Demand and Decarbonisation in 2050: Themes from Scenarios

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Abstract

In light of the emissions targets in The Climate Change Act, and reflecting the fact that the majority of UK emissions come from the production of energy, it is clear the energy sector will play a central role in the transition to a low carbon economy. In addition to the need for decarbonisation, energy must also be made secure, and affordable. These three goals are complex and often conflicting; however this paper proposes that reducing total final demand can be highly conducive to meeting all three aims of this trilemma. The paper goes on to demonstrate by means of scenario analysis that much potential exists for the UK to reduce total final energy demand, particularly in the residential and transport sectors.

A comparison of levels of final demand between twelve different scenarios, produced by four different organisations is given, followed by analysis of the finer detail of each of the scenarios. The system costs of five of the scenarios are then set out, and a number of 'hybrid' scenarios are produced, demonstrating that additional demand reduction measures can be supportive of reduced system cost. Finally a comparison between levels of demand in the scenarios and in DECC's 2030 demand projections suggest that new policies must be introduced if the UK is to follow a pathway consistent with meeting the 2050 targets.

Keywords: Scenarios, Demand, Transition, Pathway, 2050, Decarbonisation, System costs

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1. Introduction

The route to decarbonisation is uncertain. The 2008 Climate Change Act proscribes that the UK must reduce its greenhouse gas (GHG) output by 80% on 1990 levels by 2050, with an interim target of a 34% reduction by 2020 (HMG, 2008).[1] The primary source of GHG emissions are from combustion of fuels to provide energy, the use of which is concentrated in a few sectors - electricity generation, transport, industry, and the domestic sector (DECC & AEA, 2012). Choices made today will ultimately affect the UK's ability to meet its 2020 and 2050 obligations, and although The Climate Change Act explicitly sets out targets for reduction of GHG output, it does not proscribe how this should be achieved.[2] However, all policies should be written in the context of the energy trilemma, this is the notion that the UK must make the transition to a low-carbon economy, whilst ensuring that energy is both secure and affordable. These drivers are complex and often conflicting, however there are some strategies such as supporting reductions in overall energy demand, which are supportive of all three aspects. The route that the UK should take to reach its 2050 goals is widely debated, and a number of stakeholders have written scenarios setting out possible pathways to meeting the 2050 carbon targets. These scenarios are not written as predictions of what w*ill* happen, but as explanations of what *could* happen - outlining plausible pathways to 2050.

There is considerable variation in the designs of each of these pathways - ranging by development and deployment of technologies, behaviours and social trends, assumptions about the economy, and levels of final demand. These factors are not isolated from one another, interacting in many and complex ways. It is the last factor however, the level of final demand, that is the focus of this paper. This is because it has a strong bearing on many features of the energy system and how the transition to decarbonisation is managed. For example, the greater the level of total energy demand, the greater the need to maintain or expand existing infrastructure, and the more energy that each individual uses, the greater that individual's exposure to increases in energy costs.

Set out below is an explanation of how minimising levels of total final demand can be synergistic to meeting the goals of the energy trilemma. A comparison between the levels of final demand in each of the reviewed scenarios is then given, followed by individual analysis of each of the scenarios focussing on both primary and final demand, including the sectors responsible for greatest levels of final demand, and the features of the energy system behind the scenario.

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[1] For a full list of basket of included gasses, See: HMG, (2008:44) Climate Change Act.
[2] The only specific requirements for how decarbonisation must be achieved is through the Renewable Directive (European Parliament, 2009), which states that the UK must produce 15% of final energy demand from renewable sources by 2020.

Analysis will also briefly explore if evidence from the scenarios supports or refutes the positive links between overall lower demand and the goals of the trilemma. Finally, this paper will explore what lessons may be taken from the scenarios, and how policy relates to these lessons. This paper does not set out to specify an exact pathway to 2050, but to shed light on the range of possible levels of final demand in 2050, how this supports the energy trilemma, and what can be said of current policies in relation to the trends in the scenarios.

2. Demand Reduction: Supportive of the Trilemma

Making significant reductions in overall energy demand is highly supportive of the transition to an affordable, secure, and sustainable energy system. The impact of demand reduction on each factor of the trilemma is set out below.

2.1 Affordability

Demand reduction is complementary to affordability at the individual and whole-system levels. If an individual household (or business) is able to significantly and permanently reduce its demand, this will not only lower its current energy bills, but also help to limit the impact on that household of any future price rises which may accompany the transition to a low carbon system. Similarly, if the price of energy begins to fluctuate, low levels of demand will limit the impact on consumers of this volatility.

Demand reduction also has financial benefits at the whole-system level. Although demand-reduction by its nature requires upfront investment, it is likely to have broad, societal cost benefits in the long term. This is because effects are long-lasting and have minimal operating costs. If lower levels of demand are fixed into the system, less investment in new generation plant will be required in order to meet future demand, thus helping to reduce the overall cost of the transition. This is set out by Green Alliance in 'The Power of Negawatts' (Green Alliance, 2012), pointing to evidence in the USA showing it was three times cheaper to invest in efficiency programmes than in new electrical generation. This is also supported by McKinsey & Co. (2009) who suggest that many demand reduction measures lead to a net cost-benefit, independent of the carbon benefits, and that the number of measures that fit this description is increasing with energy prices.

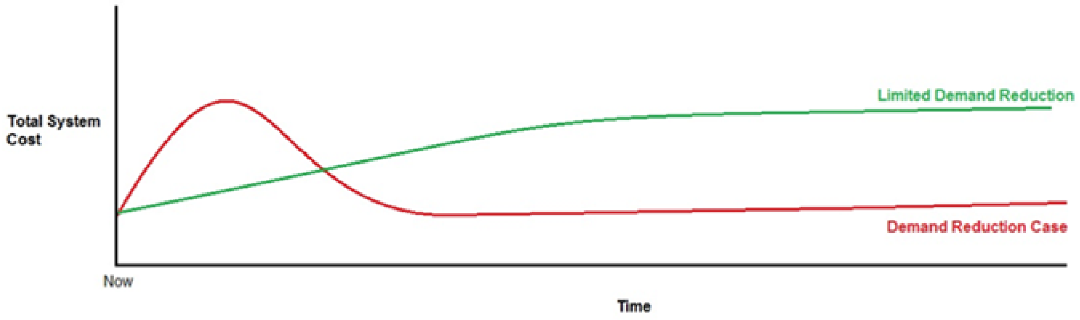


Figure 1 - Conceptual Demonstration of Total System Cost under Demand Reduction

Source: Author's Own

Figure 1 gives a conceptual demonstration of this argument. Following the initial up-front cost of investment in smarter, lower-demand infrastructure[3], the total system cost remains considerably lower than would otherwise have otherwise been the case. The nature of the investment means that the distribution of costs should be managed so to avoid exacerbating fuel poverty (Hills, 2012; Stockton & Campbell, 2011).

In Section 5 below, outputs from some of the scenarios will be used to examine the connection between level of demand, and system cost. It must be noted that although scenarios offer cost information, they do not explain how costs should be most equitably managed across society. How the costs of transition may be most responsibly managed lie outside the bound of this paper, but will form the basis of much future research.

2.2 Sustainability

Demand reduction is also supportive of the sustainability agenda, in particular relating to, although not limited to, reductions in emissions. This relationship is easily demonstrated. Between 2010 and 2011, the sector which exhibited the greatest reduction in emissions was the residential sector, which showed a 22% reduction in emissions owing to a 23% reduction in natural gas demand for heating, as a product of a milder winter (DECC, 2012a). [4] This connection is conceptually simple - reducing demand for energy from a carbon-intensive energy source led to reductions in carbon output. However, short term reductions in demand such as this cause only short term reductions in emissions. For long-term reductions, demand must be reduced permanently. This reduces the use of carbon-intensive energy generation infrastructure, and potentially facilitates more, and lower carbon, options for its replacement. In

[3] Change in infrastructure is taken to mean efficiency improvements in the housing stock and its associated energy systems (eg. boilers, lighting etc), changes to networks (i.e. smart grids), and technical deployment facilitating demand response (eg. smart meters and appliances).
[4] Residential emissions only relate to fossil-fired central heating - that is to say that any demand reduction from households with electric central heating will be registered as emission reductions for electricity generation.

addition to reduction in point-of-use emissions, reduced demand sends ripples of emission reductions up the supply chain - less demand leads to less need for construction of new plant, leading to less extraction of raw materials, and less extraction of fuels to run them - all of which are highly carbon intensive activities, and can have wider detrimental environmental impacts.

2.3 Energy Security

Intuitively, it would seem that reducing energy demand can hold benefits for energy security. For example, if demand for oil or gas is halved, there would appear to be some security benefit in needing to source half as much energy. Similarly, if total final energy demand is reduced, then there is a need for fewer power plants and manufacturing concerns, which should reduce the likelihood of failure. This argument is widely stated as a truism (Eg. DECC, 2012b).

Many definitions of energy security (such as DECC, 2012a and International Energy Agency, 2013) also include consideration that energy is insecure when it cannot be accessed because it is unaffordable. Taking this broader understanding of energy security further supports demand reduction as an energy security measure.

However, Hoggett, Eyre, & Keay (2013) suggest that the relationship between demand and security is highly complex, and is defined largely by three things: the driver of demand reduction, the nature of the threat to energy security, and the circumstances of the country in question. Whilst overall they accept that reduced demand can increase energy security in some situations, this is very time and site specific and general statements such as ‘energy efficiency leads to greater energy security’ should be avoided.

3. Scenarios: Final Demand Comparison

This paper makes use of scenarios to examine possible technological and behavioural pathways to 2050. This is done to highlight the range of different viable levels of final demand, and what aspects of society must change in order to achieve them. The scenarios were produced by a number of different stakeholders - DECC, AEA, UKERC, and Friends of the Earth (FOE).

Scenarios are designed as plausible depictions of *possible* futures (Phelps et al., 2001; Postma & Liebl, 2005), as opposed to being predictive of *probable* futures (Goodwin & Wright, 2010), and are therefore bounded by that which the designers deem to be possible (Postma & Liebl, 2005). Scenarios treat behaviour and choices as inputs, and do not offer information on what policies may lead to these choices. For example, some scenarios assume in-home temperatures drop dramatically to 16°C, which represents a reversal of current trends, however the scenario does not give information on what may have caused this change in consumer behaviour, and could be a result of any number of policy or social changes.

The level of detail of output available varies between scenarios, for this reason, not all aspects of each scenario may be compared with every other. For example is some scenarios give final demand by sector of the economy, while others give it by end-use. It is important to note too that the scenarios were drawn up using a range of different modelling tools, therefore introducing other inherent differences. DECC and Friends of the Earth make use of the DECC 2050 Calculator, UKERC and AEA both make use of the Market Allocation (MARKAL) model (for an explanation see Appendix A). The UKERC lifestyle scenarios also use the UK Domestic Carbon Model, and the UK Transport Carbon Model to form inputs to MARKAL analysis. Although both AEA and UKERC made use of the MARKAL model with elastic demand, their respective assumptions may differ slightly in that AEA made some alterations to the MARKAL model as part of the scenario building process. In spite of these differences, all scenarios were constructed as plausible explanations of pathways, and although some model designers may differ slightly on the fine detail of some of the variables, it is still possible to draw general trends.

Each of the scenarios is assigned a letter (A-L). This is done to make the graph in figure 2 and the information that follows easier to read together. NB. Some of the bars in figure 2 appear in a different order in the graph to in the text. This is done because in the text they are grouped by the institution that generated them, and in the graph they are placed adjacent to relevant comparator scenarios i.e. the two 'Business-As-Usual' cases are placed alongside one another.

Figure 2 shows the range of levels of final demand in 2030 and 2050 in Terawatt Hours (TWh), from the scenarios reviewed in detail below. The graph on the left hand side shows levels of demand from various scenarios in 2030 alongside the level of demand in 2012 (line i). The two 'Business-As-Usual' type scenarios which are not based on achieving carbon reductions (Scenarios A & B) are given alongside a range of carbon-reduction scenarios (Scenarios C-L). The right hand graph addresses the modelled levels of demand in 2050. For context, 2012 final UK energy demand totalled 1654 TWh, this was predominantly a product of transport (595 TWh) and domestic consumption (480TWh) (DECC, 2013c).

What is immediately apparent is the vast range of possible levels of demand in 2050. These levels are affected by assumed changes in technology development and deployment, service demand, and social norms over the period between now and 2050.

The two 'Business-As-Usual' scenarios give very different pathways to 2050. The UKERC REF scenario (Scenario A) shows a gradual increase in demand between now and 2050, whereas the AEA BAU scenario (Scenario B) shows reducing final demand to 2030, which then increases towards 2050. The UKERC REF scenario (scenario A) exhibits the highest level of 2050 demand of all scenarios reviewed here, whereas the AEA BAU scenario shows a level of demand between two carbon reduction scenarios - DECC's High Nuclear, Less Energy Efficiency' and 'High CCS and Bio-Energy' (Scenarios E & F).

There is an apparent similarity in levels of final demand in 2050 between the 'DECC MARKAL scenario'(Scenario C), the 'AEA 90% reduction scenario'(Scenario G) and three of the UKERC scenarios LC, LC-90 and LS-REF (Scenarios I, J & H). In spite of this similar end-point however, major differences can be found in the trajectories of this demand reduction, as seen in the levels of demand level in 2030. The 'DECC MARKAL Analogy' (scenario C), and the UKERC LS-REF show a fairly constant level of reduction, with slightly more taking place before 2030 than after. The 'AEA 90%' scenario (Scenario G) shows very large amounts of demand reduction taking place by 2030, and demand increases slightly on the approach to 2050. UKERC LC (Scenario I) shows a slight increase in demand between 2012 and 2030, and then a sharp decline by 2050, and finally UKERC LC-90 (Scenario J) shows decreasing levels of demand to 2030, and then an accelerated level of demand reduction in the years to 2050. All except the UKERC LS-REF scenario (Scenario H) met the 2050 carbon targets, but all take very different paths. In spite of the UKERC LS-REF scenario having similar levels of final demand, in 2050 is has a carbon output over 2.5 times higher than the level required by the Climate Change Act.

What is common among all the scenarios which met the 2050 carbon targets, with the exception of the DECC 'High Nuclear, Low Energy Efficiency' scenario (Scenario E), was a high level of demand reduction compared to current levels. Consistently these reductions were derived in the greatest proportion from the domestic and transport sectors, with the electrification of heat and road-travel. Considerable improvements in the thermal efficiency of housing is another widespread trend. Although scenarios are not designed as predictive, the consistent reappearance of these features of an energy system which meets the 2050 targets implies that they may be essential to the UK meeting its 2050 commitments in a cost-effective way.

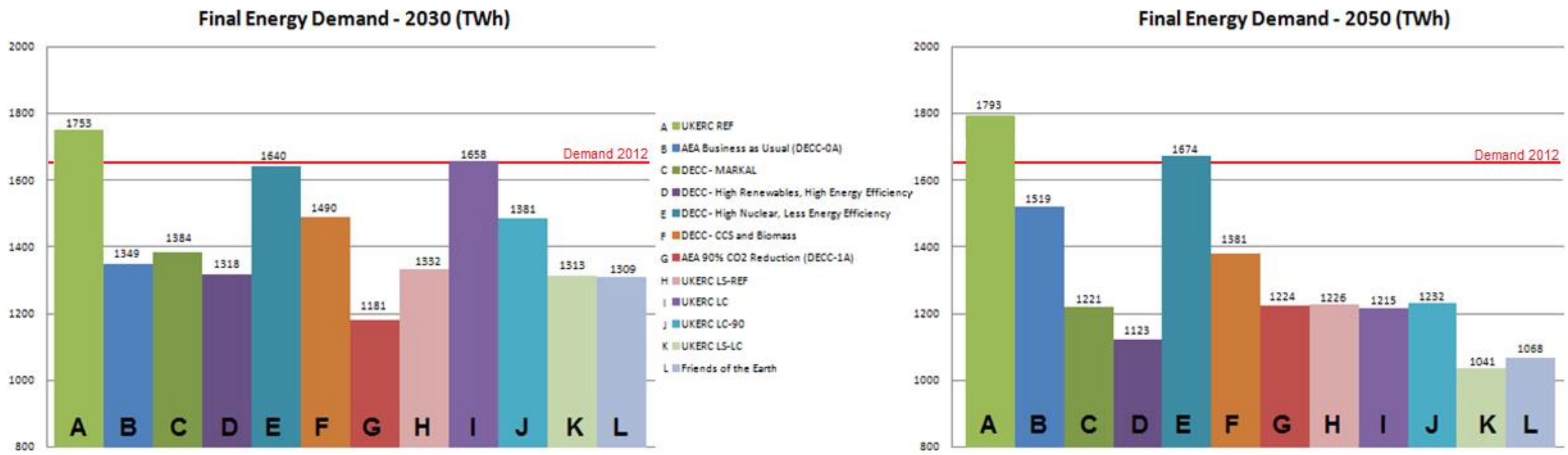


Figure 2 - Comparison of Final Energy Demand Across Scenarios,

Source: Author's Own

4. Scenarios in Detail

This section sets the individual scenarios in greater detail. Primary and final levels of energy demand are given. The difference between these is due to losses in generation, which are particularly associated with thermal electricity generation, and the traditional internal combustion engine. Losses are also associated with transmission of electricity, and conversion of biomass into consumable fuels. (For visual representation, see appendix B).

4.1 DECC Scenarios

The DECC 2050 Pathways Calculator was used to produce the DECC scenarios. It is an open-source model designed by DECC in consultation with a number of stakeholders. It allows the user to experiment with different assumptions about behaviour and technology deployment in order to view possible impacts on the path to 2050 with respect to final energy demand, primary energy supply, and progress on the 2050 GHG target. The four scenarios explored here are the central case which has been created as analogous to a MARKAL scenario, and three stress-tests: 'Higher Renewables, More Energy Efficiency', 'Higher Nuclear, Less Energy Efficiency' and 'Higher CCS, More Bio-Energy'.

4.1.1 'MARKAL Analogy' Scenario (Scenario C)

2050 Energy Demand: 1221 TWh, 2020 & 2050 Carbon Targets Met

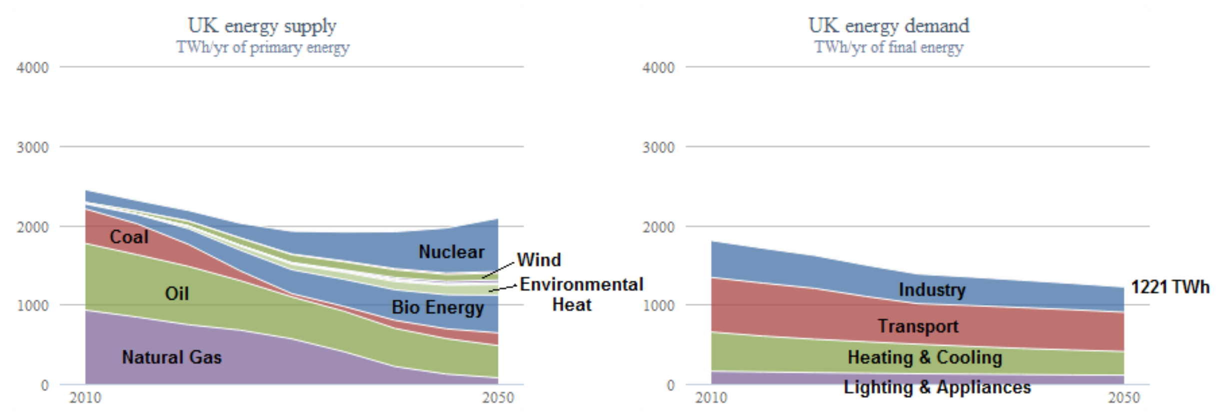


Figure 3 - 'MARKAL Analogy' Primary and Final Demand,

Source: After DECC Online

NB. Small amounts of renewables between wind and environmental heat.

Figure 3 shows the levels of primary and final energy demand, and the related fuels and end-uses respectively. An overall reduction in both primary and final energy demand is visible, accompanied by a reduction in fossil fuel use, replaced primarily by bio-energy, other renewables, and nuclear power. The remaining fossil fuel use is predominantly in conjunction with CCS. These accompany the widespread electrification of heating and transport, and an increased shift to public transport for domestic travel, and rail for freight transport.

This scenario helps to highlight the potential opportunities for different forms of demand reduction. In this scenario, energy demand from domestic lighting and appliances drops by 60%, primarily as a result of improvements in efficiency. Also, average winter home temperatures are assumed to drop to 16°C, representing a major social change which goes against current trends (DTI, 2006). This has considerable benefits for demand reduction. In this scenario, the greatest sources of demand are Transport (494 TWh) and Heating & Cooling (298 TWh).

4.1.2 'Higher Renewables and More Energy Efficiency' Scenario (Scenario D)

Annual Energy Demand: 1123 TWh, 2020 & 2050 Carbon Targets Met

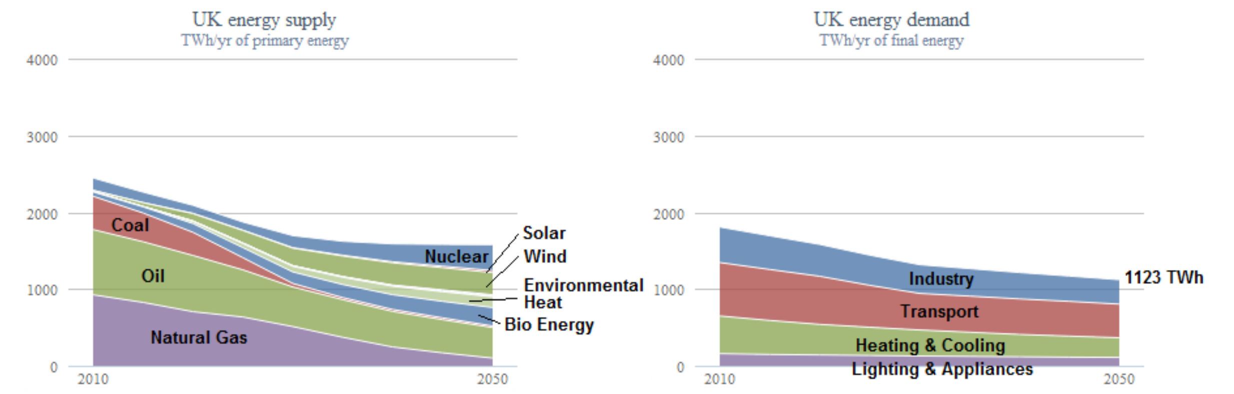


Figure 4 - 'Higher Renewables and More Energy Efficiency' Primary and Final Demand,

Source: After DECC Online

NB. Small amounts of renewables between wind and environmental heat.

This scenario is a first stress-test of the central 'MARKAL Analogy' scenario, and is designed to be consistent with a world of high fossil prices. Nuclear and CCS play a significant role in this scenario, but both have approximately half the installed capacity than under the 'MARKAL Analogy' case, and larger volumes of a range of renewables are deployed (see figure 4). Demand in this scenario is considerably reduced on 2012, and on the 'MARKAL Analogy' case - by 32% and 8% respectively. This is achieved by means of widespread electrification of heat, and improvements in lighting and appliances. Substantial improvements in domestic insulation are assumed, alongside (an arguably counterintuitive) drop in average winter in-home temperatures to 16°C. Energy demand for transport drops by 37%, facilitated by efficiency gains in international aviation and shipping, high levels of electrification of road travel, and a significant shift to public transport. Greatest levels of demand come from Transport (436 TWh) and Industry (319 TWh).

4.1.3 'Higher Nuclear and Less Energy Efficiency' Scenario (Scenario E)

Annual Energy Demand: 1674 TWh, 2020 Carbon Target not Met, 2050 Carbon Target Met

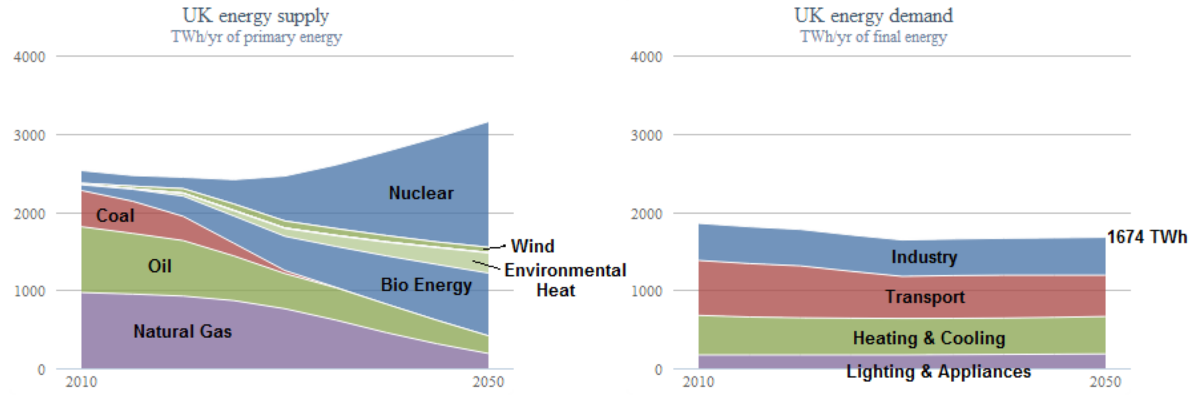


Figure 5 - 'High Nuclear, Less Energy Efficiency' Primary and Final Demand, Source: After DECC Online

NB. Small amounts of renewables between wind and environmental heat.

This pathway is dominated by commissioning of 25 new nuclear plants. This is accompanied by comparatively small amounts of renewable generation and CCS. The majority of space and water heating is electrified through the use of heat pumps, however over 10% is met through district heating connected to thermal electricity generation. A large portion of ground transport is also electrified. High levels of domestic insulation are deployed, and average home temperatures are fairly consistent with current levels at 18°C. This scenario is the only of the four DECC scenarios to show an increase in primary energy demand (see Figure 5), with little change in final energy demand. This scenario has dramatically greater levels of both primary and final energy demand than any of the other DECC pathways. This scenario also shows the greatest difference between primary and final energy demand, owing principally to the considerable losses associated with this level of thermal plant. The only sector which shows marked decrease in energy demand is road transport, supported by deployment of hybrid, electric, and hydrogen vehicles. This scenario is the only carbon-reduction scenario reviewed here which fails to meet the 2020 commitment, with emissions 5.6% above the target. Greatest levels of demand come from Transport (527 TWh) and Industry (484 TWh).

4.1.4 'High CCS and Bio-Energy' Scenario (Scenario F)

Annual Energy Demand: 1381 TWh, 2020 & 2050 Carbon Targets Met

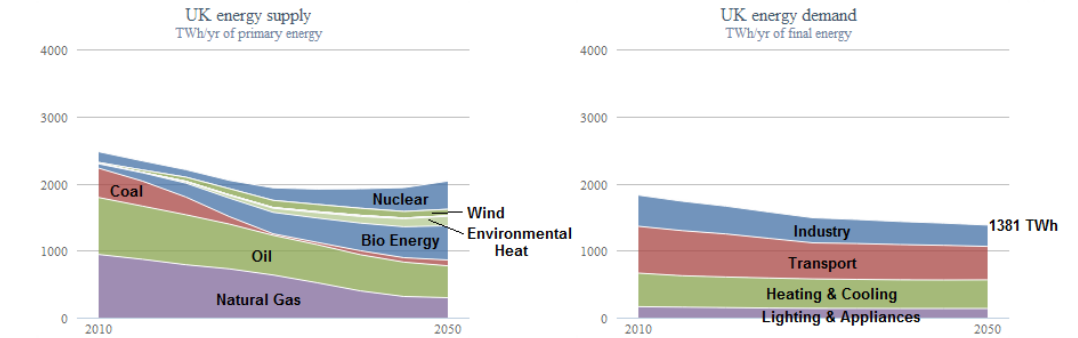


Figure 6 - 'High CCS and Bio-Energy' Primary and Final Demand,

Source: After DECC Online

NB. Small amounts of renewables between wind and environmental heat.

This pathway is built on the assumption of widespread successful deployment of CCS at a commercial scale, accompanied by low fossil-fuel prices going forward. It also assumes high availability of sustainable bio-energy resources. Under this scenario, some biomass generation is fitted with CCS in order to create 'negative emissions' by locking in CO_2 that would otherwise have remained in the atmosphere. Energy demand in this scenario is reduced compared to today, but to a lesser extent than the 'MARKAL Analogy' (Scenario C), and 'Higher Renewables and More Energy Efficiency' (Scenario D) scenarios.

Once again the end-use with greatest demand reduction under this scenario is the transport sector - particularly in road transport. In homes, there is slightly increased levels of insulation rollout compared to the 'High Nuclear, Less Energy Efficiency' scenario (Scenario E), and consumers accept slightly lower average temperatures. Energy demand for domestic lights and appliances is reduced 40% on present day levels. There is limited electrification of heat in the domestic sector, but is much higher levels in the commercial sector (80%-100%). The greatest proportion of energy demand comes from Transport (497 TWh), and Heating & Cooling (428 TWh).

4.2 Friends of the Earth Scenario (Scenario L)

Annual Energy Demand: 1068 TWh, 2020 & 2050 Carbon Targets Met

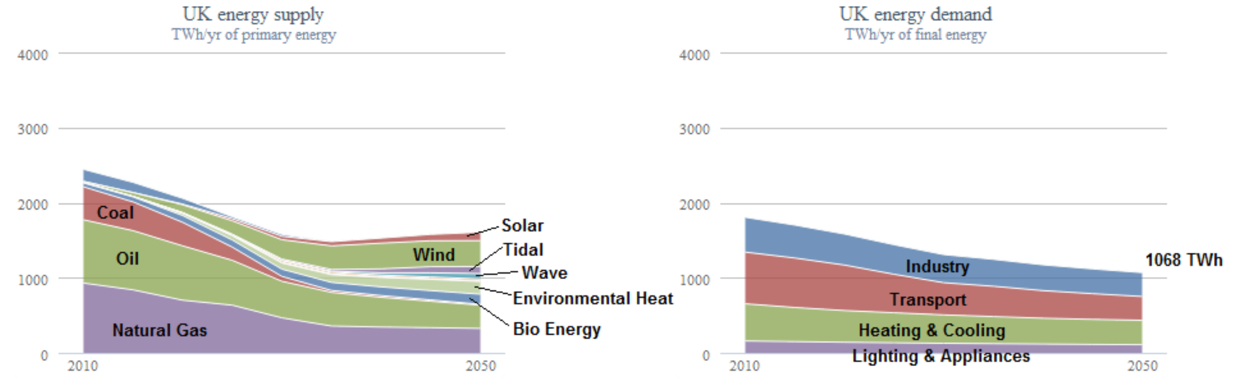


Figure 7 - Friends of the Earth Pathway - Primary and Final Demand,

Source: After DECC Online

Friends of the Earth (FOE) made use of the DECC 2050 Pathways Calculator to produce a scenario. This means it is bounded by the assumptions of the DECC model, as opposed to particular options that FOE particularly believes to be feasible. Its results are included here to allow direct comparisons between the other scenarios, and an overtly environmentally motivated scenario. Energy is supplied by a range of renewables, oil, and a relatively high reliance on natural gas (as compared to the four DECC scenarios), as supported by CCS. Nuclear is completely removed from the scenario.

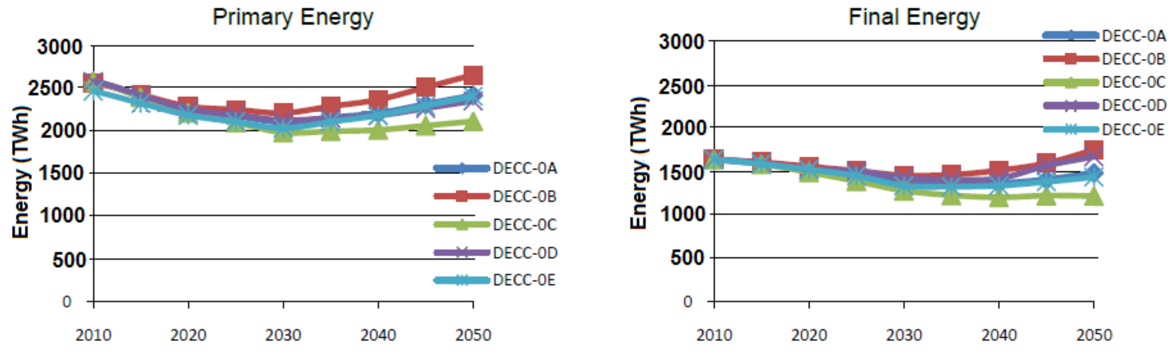
There are dramatic improvements in domestic energy efficiency. Space heating is electrified, and very high levels of insulation rollout occur. In spite of this high level of domestic demand reduction, some of which are reliant upon dramatic behavioural shifts, unlike the 'MARKAL Analogy' and 'High Renewables, High Energy Efficiency' scenarios (Scenarios C & D) this scenario does not rely on consumers reducing home temperatures to 16°C (comparable to 1990 levels), instead basing assumptions on an average in-home temperature of 17°C, half a degree below 2007 levels. Transport efficiency is also dramatically improved, in common with the other scenarios reviewed thus far land-based transport is decarbonised by means of electrification, and there is also a significant move towards public transport. Aviation experiences an 85% increase in passenger numbers but with only a 5% increase in fuel-use, and overall shipping emissions are reduced by 46%. Greatest sources of demand are heating & cooling (326 TWh) and industry (318 TWh). Overall demand is considerably lower than today's levels, and lower even than the lowest demand DECC scenario 'High Renewables, High Energy Efficiency' (Scenario D).

4.3 AEA Scenarios

AEA has produced a number of scenarios as supporting evidence for the fourth carbon budget. These scenarios are based on the MARKAL model, and were formulated with consultation of a number of stakeholders (AEA, 2011a). The scenarios were produced in sets, with a central theme underlying the scenario, and then different permutations for levels of service demand and fossil-fuel price. Two AEA scenario runs are reviewed here.

4.3.1 AEA Business-As-Usual (Scenario B)

Total Energy Demand (DECC-0A): 1519 TWh, 2020 & 2050 Carbon Targets Not Met



DECC-0A	Central Service Demand, Central Fossil-Fuel Price
DECC-0B	High Service Demand, Central Fossil-Fuel Price
DECC-0C	Low Service Demand, Central Fossil-Fuel Price
DECC-0D	Central Service Demand, Low Fossil Fuel Price
DECC-0E	Central Service Demand, High Fossil-Fuel Price

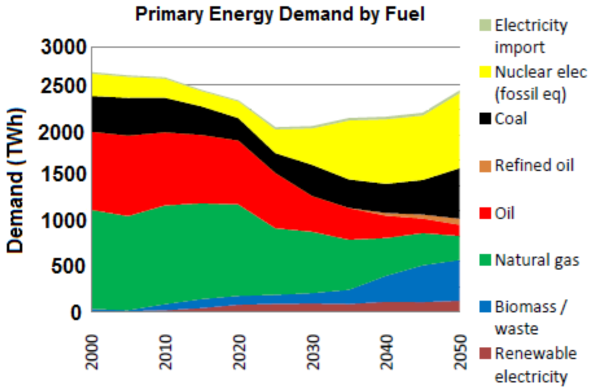
Figure 8- Business as Usual Scenario-Set Primary and Final Energy Consumption,

Source: After AEA, 2011b:9

Five 'Business-As-Usual' (BAU) cases are offered under differing levels of service demand and fossil-fuel price. Unlike the DECC scenarios, the AEA BAU cases are not designed to meet the UK carbon commitments under the Climate Change Act, for this reason they will not be explored in detail here. They are included as a comparator for level of demand in a scenario not bounded by carbon commitments. The underlying assumption of the BAU cases are the following of the carbon plan until 2020, after which time the carbon constraints are removed and the model is free to create a least-cost pathway. Figure 8 shows that changes in service demand can have a marked impact on level of final demand. However it is not possible to draw general lessons around the relative effects of changes in service demand or fossil fuel prices because the degree of change of each are not given. A lack of detail in the AEA publications means it is not possible to explore drivers for levels of demand. The central service demand, central fossil-fuel price case (DECC-0A) will be used for comparison.

4.3.2 AEA 90% Reduction (Scenario G)

2050 Energy Demand: 1224 TWh, 2020 & 2050 Carbon Targets Met



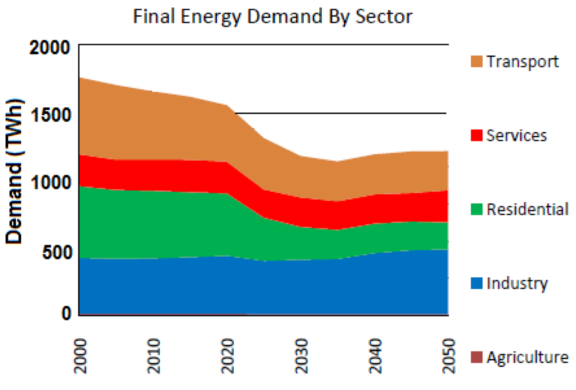


Figure 9 - 90% CO_2 reduction Primary Energy Demand by Fuel, and Final Energy Demand by Sector

Source: AEA, 2011b:22&25

AEA also produced a range of scenarios making carbon reductions, which (as above) varied by future level of service demand and fossil fuel prices. This paper will make use of the central case for both. The AEA 90% scenario is based on the assumption that the energy sector will have to decrease its GHG output by 90% to compensate for other sectors that may have difficulty meeting the 80% requirement for reduction. This scenario is based upon considerable increased use of nuclear power and biomass. Coal is co-fired with biomass and CCS is deployed. In this scenario, residential energy demand drops considerably, this is partially due to reduced service demand, and increased use of heat pumps and solar water heaters. In transport there is a steep reduction in final energy demand, this is driven by a shift to a mixed fleet of electric, fuel-cell and traditional hybrid vehicles. Neither industry nor the services sector make substantial reduction in demand, although there is some fuel switching in the service sector, and deployment of CCS in the industrial sector to support decarbonisation.

Greatest sources of final demand are industry (472TWh) and transport (292 TWh).

4.4 UKERC Scenarios

The UK Energy Research Centre (UKERC) undertook a MARKAL-based investigation involving the generation of thirty-one 2050 scenarios, under differing carbon and cost constraints, three of which are examined here, and a further two below.

4.4.1 UKERC REF (Scenario A)

2050 energy demand: 1793 TWh, 2020 & 2050 Carbon Targets Not Met

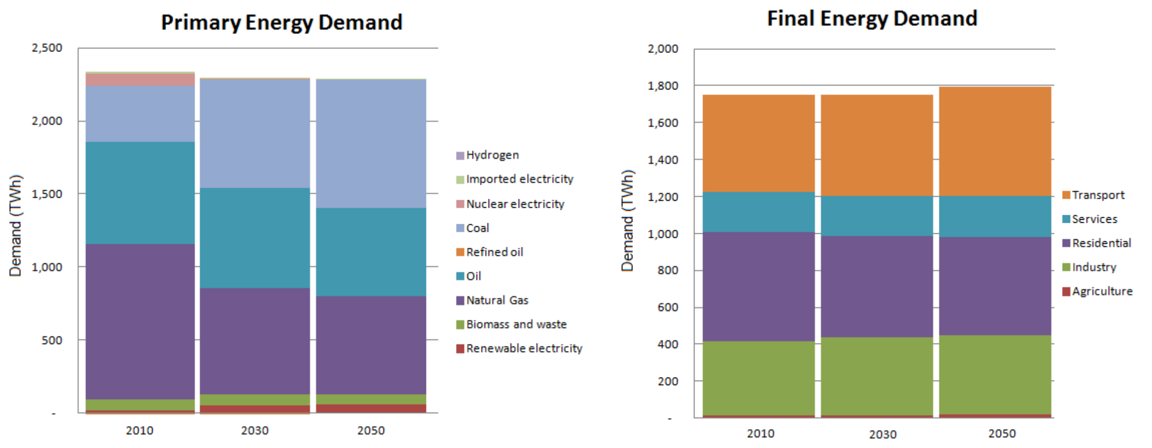


Figure 10 - UKERC REF Primary Energy Demand by Fuel & Final Energy Demand by Sector

Source: After Skea, Ekins, & Winskel, 2011

This scenario is not designed to meet the 2050 carbon targets. It represents a least-cost pathway, free from carbon constraints, with existing policies such as the Renewable Obligation included, but not replaced on their expiry. This is similar to the AEA BAU scenario (scenario B), and is again included as a comparator. This scenario shows gradually increasing demand to 2050, almost completely due to increased final energy demand in the transport sector - increasing 13% from 2010 to 2050. This, along with increased demand from agriculture and industry, serves to outweigh drops in demand from the residential and service sectors. Agriculture shows the greatest percentage increase of 25% between 2010 and 2050, but owing to its minimal contribution to total demand, contributes considerably less to the overall trend for growth in demand. Greatest sources of demand are the transport (592 TWh) and Residential (533 TWh) sectors.

4.4.2 UKERC LC (Scenario I)

2050 Demand 1215 TWh, 2020 & 2050 Carbon Targets Met

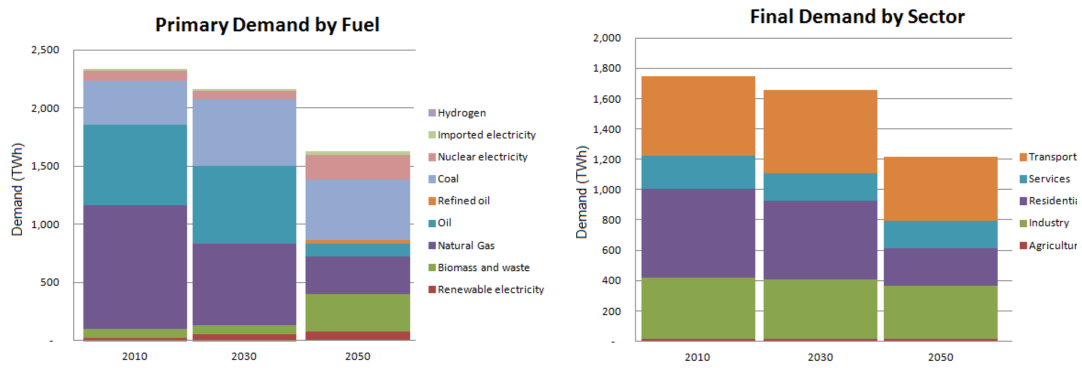


Figure 11 - UKERC LC Primary Energy Demand by Fuel & Final Energy Demand by Sector

Source: After Skea, Ekins, & Winskel, 2011

This scenario is based on all sectors of the economy achieving an 80% GHG emission reduction by 2050. In this scenario, there are considerable reductions in both primary and final energy demand, both on current levels, and in comparison to the UKERC REF scenario (Scenario A). Both coal with CCS, and biomass provide a substantial amount of energy, there is also increased deployment of nuclear power.

All sectors show reductions in final energy demand, the greatest of which is in the residential sector (reduction of 57%). This is facilitated by an increased level of efficiency among domestic appliances, dramatic improvements in the thermal efficiency of the housing stock, and an increased level of electrification of domestic space and water heating. High-efficiency gas boilers do continue to play a role however. Domestic efficiency improvements are supported by a reduced level of service demand. Decarbonisation of the transport sector is achieved by means of deployment of a range of technologies including hybrids, plug-in vehicles, bio-fuels and fuel-cell vehicles.

The majority of demand in 2050 is centred in the transport (420TWh) and Industry (355TWh) sectors.

4.4.3 UKERC LC-90 (Scenario J)

2050 Demand 1232 TWh, 2020 & 2050 Carbon Targets Met

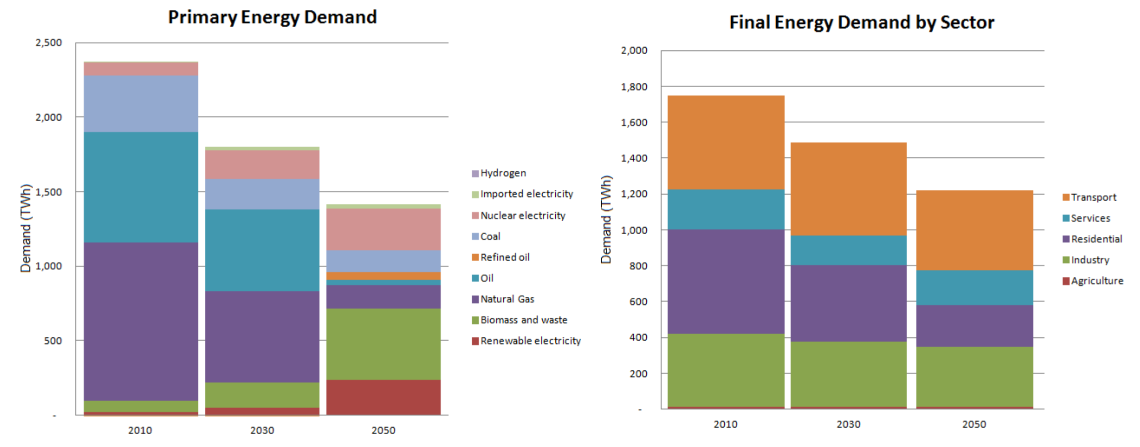


Figure 12 - UKERC REF Primary Energy Demand by Fuel & Final Energy Demand by Sector

Source: After Skea, Ekins, & Winskel, 2011

The LC-90 scenario, as with the AEA 90% reduction scenario (scenario G), is based on the premise that the energy system must offer a higher level of decarbonisation than other areas of the economy, therefore assuming the energy system reduces carbon output by 90%. This scenario features very high consumption of biomass, renewable electricity, and nuclear power. There is a considerably reduced role for coal compared to the UKERC LC scenario (scenario I) because CCS is suggested to capture only approximately 90% of emissions, making it too carbon intensive to achieve a 90% carbon reduction.

Demand is considerably decreased on present day levels, however is slightly higher than in the UKERC LC scenario (Scenario I) because some efficiency is lost in securing the additional levels of carbon reduction, however demand reduction is still present in all sectors. The greatest level of demand reduction is, as in the LC scenario, in the residential sector (reduction of 60%) based on considerably increased housing efficiency, electrification of space and water heating, and reduced service demand. The service sector makes considerable use of biomass heating to support an overall sector carbon reduction of 94%. There is a lower level of plug-in or hybrid vehicle use, in favour of liquid bio-fuels. Total final demand in this scenario is very similar to that of the AEA 90% reduction scenario (scenario G) - 1224TWh. Highest levels of demand come from transport (451TWh) and Industry (336TWh).

4.4.4 UKERC LS-REF (Scenario H)

2050 Demand: 1226 TWh, 2020 Carbon Target Met, 2050 Carbon Target Not Met

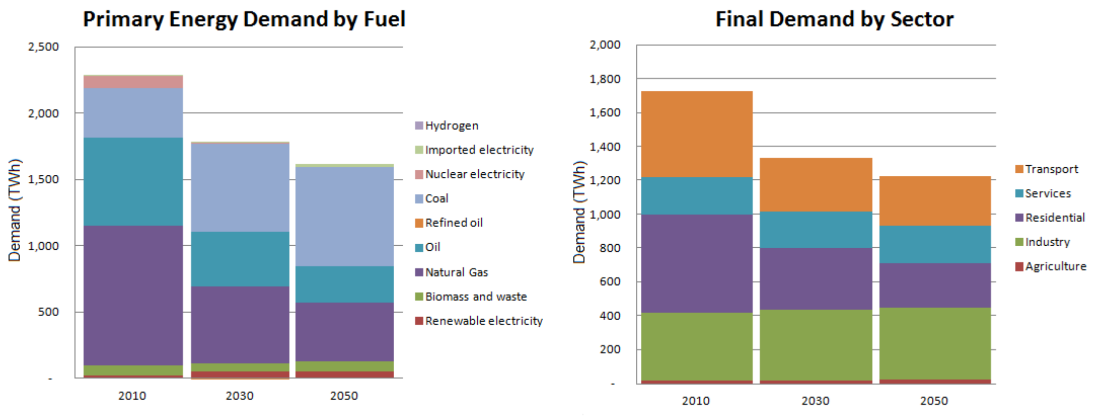


Figure 13 - UKERC REF Primary Energy Demand by Fuel & Final Energy Demand by Sector

Source: After Skea, Ekins, & Winskel, 2011

Alongside the above-examined UKERC scenarios, the UKERC Energy 2050 project included modelling the potential for energy and carbon reductions brought about by changes in consumer lifestyles. Assumptions around behaviour are unavoidable, and different modellers consider such variables more or less explicitly. The UKERC Lifestyle and Energy Consumption scenarios (LS REF & LS LC) specifically examine the effect of behaviour; based around the assumption that individuals' decisions are not solely made on the basis of economic rationale, but are also a product of a number of factors such as social norms, values, beliefs, fashions, and identity.

The LS-REF scenario mimics the above-discussed REF scenario, in that it does not have any carbon output restrictions, however this scenario includes dramatic changes in lifestyles. It is clear that by 2050, such lifestyle changes could lead to a demand reduction not dissimilar to that following the imposition of carbon targets alone. Overall final demand in 2050 in this scenario is 1226TWh, this compares to the UKERC LC scenario (Scenario I) where an 80% carbon reduction was imposed 2050 leading demand to drop to 1215 TWh. The relative primary energy mix of this scenario is not dissimilar to the UKERC REF scenario (Scenario A), except that the scale of the system is much smaller, owing to the smaller final demand brought on by behavioural change.

Most notably, there are considerable reductions in levels of final demand in the residential and transport sectors. Transport becomes more focussed on quality of journey, and expectation for greater accessibility of amenities - i.e. that more amenities should be within walking distance of settlements, facilitating less reliance on transport. Also social pressures drive people away from large vehicles, encourage more shared transport, and efficient driving habits.

In the residential sector there is increasing awareness of, and demand for, low-energy technologies. This is accompanied by reducing levels of service demand owed to increased energy-literacy, higher prices, and improved access to real-time information. These allow pro-environmental attitudes to be reflected in behaviour. Social norms drive increasing environmental performance, conspicuous consumption of energy becomes socially unacceptable, and a social expectation of high levels of building insulation become widespread. In spite of levels of demand reduction, similar to that of the UKERC LC scenario, carbon output in this scenario is over 2.5 times the level required to meet the commitments in the Climate Change Act.

Under this scenario, the greatest sources of demand are industry (427 TWh) and transport (296 TWh).

4.4.5 UKERC LS-LC (Scenarios K)

2050 Demand: 1042 TWh, 2020 & 2050 Carbon Targets Met

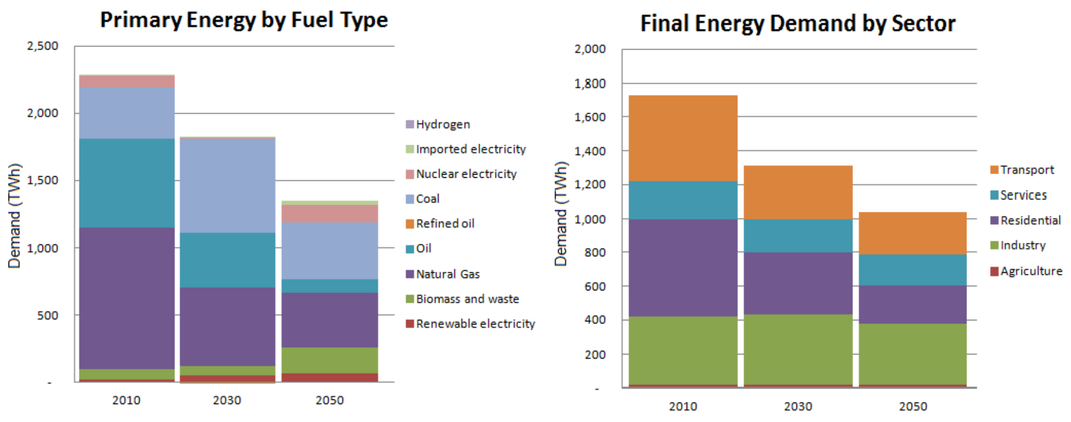


Figure 14 - UKERC REF Primary Energy Demand by Fuel & Final Energy Demand by Sector

Source: After Skea, Ekins, & Winskel, 2011

The LS-LC scenario combines the social trend changes in the LS-REF scenario (scenario H), with the carbon restrictions of the LC scenario (Scenario I). This leads demand levels to fall even further than under the LS-REF scenario, as supported now by a decarbonised energy supply, based primarily on CCS-backed fossil fuels. Demand is approximately 40% lower than both the UKERC REF Scenario (Scenario A) and present day levels, resulting in the lowest level of overall demand in 2050 of all scenarios reviewed here. Under this scenario, the same sectors are responsible for the greatest proportion of demand as under the LS-REF scenario (Scenario H), however at lower levels - industry (359 TWh) and transport (256 TWh).

5. Demand Reduction & The Trilemma

5.1 Sustainability

Scenarios do not offer outputs of wider considerations of sustainability beyond carbon output. ‘The results of the scenario analysis add weight to the idea that demand reduction can be supportive of decarbonisation. This is not a *certain* relationship, as demonstrated in the UKERC LS-REF scenario which showed low levels of demand, but high levels of carbon output. However the reliance of demand reduction in all bar one of the scenarios which met the 2050 targets (the exception being the DECC 'High Nuclear, Less energy Efficiency' scenario) does demonstrate the synergistic nature if reductions in carbon, and reductions in final demand.

5.2 Affordability

It is important to make the distinction between overall system cost, and affordability. If a system is low-cost, but the costs that do exist fall on those least able to bear them, a system may be said to be unaffordable. Scenarios do not examine how costs should best be spread across society, and this will form a major part of future work. However, some scenarios offer information on total system costs, the minimisation of which is conducive to creating a more affordable system. Therefore, analysis of lessons in affordability will here be limited to that of total system cost.

The majority of the scenarios examined here were published with cost outputs, set out as either average system costs per capita over time, total system costs each year, or economic welfare loss. Owing to differences in economic assumptions, and publications of results, it is not possible to make direct cost comparisons between scenarios produced by different stakeholders. However, the range of scenarios that were produced using the DECC 2050 calculator allows some analysis of the connections between scenario choices, levels of demand, and annual system cost. In spite of the broad range of scenarios, they are not all representative of all those examined in this study. For example, although the MARKAL Analogy scenario (scenario C) does have a very similar final level of demand to the other MARKAL produced scenarios, as set out above, the trajectory to that level of demand differs from the MARKAL scenarios. This trajectory of reduction will inevitably affect the overall cost of transition. In spite of this, the analysis of costs here allows insight into the relationship between overall demand, and overall cost[5].

[5] It is worth noting that technology development and deployment costs vary enormously in the literature, however analysis of this area lies outside the bounds of this paper. For full details of the cost assumptions made by the DECC 2050 Calculator, see https://www.gov.uk/2050-pathways-analysis.

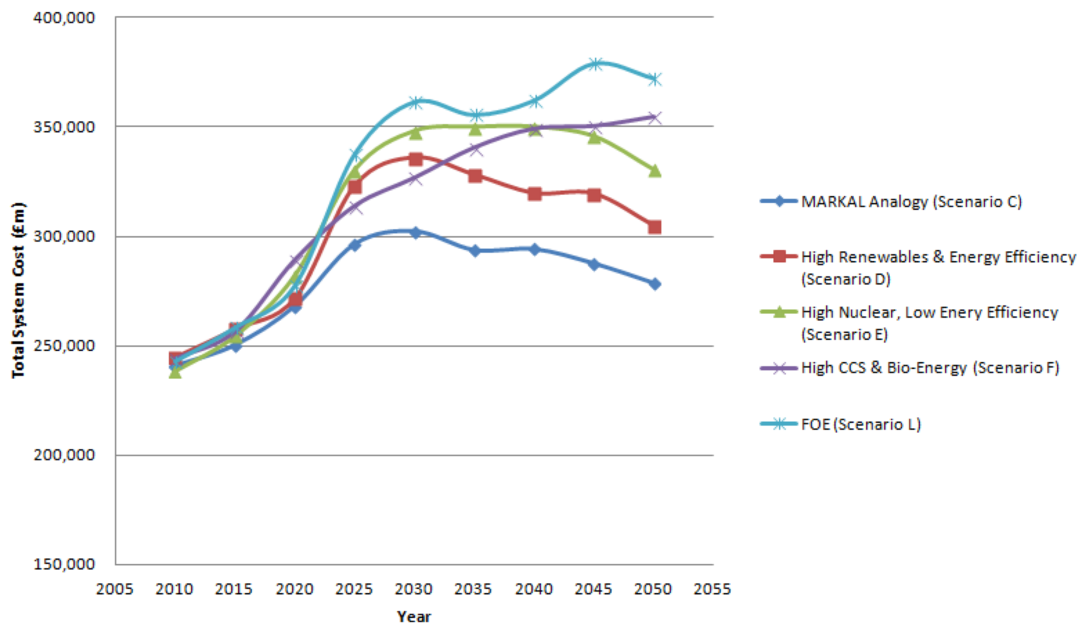


Figure 15 - Scenario Cost Comparison

Source: After DECC, 2013b

Figure 15 shows the annual total system costs over time of the various scenarios constructed using the DECC 2050 pathways calculator. This paper argues that constructing a smaller overall system (i.e. one supporting a lower level of final demand) is conducive to creating a lower long-term system cost. However, the FOE scenario (Scenario L) exhibits both the lowest demand, and the highest cost, whereas the DECC 'High Renewables, High Efficiency' scenario (Scenario D) exhibits both the second-highest level of demand reduction (of the 2050 Calculator scenarios) and the second-lowest cost. This may be explained however by the greater levels of carbon reduction achieved by the FOE scenario; where the four DECC scenarios all achieve a carbon reduction of 80%-82%, the FOE scenario achieves a 96% reduction, suggesting that the additional cost yields additional environmental value. Evidently the relationship between demand and cost is complex.

In order to achieve some clarity around the relationship between cost and demand, 3 hybrid scenarios have been created (figures 16-18). These combine the supply-side measures from three of the DECC scenarios ('High Nuclear, Less Energy Efficiency', 'CCS with Bio-Energy', and 'MARKAL Analogy') with the demand-side measures from the DECC 'High Renewables and Energy Efficiency' scenario - the DECC pathway with the lowest level of demand. The cost curves of these 'hybrid scenarios' were then plotted.

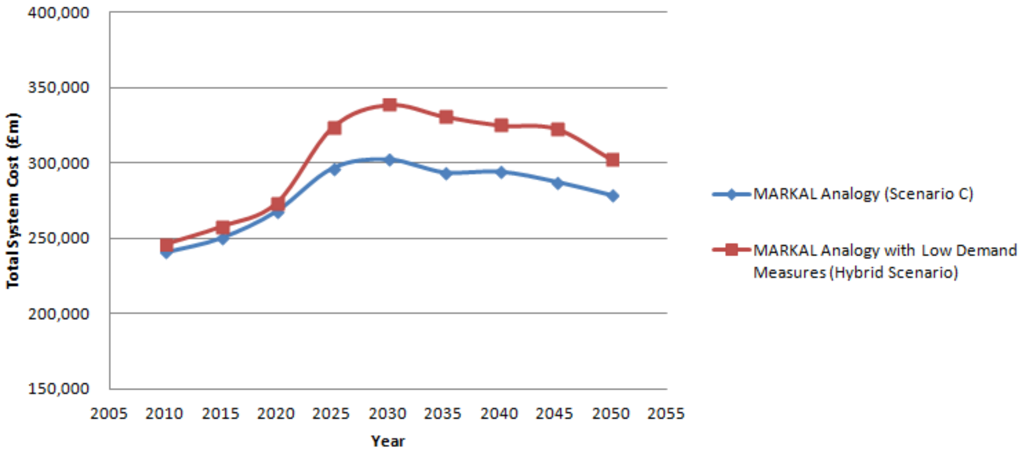


Figure 16 - Cost Impact of Low Demand Measures Hybrid with DECC 'MARKAL Analogy'

Source: After DECC, 2013b

Figure 16 shows a hybrid scenario, combining the supply-side options of the DECC 'MARKAL Analogy' scenario (Scenario C), and the demand-side options of the DECC 'High Renewables, High Energy Efficiency' scenario (Scenario D). It is evident that the low demand-measures add additional cost to the scenario over this time period, most significantly in the medium term, the majority of which is associated with transition of the transport sector. The MARKAL scenario selects for a higher-carbon road transport fleet, with just under half of all vehicles being zero-emissions, of which all are plug-in electric. This is in contrast to the higher efficiency scenario where all vehicles are zero-emissions, and the car fleet is an 80:20 split between electric and fuel-cell vehicles.

What is not clear however, is how the cost-curves develop post-2050. It is possible (although far from guaranteed) that system cost would fall below the counterfactual of the original 'MARKAL Analogy' scenario post-2050. It is worth noting however, that this scenario produces an 87% reduction in CO_2 output by 2050 (as opposed to the MARKAL Analogy 82%reduction), which adds additional social value which is not captured here. It is perhaps unsurprising that the addition of lower demand measures does not bring additional financial value to the MARKAL Analogy scenario, owing to MARKAL being designed as a cost optimisation model. This means that any alternative pathway that could reduce the system cost, whilst still meeting the carbon constraints, would have been selected for in the original MARKAL model run.

Additional clarity is given from two more hybrid scenarios. The demand-side measures of the 'High Renewables, High Energy Efficiency' scenario (Scenario D) were combined with the supply-side measures of 'Higher CCS & Bio-Energy' (Scenario F) (See Figure 17), and also with the supply-side measures of 'Higher Nuclear, Less Energy Efficiency' (scenario E) (See Figure 18).

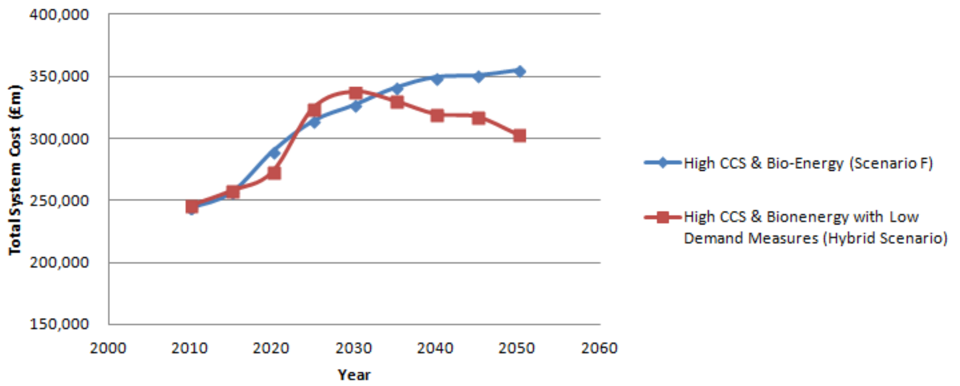


Figure 17 - Cost Impact of Low Demand Measures Hybrid with DECC 'High CCS & Bio-Energy'

Source: After DECC, 2013b

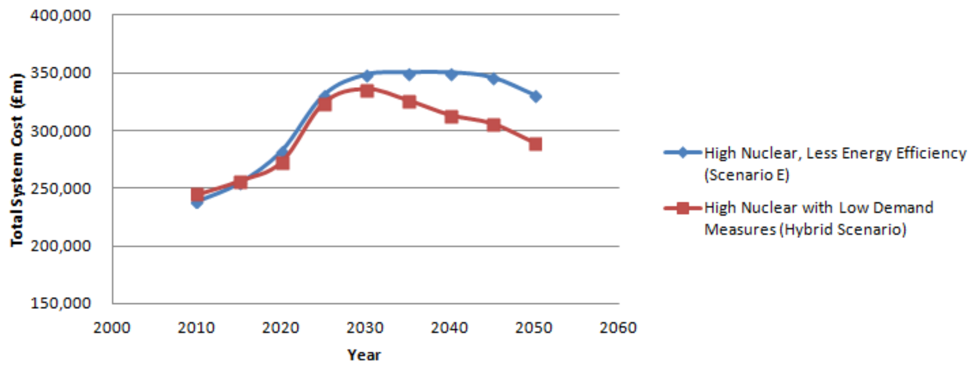


Figure 18 - Cost Impact of Low Demand Measures Hybrid with DECC 'High Nuclear, Less Energy Efficiency'

Source: After DECC, 2013b

It is evident that both of these lower demand, 'hybrid' scenarios (Figures 17 & 18) offer lower long-term total system costs than their unaltered equivalents. In the case of the hybrid 'High Nuclear' scenario (Figure 18), the demand-reduction pathway becomes lower cost very early on. In addition to the cost benefits of demand reduction to the High CCS and Bio-Energy scenario (Scenario F),the pathway also yields increased CO_2 reductions of 87%. It is clear from these three scenarios that demand reduction can offer significant system cost benefits, however there is likely to be a cost-optimal level of demand reduction.

The significant cost benefits of demand reduction are also apparent from the results of the various MARKAL models. MARKAL is a cost-optimising model, and although the various runs of the model give different trajectories to 2050, they converge on a very similar level of demand - in the order of 30% lower than today's level.

5.3 Energy Security

Scenarios offer little evidence either in support of, or against, the notion that demand reduction is supportive of overall energy security, beyond that it can be supportive of price security, as a factor of affordability (see above). This is partially a product of the complexity of measurement of energy security, particularly in relation to demand-side measures(Axon, Darton, & Winzer, 2013). Detailed investigation of the relationship between level of energy demand, and inherently difficult to measure energy security levels, lie outside the bounds of this paper.

6. DECC Forecasts

As set out above, scenarios are designed as plausible explanations of possible futures, not predictions of what will happen in future. However DECC also produces forecasts for demand up to 2030 (See Figure 19). The projections are based purely on existing policies, and do not make assumptions about introduction of new policies thereafter, however they give some insight into governmental expectations of future levels of demand.

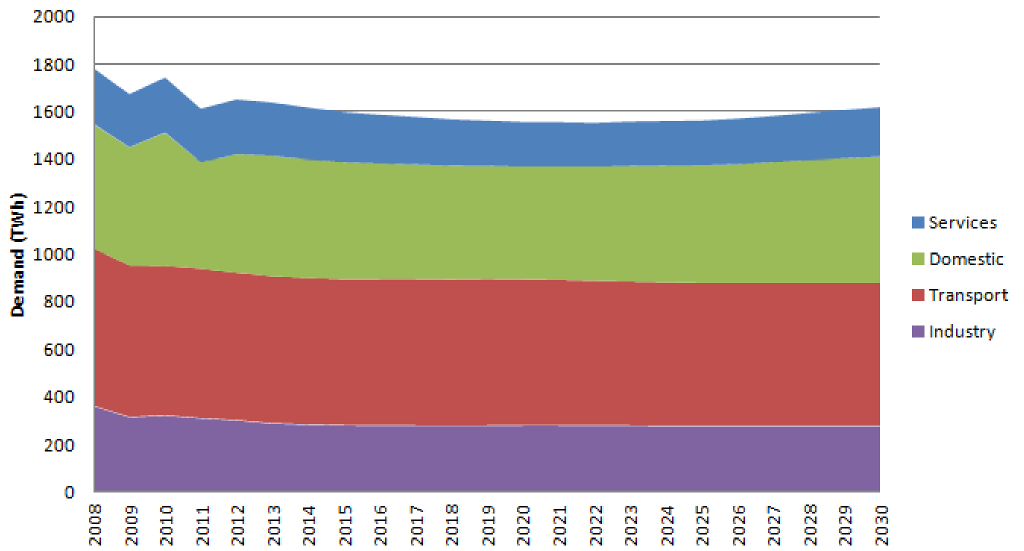


Figure 19 - DECC Final Energy Demand Forecast by Sector

Source: After, DECC, 2013c

As can be seen in figure 19, the general trend is one of continued high levels of demand across all sectors. There are moderate reductions anticipated into the early 2020s, but levels soon return to that of the present day. This is in stark contrast to all but two of the scenarios - which show considerable reductions in energy demand by 2030. As stated, the projections only consider impact of existing policies and therefore are unable to consider policies that may be introduced in future, and this may account for the higher levels of demand the years to 2030. However, this demonstrates that there are presently no long-term policies in place to support the significant levels of demand reduction that the majority of scenarios bear out as necessary for reaching the 2050 targets. There are however two scenarios which meet the 2050 targets with no reduction in demand by 2030. These are the UKERC-LC scenario, and the DECC 'High Nuclear, Less Energy Efficiency' scenarios. This could be taken as indicative either of a desire to follow pathways resembling either of these scenarios, or that it is expected that policies will be implemented later to bring about the necessary reductions in demand required to follow a route more similar to one of the other scenarios. What is certain however is that there are currently no long-term policies in place that guide the UK to continuing and gradual demand reductions to 2030 and beyond, which are borne out in the majority of the scenarios explored here.

These projections must be put in the context of their accompanying carbon predictions. DECC predicts a gradual reduction in co2 output, consistent with meeting the first three carbon budgets (see appendix 3). However, emissions in the fourth carbon budget (2023-2027) are considerably higher than the budget allows. This is in spite of sudden drop in carbon output between 2022 and 2023 approximately equivalent to that brought about by the 2008 financial crisis. The projected 2030 emission level is also considerably higher than the 2030 level set out in all four DECC scenarios. It is necessary to reiterate that these projections only take account of existing policy measures. However, this does underline the fact that further measures must be implemented in order to meet the carbon budgets, and to ensure that carbon targets are reached.

The current long-term policy mix therefore appears to be either unnecessarily expensive, highly risky, or potentially both. The DECC 'High Nuclear, Low Energy Efficiency' pathway has been shown to be more expensive than its low-demand equivalent, meaning a pursuit of a similar pathway would lead to needlessly high costs. If governmental intention is to follow a pathway more similar to the UKERC LC scenario, given the UK's lack of progress on demand reduction in previous years, the vast level of demand-reduction required post-2030 risk missing the 2050 targets altogether. Finally, if it is anticipated that substantial demand reduction must be brought about ahead of 2030, but the policies have yet to be written to achieve this, then policy-risk is inherently being created. It appears that a risky game is being played with total system cost, and the UK's ability to meet its carbon commitments.

7. Conclusion

The work in this paper demonstrates that there are many different plausible pathways to meeting to 2050 carbon targets, however there are some commonalities across scenarios. The vast majority are based upon an assumption of considerable reductions in final energy demand, and almost all the scenarios assume the widespread electrification of heat and transport, alongside dramatic increases in efficiency of the domestic sector. The majority of scenarios attribute the greatest proportions of demand to industry, and the transport sector.

In addition to theoretical arguments set out early in this paper, scenario analysis has demonstrated reductions in final demand to be supportive of two of the three areas of the trilemma - affordability (specifically with relation to overall system cost) and sustainability (specifically carbon reductions). Relationships between demand reduction and energy security, beyond support for price-security, are less transparent however, partially as a result of the challenges for quantifying improvement in energy security.

With respect to financial implications, it is clear that the most cost-effective route to meeting the 2050 targets includes a substantial amount of demand reduction. However, given the level of the 2050 target, there appears to be a cost-optimal level for this demand reduction. Although, given the limited expectation for such reduction set out in the DECC forecasts, the risk of over-achieving in demand reduction and therefore treading a 'cost-heavy' pathway is unlikely to outweigh the risk of failing to make necessary reductions at all. Any such failure could either lead to missing the 2050 targets completely, or having to make a steep trajectory of reductions as the 2050 deadline approaches.

In spite of the majority of scenarios setting out a steady reduction in overall demand between now and 2050, this does not appear to be reflected in the DECC projections to 2030. This may be considered reflective of either a desire to follow a high demand pathway (shown to be costly), a late demand-reduction pathway (potentially risky) or that necessary policies to reduce demand ahead of 2030 are yet to be written (indicative of a lack of attention, or appropriate ambition, in the policy area). Whatever the driving force behind the current absence of policies to bring about substantial levels of demand reduction, the evidence from this paper suggests that a dramatic change in this position is necessary if carbon reduction commitments are to be met in a cost effective manner.

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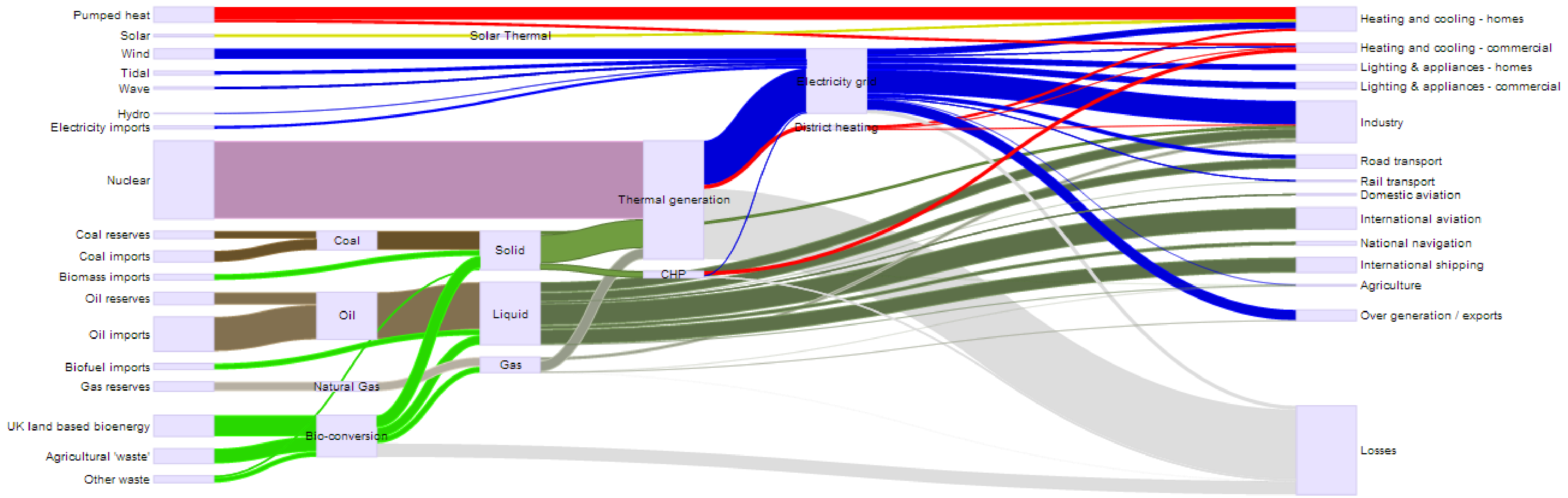
Appendices

Appendix A - MARKAL Modelling

MARKAL is 'a widely applied energy service driven, technology rich, least cost optimization linear programming (LP) model' (Kannan & Strachan, 2009) It was initially developed by the International Energy Agency (IEA), and now forms the basis of much of the energy systems modelling around the world. MARKAL, in common with other branches of scenario-making, is not designed to be predictive, but as a complex 'What-If' framework (Kannan & Strachan, 2009). MARKAL begins with input parameters such as resource supply curves, technology cost curves, learning-curves for less mature technologies, and the energy service demands from a range of sectors (Kannan & Strachan, 2009). When the model is run, it solves to minimise discounted energy system cost in five-year increments from 2000 to 2070. Policy and physical constraints may be included to generate a range of different scenarios (Kannan & Strachan, 2009). MARKAL benefits from modelling the entire energy system in an aggregate fashion (AEA, 2011b), but is still technology-rich in its design (Strachan et al., 2008), and has undergone extensive redevelopment since 2005 (Strachan et al., 2008). In spite of this, it is not without its shortcomings - failing to include emissions from international transport, or non-energy non-CO_2 GHGs from agriculture, waste and land-use change and forestry (AEA, 2011b).

The scenarios examined in this paper make use of the UK MARKAL-MED model, this is a specific incarnation of MARKAL which is based on UK energy systems and also features an elastic-demand function. That is to say that the levels of demand are able to flex in reaction to price of energy, availability, and cost of conservation measures, efficiency, and opportunity for fuel-switching (Anandarajah & Strachan, 2010).

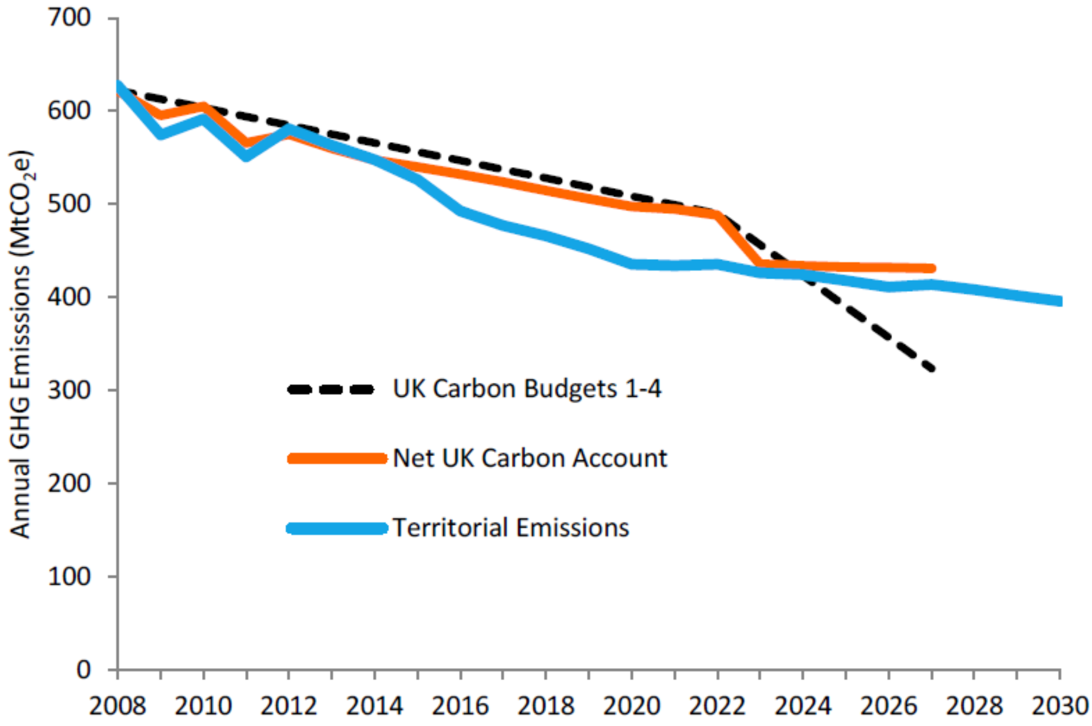
Appendix B - 'Sanky' Diagram - Primary to Final Energy Pathways



MARKAL Analogy Scenario (Scenario C) Sanky Diagram

Source: (DECC, 2013b)

Appendix C - DECC Emissions Projections



Net UK Carbon account and Territorial Emissions Projections to 2030

Source: DECC, 2013c