Programme Area: Distributed Energy

Project: Micro DE

Title: Review of Existing Scenarios

Abstract:

Please note this report was produced in 2010/2011 and its contents may be out of date. This deliverable is number 7 of 9 in Work Package 1. It provides a review of a range of existing scenarios relating to the UK energy and electricity system. Suitable scenarios are needed for the ETI Micro DE project to provide a framework to explore a number of technical questions relating to how the UK energy systems could perform with the introduction of the DE technologies studied within the project. The report recommends that the UKERC Energy 2050 scenarios are the most appropriate to use as a framework within the ETI Micro DE project

Context:

The project was a scoping and feasibility study to identify opportunities for micro-generation storage and control technology development at an individual dwelling level in the UK. The study investigated the potential for reducing energy consumption and CO2 emissions through Distributed Energy (DE) technologies. This was achieved through the development of a segmented model of the UK housing stock supplemented with detailed, real-time supply and demand energy-usage gathered from field trials of micro distributed generation and storage technology in conjunction with building control systems. The outputs of this project now feed into the Smart Systems and Heat programme.

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ETI project report

Micro Distributed Energy and Energy Services Management Application to existing UK residential buildings

WP1.7 Review of Existing Scenarios

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20/12/2010
Ref.: ETI Micro DE

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Executive Summary

This report provides a review of a range of existing viable scenarios relating to the UK energy and electricity system, and considers the purpose and underlying assumptions of each. The report also outlines the approach adopted to determine the optimum approach for use in the Micro Distributed Energy and Energy Services Management Application to existing UK residential buildings (Micro-DE) project.

To achieve this, a two stage assessment process of the scenarios is undertaken. The first stage involves a preliminary assessment which considers such factors as the inclusion of more current information and requisite level of detail as well as the accessibility of the related model/information to the consortium. Accordingly, the Electricity Network Scenarios for Great Britain in 2050 LENS project (a trend based study) and UKERC Energy 2050 (a modelling study) scenarios are highlighted as being the most appropriate.

The second stage of the approach involves the further assessment of these two options and highlights the UKERC 2050 as the preferred option for the project. The main factors contributing to this selection include the *applicability of the scenario* due to its association with decarbonisation of electricity generation and relevancy to the UK, in addition to the *high degree of technological detail* that it employs which enable broader depictions of energy system interactions between different supply and demand sectors and the exploration of a wider scope of supply–demand mixes. Furthermore, the previous experience and skill of UCL as consortium partner with the UKERC 2050 scenarios, and the consequent deep understanding of their applicability, is also considered as an important factor contributing to its selection.

The UKERC 2050 aims to use a scenarios format to explore a number of technical questions relating to how the energy system could perform under various combinations of policy and societal imperatives. A set of four "core" UKERC Energy 2050 scenarios are used to highlight key policy issues and provide a starting point for variant scenarios, these are the “Reference” (REF) scenario, the “Ambition” (CAM) scenario, the “Resilience” (R) scenario and the “Low Carbon Resilient” (LCR) scenario

From these core scenarios further variant scenarios are generated by relaxing the restrictive assumptions in the core scenarios to allow the exploration of options concerning the development of the energy system such as carbon ambition, changes arising from technological acceleration and lifestyle and behaviour changes. Variant scenarios also

provide the opportunity to explore uncertainties in the wider context such as global energy markets and low probability/high-impact events.

Of the variant scenarios discussed, the Carbon Ambitions scenario (CAM) is selected as the reference low carbon scenario to be used for the purposes of developing scenarios for the Micro-DE project. This selection is based on various factors that consider its close alignment with current Government policy and emissions reduction targets, its previous use as UKERC reference scenario for other projects (i.e. United Kingdom Sustainable Hydrogen Energy Consortium UK-SHEC) and the accessibility of its assumptions, model workings and full outputs to the consortia and relevant audience. The key assumptions used in the proposed CAM scenario are summarised at the end of the report.

1 Introduction

This review considers the range of existing viable scenarios relating to the UK energy and electricity system, and considers the purpose and underlying assumptions of each. The process for scenario selection is discussed, leading to the identification of the preferred scenario that is to be used as the basis for the development of the set of reference scenarios for the ETI Micro DE project.

The development of scenarios for the ETI Micro DE project aims to explore a number of technical questions relating to how the energy system could perform with the introduction of the DE technologies selected for study.

2 Background

This section introduces the concept of scenarios and presents an overview of the underlying need for the move towards the decarbonisation of the National Grid through the use of renewable generation technologies. The particular potential impact of policies in the area on the domestic sector is highlighted.

2.1 Scenarios Philosophy

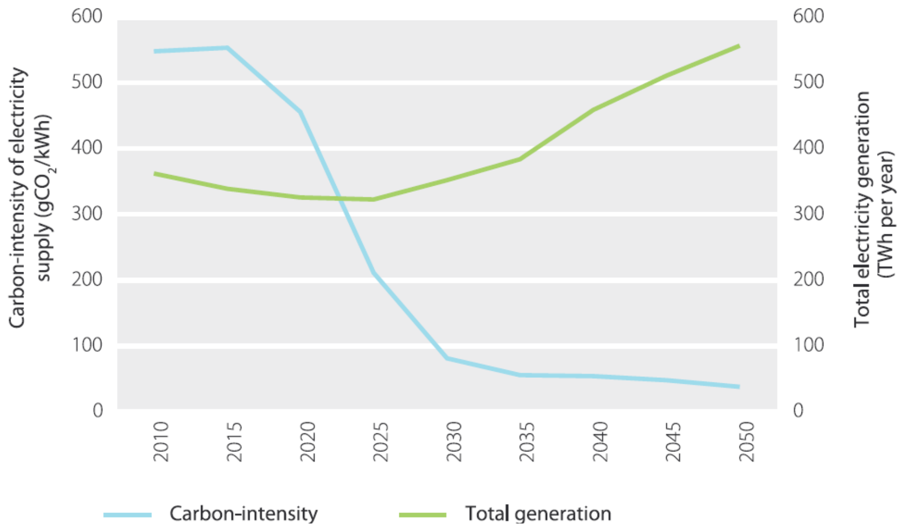
In the face of a changing agenda mainly influenced by climate change and energy security, scenarios have been used extensively in the energy industry to provide insights into possible outcomes for the sector (Ault et al. 2008).

Scenarios can be considered as possible, internally consistent visions of energy futures. However, they are neither predictions nor consensus views of desirable futures. Insights can be generated by systematically exploring differences between scenarios and by differentiating scenarios to a suitable degree, the effectiveness of policies and measures can therefore be assessed (Skea 2008).

2.2 Decarbonising Electricity Generation

The range of scenarios set out in the first Committee on Climate Change report “Building a low-carbon economy - the UK's contribution to tackling climate change” (December 2008) (CCC 2008) to meet the 80% emissions reduction target in 2050 concluded that it was vital that emissions from the power sector are reduced by more than 90%. The report discussed the significant relationship between the carbon intensity of power generation and electricity demand, highlighting the important role of electricity in achieving required emissions reductions (Figure 2.1). Such an increase reflects the critical role of low (or zero) carbon electricity in a decarbonised energy system, via electrification of space and water heating in teh residential and commercial buildings sector (electric boilers and heat pumps), a growing share of electric vehicles, the use of electrolysis in the production of hydrogen, growing electrification of key industrial sectors, and upstream requirements of electricity in carbon capture and storage (CCS). These factors outweigh efficiency improvements and behavioural changes for demand reduction, resulting in a higher overall level of electricity through 2050.

The subsequent report “Meeting Carbon Budgets – the need for a step change: Progress report to Parliament” (October 2009) (CCC 2009), further indicated this requirement for decarbonisation of the National Grid outlined the range of low-carbon sources to facilitate decarbonisation of electricity generation in the near term and presented an analysis of the policies and measures required to meet the specified carbon budgets.



Source: CCC based on AEA (2008) MARKAL-MED model runs of long-term carbon reduction targets in the UK.

Figure 2. 1: Declining carbon-intensity and increasing generation of electricity to 2050

This issue is further discussed in the latest DECC energy and emissions projections “Updated Energy and Emissions Projections: June 2010” (DECC 2010), which present the net UK carbon account methodology against the first three carbon budget periods (2012, 2017 and 2022).

The central energy and emissions projections discussed in the report are based on the central price scenario, which reflect timely investment and moderate demand and outline several important trends with regards to electricity generation. These highlight the following main points with regard to the decarbonisation of electricity generation:

While there is contribution from a number of generation technologies, the major expansion in generating capacity over the projection period comes from renewables (Figure 2.2). In this study this reflects the requirements for the UK to meet its EU agreed renewables targets of 15% of final energy, necessitating markedly higher level of renewable electricity.

The generation mix of Major Power Producers (MPPs) shows that renewables electricity generation increases to 30% by 2020, consistent with the target in the Renewable Energy Strategy (Figure 2.3). This study assumes that potential volatility in electricity supply from increased renewable is manageable at this level via existing peaking natural gas plants, pumped hydro storage, and electricity imports.

The impact of the increase in renewables generation (via the 2020 renewable target) is to significantly reduce the size of the investment market available for fossil fuels. Existing fossil fuel plants remain in the system but with new investment conditional on CO_2 prices and technological status of CCS.

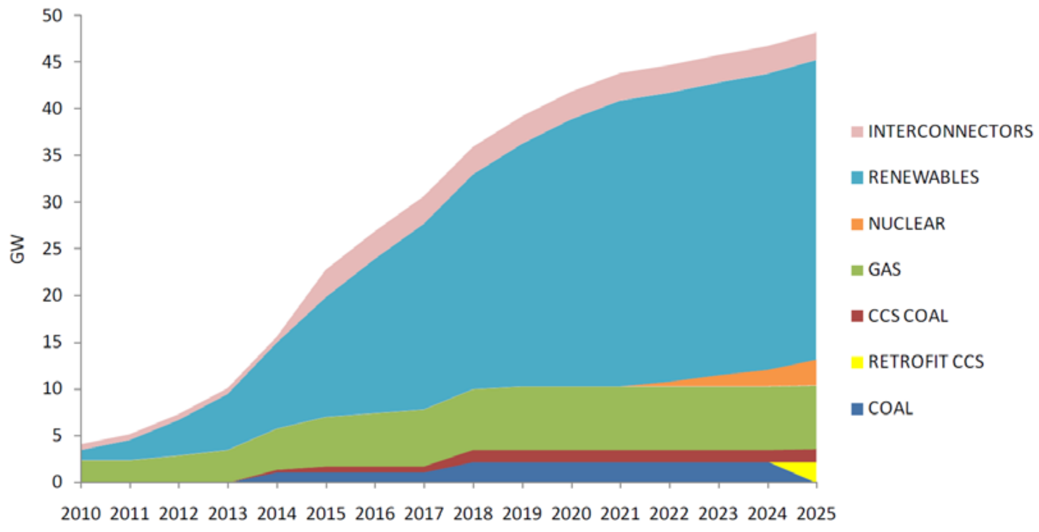


Figure 2.2: Projected cumulative new build by plant type for MPPs, 2010 to 2025.

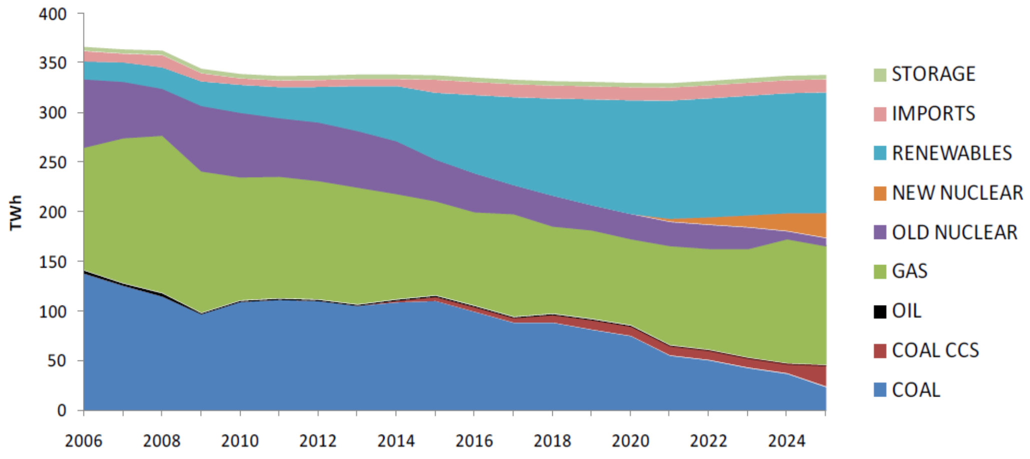


Figure 2.3: Electricity supplied by fuel for the MPPs, 2006 to 2025.

2.3 The Impact on the Domestic Sector

In the DECC report "Updated Energy and Emissions Projections: June 2010" and its appendix (c: energy demand) the projected trends in energy demand by sector are outlined (Figure 2.4). These show that the domestic sector demand is projected to decrease by 21% between 2008 and 2020, driven by (policy enabled) energy efficiency measures.

The total savings from the residential sector outlined prior to the Low Carbon Transition Plan (LCTP) and measures in the LCTP and later policies are shown in Table 2.1. These indicate substantial savings are to be achieved through a variety of measures adopted in the sector.

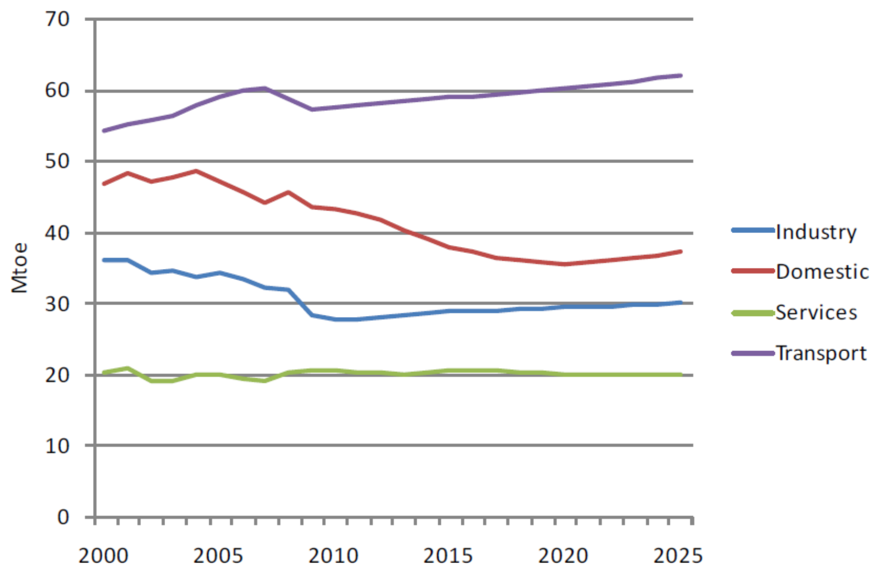


Figure 2.4: Final energy demand by sector

Table 2. 1: Savings of policy measures included in the baseline (pre-UK LCTP) and UK LCTP for the residential sector

$MtCO_2e$	Non-traded		
	Carbon Budget 1 2008-2012	Carbon Budget 2 2013-2017	Carbon Budget 3 2018-2022
Pre-UK LCTP Policy Savings	30.6	41.5	44.8
EEC 1 & EEC 2 (re-evaluated)	8.0	7.8	6.7
Building Regulations (re-evaluated)	19.0	30.2	34.6
Warm Front & Fuel Poverty Programs	3.6	3.5	3.5
UK LCTP Policy Savings	8.9	43.0	68.9
Household Energy Management Strategy	9.1	37.1	47.6
Products Policy	-0.6	0.7	3.4
DCLG Zero-Carbon Homes	0.1	0.6	2.1
Residential RHI	0.2	4.5	15.9
Total	**39.5**	**84.5**	**113.7**

3 Review of Existing Scenarios

UCL have reviewed a broad range of scenarios and related information on behalf of the consortium, with the objective of reducing uncertainty through forecasting or back casting of assumptions. The full list of the evaluated scenarios are included in the appendix of this report, these are categorised as follows:

- Table 7.1: Trend Driven Studies
- Table 7.2: Technical Feasibility Exercises
- Table 7.3. Scenarios Concerned With Modelling

As outlined in the background section of this report, the significance of electricity generation in the decline of carbon-intensity has been highlighted. The scenarios associated with decarbonisation of electricity generation can therefore be considered as the most applicable to the ETI project. Accordingly, after an extensive review of the aforementioned scenario options, those relating to the UK energy and electricity system relevant to the UK were highlighted. Table 3.1 summarises the viable options and a more detailed description of each is given below.

Table 3.1: Summary list of viable scenarios for the UK

Scenario Exercise	Authors, Date	Affiliated Organisations	Scope of Study
Electricity Network Scenarios for Great Britain in 2050	Elders et al (2006)	Supergen Future Network Technologies Consortium	UK electricity system
Electricity Network Scenarios for Great Britain in 2050 (LENS project)	Ault et al (2008)	Ofgem	UK electricity system
Decarbonising in the UK	Anderson et al. (2005)	Tyndall Centre	UK energy system
UK MARKAL (Energy White Paper & Other work)	Strachan et al. (2007)	BERR,DEFRA, Policy Studies Institute, AEA Technologies	UK energy system
Energy 2050	UK Energy Research Centre	UK Energy Research Centre	UK energy system

3.1 Electricity Network Scenarios for Great Britain in 2050

This work presents set of six scenarios (first column of Table 3.2) designed to outline the possible configurations of the electricity networks in the decades up to 2050 (Elders et al. 2006). These were derived from varying combinations of the four key parameters and resulting high-level trends (described in Table 3.2), identified through a process involving the review of other scenarios and expert consultation (Hughes and Strachan 2010) .The scenarios contain fairly detailed descriptions of novel network enabling technologies (such as FACTS, HVDC and microgrids), approximations of total and relative generation capacities and electricity demand levels (Hughes and Strachan 2010).

Table 3.2: Name and key parameters of the UK Electricity Scenarios

Scenario Name	Economic Growth	Technological Growth	Environmental Attitudes	Political & Regulatory Environment
Strong Optimism	More than recently	Revolutionary	Stronger	Liberalised
Business as Usual	Same as recently	Evolutionary	As at present	Liberalised
Economic Downturn	Less than recently	Evolutionary	Weaker	Liberalised
Green Plus	Same as recently	Revolutionary	Much stronger	Liberalised
Technological Restriction	More than recently	Evolutionary	Stronger	Liberalised
Central Direction	Same as recently	Evolutionary	Stronger	Interventionist

The key inputs to the process of generating the overall scenarios are (Elders et al. 2006):

- Narrative descriptions of proposed partial scenarios covering each of the four areas individually:
    - Energy Use
    - Electricity Generation
    - Energy Transportation
    - Markets and Regulation
- Tables of principal scenario parameters and corresponding qualitative ranges of values
- Opinions and experience from other work packages within the Supergen Future Network Technologies consortium.

3.2 Electricity Network Scenarios for Great Britain in 2050 (LENS project)

The LENS project aimed to develop scenarios designed to explore potential future implications for electricity networks in the UK, and represented these within the MARKAL Elastic Demand (MED) model (Hughes et al. 2009). The final report sets out five scenarios for the future development of electricity networks which were identified through a process involving the review of other scenarios and stakeholder workshops (Hughes & Strachan 2010).

The five scenarios contain fairly detailed descriptions of novel network enabling technologies and quantify the total and relative generation capacities, and electricity demands, tested in MARKAL. The key trends include environmental concern, active or passive consumers and regulatory approach (Hughes & Strachan 2010).

The scenarios do not impose a CO_2 reductions target as a constraint, where such a backcasting approach would normally be enacted via a CO_2 trading systems but could be done via an equivalent CO_2 price via a tax. Instead, these scenarios take a more exploratory approach to identifying a number of themes which would be of particular relevance and impact on the electricity networks in the UK and ascertain CO_2 emissions as an output (Hughes and Strachan 2010).

Each of the five scenarios identified contain intuitively plausible assumptions (Table 3.3) about various portfolios of energy technologies and their contribution to reducing carbon emissions within the contexts of the scenarios described (Ault et al. 2008).

Table 3.3: Summary list of key assumptions for LENS 2050

Variant input parameter	Big T&D	Energy Service Companies	Distribution System Operators	Microgrids	Multi-purpose networks
Carbon price (£/tCO_2)	Rising linearly to £30 by 2050	Rising linearly to £60 by 2050	Rising linearly to £100 by 2050	Rising linearly to £135 by 2050	Fluctuating between £30-£70
Sectors to which carbon price applies	Electricity & industry	Electricity & industry	All	All	Electricity & industry
Demand response	No	No	Yes	Yes	No
Technology development	As reference	Small scale wind Solar PV Micro CHP Energy efficiency	As ESCOs, plus cost reductions in hydrogen generation & end use technologies	As DSOs, plus more aggressive cost reductions & performance improvements in solar PV & micro CHP	Small scale wind, solar PV, Micro CHP as ESCOs
Reduced use of transmission system	No	No	Yes	Yes	No
Other system constraints	Capacities for electricity interconnectors increased. Barriers to uptake* of electric vehicles, CHP, district heating	Reduced barriers to uptake* of electric vehicles, residential heat technologies, energy efficiency, CHP	Reduced barriers to uptake* of hydrogen vehicles, residential heat technologies, energy efficiency, CHP	Reduced barriers to uptake* of hydrogen and electric vehicles, residential heat technologies, energy efficiency, CHP	Broad technology groups (marine, nuclear, gas, wind) forced in at different times to reflect conflicting government led programmes

3.3 Decarbonising in the UK

The Tyndall Centre Report "Decarbonising the UK- Energy for a Climate Conscious Future" (Anderson et al. 2005) is a technical feasibility study that includes five technical descriptions of UK energy systems in 2050 which would reduce carbon emissions by 60%. (this target has since been replaced by the higher goal of 80% emissions reductions in the 2008 climate change bill).

The scenarios were developed using a sectorally disaggregated spreadsheet model to conduct detailed assessments of technical and physical potentials for contribution to the energy supply and demand of the UK in order to meet a 60% reduction in CO_2 by 2050. The socioeconomic drivers which could deliver those systems are identified in a process referred to in the report as "backcasting" and "critical factors" required for a particular end point to be achieved, are highlighted (Hughes et al. 2009).

The five scenarios, which have been allocated neutral descriptors, consider changes in energy demand, through behaviour change via changing consumer preferences and energy efficiency, as well as the availability of key supply side technologies as noted in Table 3.4.

Although the scenarios do not consider economic factors, all major domestic demand sectors plus international aviation and shipping are incorporated and broad social trends and policy dynamics inferred from technical configurations are considered.

The study has a primary exogenous constraint of a 60% CO_2 emissions reduction by 2050 (Hughes & Strachan 2010). As the technical feasibility approach is a highly normative one, this study is essentially technology neutral. The mix of technologies selected in each scenario reflect the authors' assumptions about the character of that scenario, not a value judgement on the authors' part about the acceptability of any particular technology (Hughes et al. 2009). The scenarios to meet the 60% CO_2 reductions target constraint assumed the following parameters:

Table 3.4: Scenario parameters for Decarbonising the UK

	Red	Blue	Turquoise	Purple	Pink
Growth in UK GDP (per year)	3.3%	1.6 %	2.6%	3.9%	3.9%
Dominant economic sectors	Commercial	Commercial public admin non-intensive industry	Commercial construction public admin	Commercial non-intensive industry	Commercial non-intensive industry
Energy consumption (Mtoe)	90	130	200	330	330
Households (millions)	27.5	25	30	27.5	27.5
Energy use per household	Large reduction	Very large reduction	Small reduction	Similar to current	Similar to current
Supply mix	Coal (with and without CCS) renewable, H_2 biofuels	Coal (with CCS) nuclear, CHP, biofuels	Gas (with/ without CCS), biofuels, nuclear, H_2 renewables	Nuclear, renewables H_2, biofuels	Nuclear CCS (coal & gas), renewables biofuels
Decarbonisation policies	Innovation and technology driven	Collectivist approaches to demand-side policy	Similar to today with focus on supply	Strongly market- focused government	Strongly market-focused government
Transport	Low growth in aviation reduction in car use very large increase in public transport	Medium growth in aviation low growth in car use large increase in public transport	Large growth in aviation no growth in car use small increase in public transport	Very large growth in aviation large growth in car use large growth in public transport	Very large growth in aviation large growth in car use large growth in public transport
Transport fuels	Oil, electricity, H_2	Oil, electricity, H_2	Oil, biofuels, electricity,H_2	Oil, biofuels, electricity, H_2	Oil, biofuels, electricity
Hydrogen	Stationary & transport uses production from gas- ification with CCS & renewables no pipelines	Transport uses production from gas-ification with CCS, nuclear & renewables no pipelines	All sectors incl. aviation production from gas-ification with CCS, nuclear & renewables pipelines & H2 by wire	Stationary & transport uses production from renewables & nuclear extensive pipeline system	No hydrogen

3.4 UK MARKAL (MARKet ALlocation dynamic optimization model)

MARKAL is a widely applied bottom-up technology model of the energy system, supported by the International Energy Agency (IEA) via the Energy Technology and Systems Analysis Program (ETSAP). (Anandarajah et al. 2009). Rather than a forecasting model, MARKAL can be considered a “what-if” framework that provides a systematic approach to the exploration of least cost energy system configurations under a broad, integrated set of input assumptions (Kannan et al. 2007). Various extensions and variants on the MARKAL model include MARKAL-Macro (M-M) and Elastic Demand (MED).

The UK MARKAL model and its variants have been applied to a wide range of UK policy analyses, research collaborations and academic publications from 2006 through 2009 (Kannan and Strachan 2009). The key distinctive advantage of the MARKAL model for energy policy analysis is its quantitatively detailed view of the whole energy system, which includes the various energy service demands from all economic sectors, bringing a flexible approach to choosing which technologies and resources can meet these demands (Ault et al. 2008).

MARKAL offers a wide array of outputs, some examples of which include: total and annual energy system costs, investments and capacity utilization of technologies, primary energy, final energy (by sector and/or by fuel), CO_2 (by fuel, sector and end-use sector) and average and marginal emissions prices(Strachan 2007). The model covers all domestic UK energy demand sectors and is highly detailed particularly in electricity generation, transport and residential sectors and is less detailed in industry and agriculture (Hughes & Strachan 2010).

Successive model applications use alternate assumptions and various models assume an exogenous constraint of a (variable) reduction target in CO_2 emissions, although the model can equivalently impose a carbon price approach (Hughes & Strachan 2010). In MARKAL’s partial equilibrium formulation all prices and quantities are optimised, and in the Macro variant this equilibrium approach is extended to non energy UK economic output. One of teh major advantages of UK MARKAL, it that its various assumptions (used for different sectors analysed (transport, energy...etc.)) are fully documented and available, for example those relevant to the UK residential module can be summarised below from (Kannan et al. 2007): Note that for the other studies’ buildings assumptions, these must be gleaned from the relevant reports cited in this review.

- Number of households in the base year 25.28 million & 35.6 million in 2050

- Historical (1992-2002) average house demolition rate - 0.0762%
- Average space heating demand for existing house was 32.7 GJ per year per household & 19.9 GJ for new houses**.**
- For the rest of the time series, energy service demands are linearly extrapolated based on house demolition/build rate.
- For appliances ownership rate of MTP (2006) & 40% House is assumed
- Specific energy use of appliances and their market share in each energy label classes are adopted from BRE.
- For the new houses, existing appliances ownership rate is used.
- To account for improvement in energy use pattern of the existing housing stock, conservation measures (insulation, double glazing) are included.

3.5 UKERC Energy 2050

UKERC 2050 aims to use a scenario format to explore a number of technical questions relating to how the energy system could perform under various combinations of policy and societal imperatives. The UKERC 2050 model employs the UK MARKAL Elastic Demand (MED) model – this retains technological detail across the energy systems and adds a detailed behavioural response to price changes at the end use sub-sectoral level (which then feeds into demand changes for intermediate energy carriers such as electricity. As ever in model trade-offs this detailed price response in a partial equilibrium framework is achieved at the loss of insights into macro-economic impacts. The project is strongly oriented to producing model inputs to generate model runs, for the purpose of conducting analyses with high levels of quantified detail, including sectoral contributions to CO_2 mitigation effort, economic impacts, and the effects of changing key economic assumptions such as discount rates (Hughes et al. 2009).

UKERC researchers and associates have developed a set of “back-casting” scenarios describing possible future energy systems that are both low-carbon, and resilient to external and internal shocks. A set of four "core" UKERC Energy 2050 scenarios are used to highlight key policy issues and provide a starting point for variant scenarios (Anandarajah et al. 2009) and number of variant scenarios are then developed from these.

As a modelling based study, UKERC 2050 offers a high detail or technological detail particularly in electricity generation, transport and residential sectors, less in industry and agriculture. The model covers all domestic UK energy demand sectors. The model assumes an exogenous constraint for the UK Energy system, falling linearly to a 60% or 80% reduction in CO_2 emissions by 2050 (Hughes & Strachan 2010).

4 Process and Rationale for Scenario Selection

The viable scenario options for the UK described in Section 3 were reviewed and assessed in terms of their inclusion of more current information, the requisite level of detail as well as the accessibility of the model/information to the consortium (as discussed below). According to this preliminary assessment, both the Electricity Network Scenarios for Great Britain in 2050 LENS project (a trend based study) and UKERC Energy 2050 (a modelling study) scenarios emerged as being the most appropriate. Of these two options, the preferred option is highlighted as the UKERC 2050. The factors contributing to its selection as the preferred scenario can be briefly listed as follows:

- ***Scenario applicability:*** The UKERC 2050 scenarios are both associated with decarbonisation of electricity generation and relevant to the UK. The UKERC 2050 can therefore be deemed applicable to the ETI project.
- ***A high degree of technological detail:*** The modelling approach extends the technical feasibility studies in that it employs greater levels of technical detail. This enables broader depictions of energy system interactions between different supply and demand sectors and the exploration of a wider scope of supply–demand mixes which will meet certain energy service demands, usually within a system-wide carbon constraint. As a modelling based study, the UKERC 2050 therefore allows for a greater degree of technological detail than that in the LENS project.
- ***Previous experience and skill:*** As a consortium partner, UCL was involved in the creation of the UKERC 2050 scenarios and, hence, has a deep understanding of their applicability.

5 The Preferred Scenario Set: UKERC 2050

A brief introduction to UKERC 2050 was presented in Section 3: Review of Existing Scenarios. Here a more detailed description of the UKERC scenarios set, its underlying assumptions, the research tools used and the main outputs it produces will be outlined. The scenario option that is to be used for the ETI Micro DE project will be discussed in further detail.

5.1 Description of UKERC Scenarios

UKERC 2050 aims to use a scenarios format to explore a number of technical questions relating to how the energy system could perform under various combinations of policy and societal imperatives. The main questions are:

- What additional steps must be taken to secure deep cuts (80% of UK energy emission relative to a 1990 baseline) in CO_2 emissions by 2050?
- How will this affect the share of fuels and technologies in the energy mix? Will it involve systemic change?
- What is the additional cost of investing in resilience compared to CO_2 emission reductions?
- Will investing in a more resilient energy system (see section 5.2) make it easier or more difficult to reduce CO_2 emissions? Will reducing CO_2 emissions make the energy system more resilient?

5.1.1 Core Scenarios

A set of four "core" UKERC Energy 2050 scenarios are used to highlight key policy issues and provide a starting point for variant scenarios, these are the "Reference" (REF) scenario, the "Ambition" (CAM) scenario, the "Resilience" (R) scenario and the "Low Carbon Resilient" (LCR) scenario (Anandarajah et al. 2009; UKERC 2007).

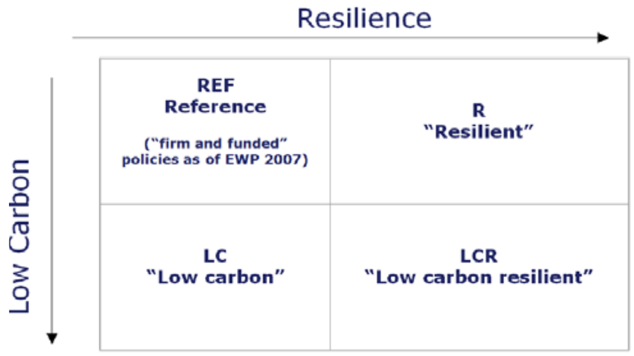


Figure 5.1: The UKERC core scenarios: energy system attributes

5.1.2 Variant Scenarios

Variant scenarios are generated by relaxing the restrictive assumptions in the core scenarios to allow the exploration of options concerning the development of the energy system such as carbon ambition, changes arising from technological acceleration and lifestyle and behaviour changes. Variant scenarios also provide the opportunity to explore uncertainties in the wider context such as global energy markets and low probability/high-impact events (Skea 2008).

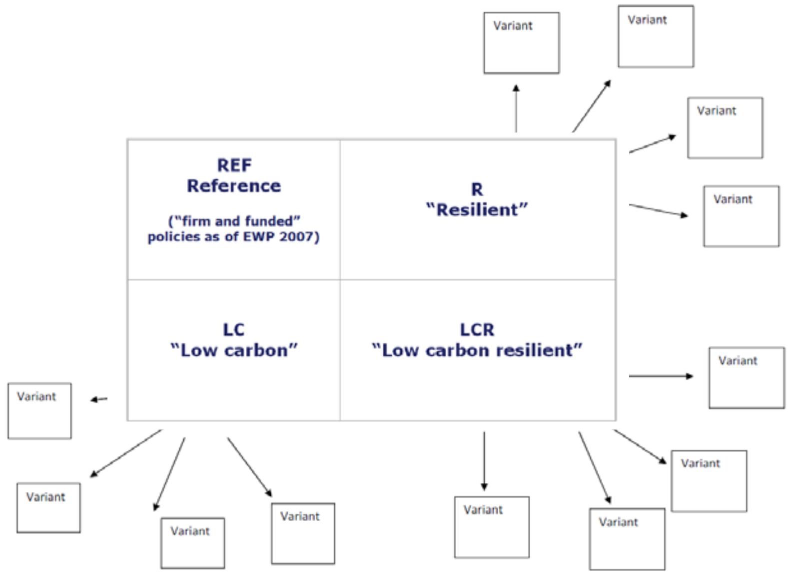


Figure 5.2: Generation of UKERC variant scenarios

5.2 Assumptions

In UKERC 2050, the MARKAL MED model was run for a base reference case and a total of seven low carbon pathways. These variant scenarios (see Table 5.1) were designed for relevance to the UK policy process for the near- and long-term targets of the Climate Change Committee.

5.2.1 Common Assumptions

A number of common assumptions are associated with all core scenarios. These can be listed as follows (Hardy 2009, Kannan 2007):

- Underlying economic growth and demand for energy services which assumes a 2% GDP growth in the long-term.
- The global energy prices of crude oil, gas and coal used are outlined in Table 7.4. These are based on a consolidated analysis of recent projections of global fossil fuel prices from the International Energy Agency (IEA) and from the UK Government (DECC) and are discussed in detail in Anandarajah 2009).
- The availability of domestic and imported energy sources or a seasonal and annual basis through 2050: This considers such aspects as the availability factor and efficiency of various sources including coal-fired, gas fired and nuclear power plants and renewable

technologies. Resource updates include revised cost curves (steps) for carbon capture and storage (CCS) (Full details available in MARKAL documentation[1]).

- Technology costs and learning rates: Future costs are based on expert assessment of technology vintages, exogenous learning curves derived from an assessment of learning rates combined with global forecasts of technology uptake. Endogenous cost reductions from learning for less mature technologies are not employed as the relatively small UK market is assumed to be a price taker for globally developed technologies.

- Investment decision criteria: A 10% real rate of return is assumed, reflecting required commercial returns for large capital investments. This is higher in sectors where there are barriers to take-up. Here, a technology specific 'hurdle' rate (set at 15%, 20% and 25%) represents information unavailability, non price determinants for purchases and market imperfections such as principal agent issues between landlords and tenants.

In addition to these core assumptions, further detail on the model assumptions and workings (e.g., in the declining capacity credit approach to fluctuating electricity supply from renewable sources) is given in Kannan et al. 2007 and Anandarajah 2009). Further, key assumptions of each of the core reference scenarios include:

- The **“Reference” (REF)** scenario assumes that concrete policies and measures in place at the time of the 2007 Energy White Paper continue into the future but that no additional measures are introduced.
- The **“Ambition” (CAM)** scenario (i.e., the low carbon core scenario) assumes the introduction of a range of policies leading to an 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020.
- The **“Resilience” (R)** scenario takes no account of the carbon reduction goal but assumes additional investment in infrastructure, demand reduction and supply diversity (namely, final energy demand falls 3.2% pa relative to GDP from 2010onwards; no single energy source (e.g. gas) accounts for more than 40% of the primary energy mix from 2015 onwards; and no single type of electricity generation (e.g. gas, nuclear) accounts
- for more than 40% of the mix from 2015 onwards) with a view to making the energy system more resilient to external shocks.
- The **“Low Carbon Resilient” (LCR**) scenario combines the carbon and resilience goals.

[1] http://www.ukerc.ac.uk/Downloads/PDF/07/0705MARKALChapters/0705%20MARKALdocCH5appx.pdf

Five important factors are held constant across the four core scenarios, these are:

- The international context (including on global economic growth and on international climate mitigation efforts);
- The trajectory of technological change;
- The way energy investment decisions are made;
- The evolution of people's lifestyles; and
- Energy consumers' preferences.

5.2.2 Variant Assumptions

The variant scenarios incorporate different assumptions concerning the following key variables (Anandarajah et al. 2009):

- Resource supply curves (updated as of 2008)
- Other international drivers (e.g. emission credit purchases)
- Technology costs (vintages and learning)
- Option of new energy technology chains
- System implementation (e.g., treatment of intermittency)
- Energy service demands (all sectors)
- ESD price responses via demand elasticities
- Policy variables (e.g., renewables obligation)
- Imposition of taxes and subsidies (e.g. fuel duties, EU-ETS)
- System and technology-specific discount rates (market vs. social)

A first set of scenarios (CFH, CLC, CAM, CSAM), focus on carbon ambition levels of CO_2 reductions (in 2050) ranging from 40% to 90% reductions. These runs also have intermediate (2020) targets of 15% to 32% reductions by 2020 (from the 1990 base year). These scenarios investigate increasingly stringent targets and the ordering of technologies, behavioural change and policy measures to meet these targets.

A second set of scenarios (CEA, CCP, CCSP) undertake sensitivities around 80% CO_2 reductions with cumulative CO_2 emission targets, notably focusing on early action and different discount rates. These scenarios investigate dynamic tradeoffs and path dependency in decarbonisation pathways.

Table 5.1: UKERC 2050 Scenarios

Scenario	Scenario name	Annual targets (reduction)	Cumulative targets	Cum. Emissions $GTCO_2$	2050 emissions $MTCO_2$
B	Base reference	-	-	30.03	583.4
CFH	Faint-heart	15% by 2020 40% by 2050	-	25.67	355.4
CLC	Low carbon reference	26% by 2020 60% by 2050	-	22.46	236.9
CAM	Ambition (low carbon core)	26% by 2020 80% by 2050	-	20.39	118.5
CSAM	Super Ambition	32% by 2020 90% by 2050	-	17.98	59.2
CEA	Early action	32% by 2020 80% by 2050	-	19.24	118.5
CCP	Least cost path	80% post 2050	Budget (2010-2050) similar to CEA	19.24	67.1
CCSP	Socially optimal least cost path	80% post 2050	Budget (2010-2050) similar to CEA	19.24	178.6

5.3 Research Tools

A combination of modelling tools is used to develop high-level insights from a systematic comparison of scenarios. The core energy systems modelling tools are:

- The UKERC 2050 model employs the **UK MARKAL Elastic Demand (MED)** model. This version of MARKAL was fully recalibrated to standard UK energy statistics and was previously used for underpinning analysis for the UK Energy White Paper and Climate Change Bill. MED allows a consumer response to changing energy prices; this retains technological detail across the energy systems and adds a detailed behavioural response to price changes, albeit at the loss of insights into macro-economic impacts.
- The **Global E3MG** macro-econometric model, with an underlying input-output structure (previous uses have included inputs into the Intergovernmental Panel on Climate Change (IPCC) and the Innovation Modelling Comparison Project (IMCP).

These are supported by a range of sectoral models such as WASP (electricity generation planning model), CGEN (combined gas and electricity networks model) and UKDCM (UK Domestic Carbon Model).

5.4 Key Outputs

The UKERC 2050 project is strongly oriented to producing input data (variables and parameters) that are used to generate model runs, for the purpose of conducting analyses with high levels of quantified detail that covers all domestic UK energy demand sectors (Hughes & Strachan 2010). Outputs include sectoral contributions to CO_2 mitigation effort, economic impacts, and the effects of changing key economic assumptions such as discount rates (Hughes et al. 2009).

A high degree of detail in output is produced particularly in electricity generation, transport and residential sectors (to a lesser degree in industry and agriculture).

5.5 The Carbon Ambitions scenario (CAM)

For the purposes of developing scenarios for the ETI micro-DE project, the Carbon Ambitions (CAM) is to be used as the reference low carbon scenario. This selection was made based on the following factors:

- The scenario assumes the introduction of a range of policies leading to an 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020 and is therefore most closely aligned with current Government policy and emissions reduction targets.
- The CAM scenario has been previously been used as UKERC reference scenario for other projects (i.e. United Kingdom Sustainable Hydrogen Energy Consortium UK-SHEC).
- The assumptions, model workings and full outputs are accessible to this consortia, and well as to our audience (via the relevant UKERC Energy 2050 report and UKERC Energy Data Centre)

The assumptions used in the CAM scenario are based on the common assumptions associated with the core scenarios (listed in 5.2) in addition to the previously mentioned carbon constraints. An exhaustive list of the assumptions is available in related MARKAL and UKERC documentation (Kanan et al 2007 & Anandarajah et al. 2009). A list of the key assumptions is summarised in the following table.

Table 5.2: CAM Scenario Key Assumptions

Assumption	**Description**
Annual targets (reduction)	26% reduction by 2020, 80% reduction by 2050
Cumulative emissions ($GTCO_2$)	20.39
2050 Emissions ($MTCO_2$)	118.5
Economic growth	2% GDP growth in the long-term.
Demand for energy services	Incorporates a range of demographic, economic and social aspects. Reflects latest trends, revised growth rates and seasonality.
Global energy prices	2000 / 2020 / 2050 Oil, 2005$/bbl: 31.38 / 55.00 / 70.00 Gas, 2005$/MMBTU: 4.77 / 7.00 / 8.91 Coal, 2005$/tonne: 35.89 / 57.04 / 72.59
The availability of energy sources	Considers such aspects as availability factor and efficiency of various sources including coal-fired, gas fired and nuclear power plants and renewable technologies. Resource updates include revised cost curves (steps) for carbon capture and storage (CCS).
Technology costs and learning rates	Future costs based on expert assessment of technology vintages and exogenous learning curves. Endogenous cost reductions from learning for less mature technologies are not employed. For space and water heating application in the residential and service sectors, learning rates include such aspects as micro generation (capital cost is reduced at 2-3% and 2% per year till 2020), heat pumps and night storage electric heating (max of 30% of total residential heating).
Investment decision criteria	A 10% real rate of return is assumed for commercial return on large capital investments. Higher in sectors where there are barriers to take-up.

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7 Appendices

7.1 Evaluated Scenarios

Table 7.1: Summary list of trend driven studies

Scenario Exercise	Authors, Date	Affiliated Organisations	Scope of Study
Special Report on Emissions Scenarios	Nakicenovic et al (2000)	Intergovernmental Panel on Climate Change	Global, energy use and land use change
Foresight Scenarios	Berkhout et al (1999)	Office of Science and Technology / Foresight Programme	UK society
Socio-economic scenarios for climate change impact assessment	UK Climate Impacts Programme (2000)		UK society
Scenario Exercise on Moving Towards a Sustainable Energy Economy	Institute for Alternative Futures, Virginia (2004)	Institute for Innovation Research, University of Manchester	UK energy and society
Transitions to a UK Hydrogen Economy	Eames and McDowall (2006)	Supergen UK Sustainable Hydrogen Energy Consortium	UK energy system
Electricity Network Scenarios for Great Britain in 2050	Elders et al (2006)	Supergen Future Network Technologies Consortium	UK electricity system
Electricity Network Scenarios for Great Britain in 2050 (LENS project)	Ault et al (2008)	Ofgem	UK electricity system

Table 7.2: Summary list of technical feasibility studies

Scenario Exercise	Authors, Date	Affiliated Organisations	Scope of Study
The Changing Climate	Royal Commission on Environmental Pollution (2000)		UK energy system
Decarbonising the UK	Anderson et al (2005)	Tyndall Centre	UK energy system
The Balance of Power- Reducing CO_2 Emissions from the UK Power Sector	ILEX (2006)	World Wildlife Fund	UK electricity system
Decentralising UK Energy	WADE (2006)	Greenpeace	UK heat and electricity system
A Bright Future: Friends of the Earth's Electricity Sector Model for 2030	FOE (2006)	Mayor of London, Greenpeace	UK electricity sector
Powering London into the 21st Century	PB Power (2006)	Buildings Research Establishment	London, heat and power from buildings
Technical Feasibility of CO_2 emissions reductions in the UK housing stock	Johnston et al (2005)	Environmental Change Institute, University of Oxford	UK, energy demands from Domestic buildings
40% house	Boardman et al (2005)		UK, energy demands from Domestic buildings

Table 7.3: Summary list of modelling studies

Scenario Exercise	Authors, Date	Affiliated Organisations	Scope of Study
UK MARKAL (Energy White Paper & Other work)	Strachan et al. (2007)	BERR,DEFRA,Policy Studies Institute,AEA Technologies	UK energy system
Energy 2050	UK Energy Research Centre	UK Energy Research Centre	UK energy system
Japan Scenarios & Actions Towards Low Carbon Societies	Fujino et al. (2008)	National Institute for Environmental Studies	Japan energy system
World Energy Outlook	International Energy Agency (2008a)		Global energy systems
Energy Technology Perspectives	International Energy Agency (2008b)		Global energy systems
World Energy Technology Outlook	European Commission (2005)	EU	Global energy systems

7.2 Detailed UKERC Scenario Assumptions Tables

Table 7.4: UKERC updated fossil resource costs

Original units		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Oil	2005$/bbl	31.38	50.62	57.50	55.00	55.00	57.50	60.00	65.00	70.00	70.00	70.00
Gas	2005$/MMBTU	4.77	7.46	6.75	6.75	7.00	7.32	7.64	8.27	8.91	8.91	8.91
Coal	2005$/tonne	35.89	60.48	55.00	55.00	57.04	59.63	62.22	67.41	72.59	72.59	72.59
PJ (GCV)		**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Oil	2000£/GJ	2.53	4.08	4.64	4.44	4.44	4.64	4.84	5.24	5.65	5.65	5.65
Gas	2000£/GJ	2.35	3.67	3.32	3.32	3.44	3.60	3.75	4.07	4.38	4.38	4.38
Coal	2000£/GJ	0.66	1.11	1.01	1.01	1.05	1.09	1.14	1.24	1.33	1.33	1.33

*Currency conversion factors £1 = $1.8 = €1.4

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