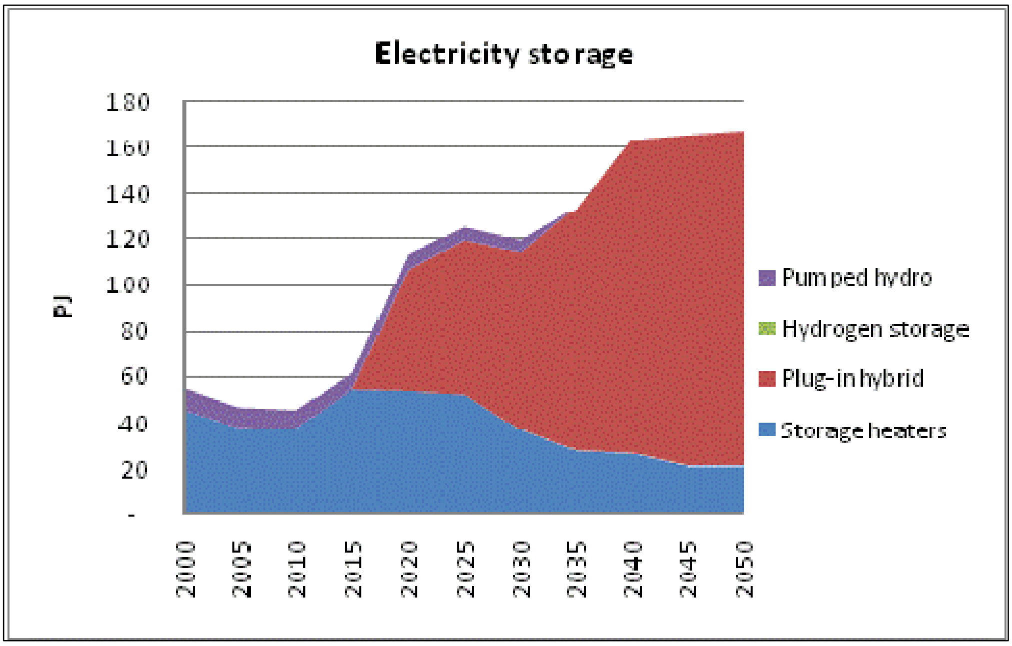

Figure 38 Multi purpose networks electricity storage activity, 2000-2050

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

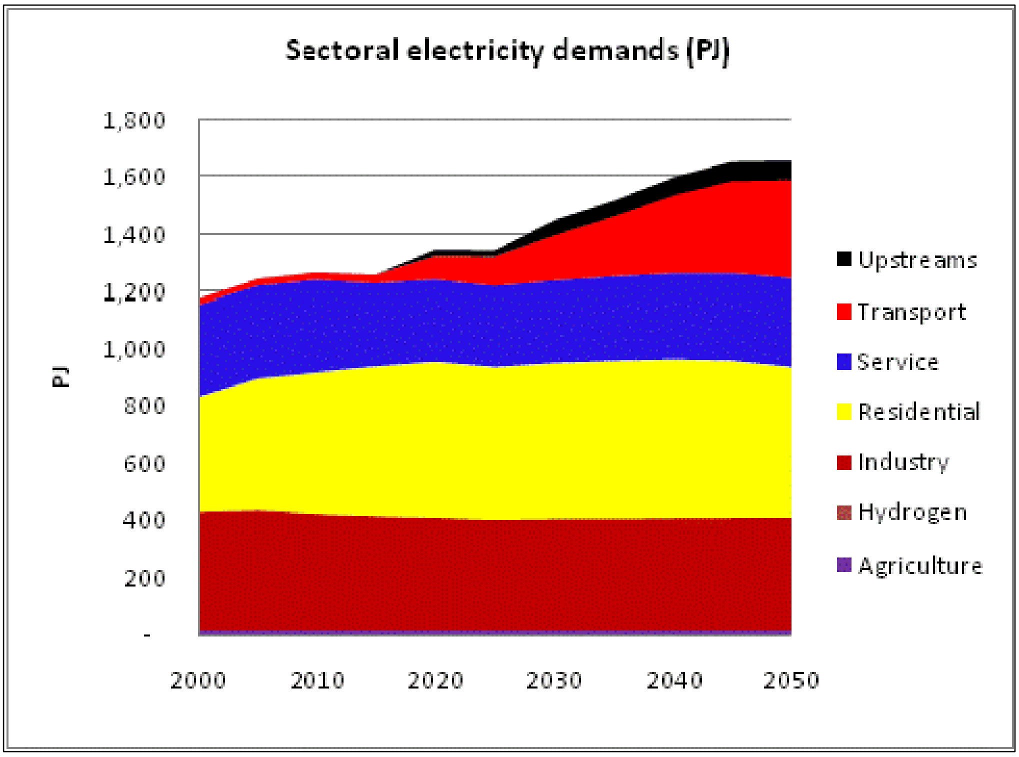

Figure 39 Multi purpose networks sectoral electricity demands, 2000-2050

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.

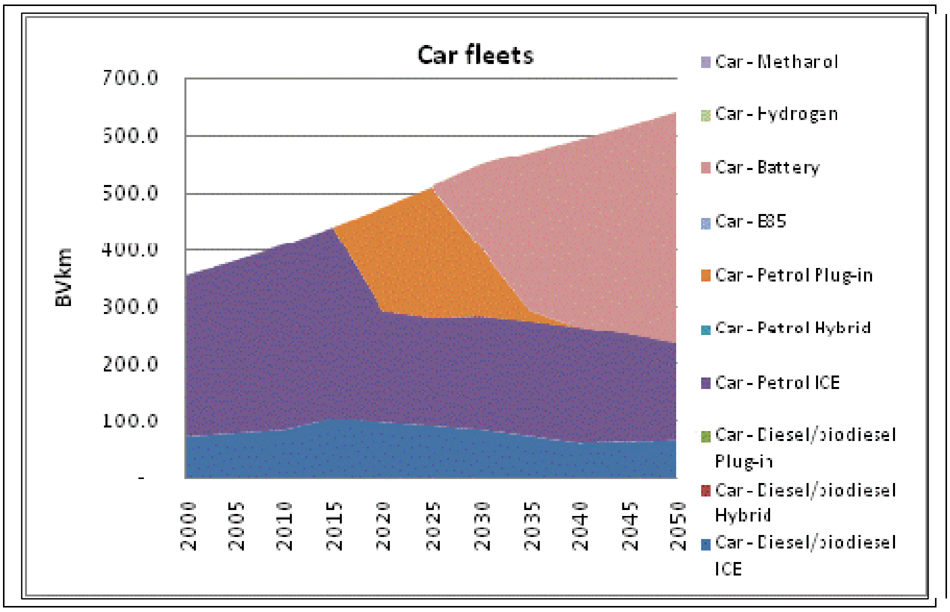

Figure 40 Multi purpose networks car fleet technologies, 2000-2050.

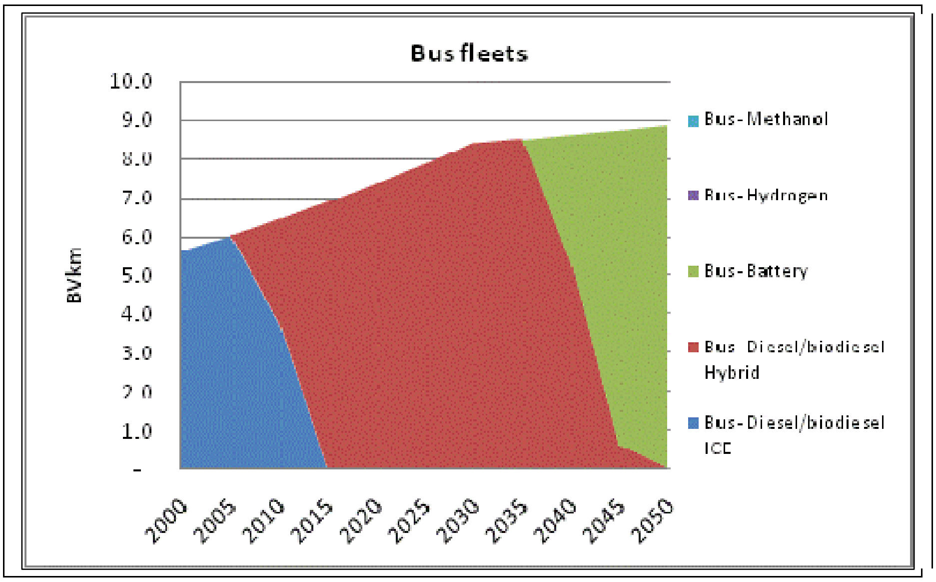

Figure 41 Multi purpose networks bus fleet technologies, 2000-2050

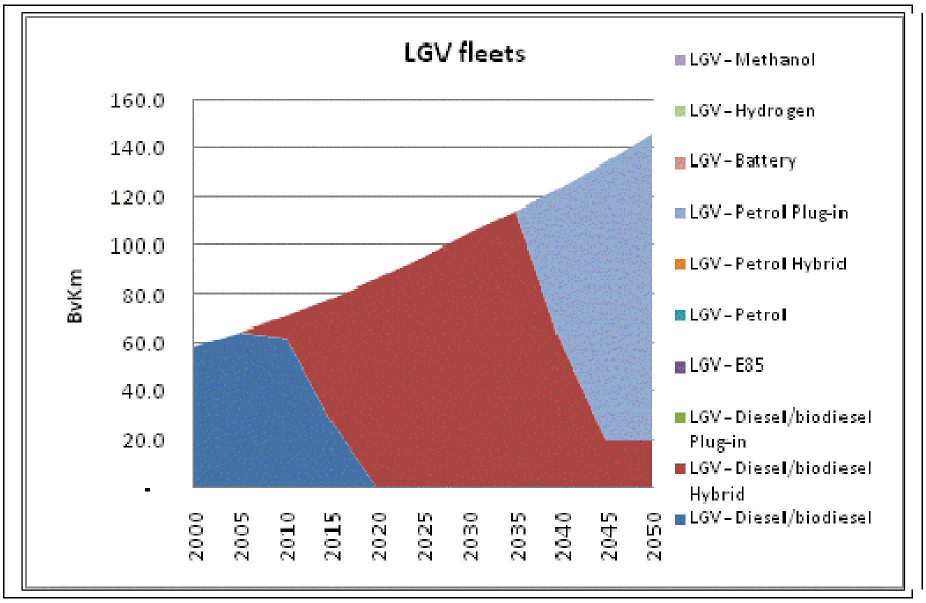

Figure 42 Multi purpose networks LGV fleet technologies, 2000-2050

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 45% 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.

8.5.3 Model results: details

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**

Total emissions (Million t- CO2)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	548,824.00	555,442.50	512,023.33	496,699.02	389,653.82	344,310.21	298,605.48	293,511.06	301,593.26	300,306.56	299,423.79
Electricity sector	181,236.66	193,624.63	171,749.46	172,816.46	88,489.66	50,696.15	20,372.50	19,966.28	36,641.14	37,888.98	37,888.99

% emissions reductions from year 2000 levels

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Whole system	0	-1.2	6.7	9.5	29.0	37.3	45.6	46.5	45.0	45.3	45.4
Electricity sector	0	-6.8	5.2	4.6	51.2	72.0	88.8	89.0	79.8	79.1	79.1

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
4. ‘Sectoral Emissions’ are incomplete before 2030 as imports and exports of fossil fuels are not completely captured in these metrics before this time period, due to model calibration. Thus summing of sectoral emissions in time periods prior to 2030 does not produce the true total. For accurate total emissions in all time periods, see tables 'Total emissions' and '% emissions reductions from year 2000 levels'.

9 Appendix C – References

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10 Appendix D – Bibliography

The LENS project drew on many sources of background information and data throughout the course of the project, but especially in the first phases of information gathering. This bibliography provides the details of the major reference sources used in the project in alphabetical order, from which no assumption about the relative importance should be drawn.

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11 Appendix E – 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	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