Energy system crossroads - time for decisions

Analytical annex

Analytical Annex to ICEPT Discussion Paper

Energy system crossroads - time for decisions: UK 2030 low carbon scenarios and pathways

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List of acronyms

Battery Electric Vehicle	BEV
Biomass-to-Liquid	BtL
Combined Heat and Power	CHP
Committee on Climate Change	CCC
Carbon Capture and Storage	CCS
Carbon Dioxide	CO_2
Department of Energy and Climate Change	DECC
Electricity Market Reform	EMR
Electric Vehicle	EV
Future Energy Scenario	FES
Green House Gases	GHG
Gigawatt	GW
Hydrogen Fuel-cell Vehicle	HFCV
Heavy Goods Vehicle	HGV
Internal Combustion Engine	ICE
Large Combustion Plant Directive	LCPD
Light Goods Vehicle	LGV
Kilowatt-hour	kWh
Megawatt	MW
Megawatt-hour	MWh
Mega-tons Carbon Dioxide	$MTCO_2$
Plug-in Hybrid Electric Vehicle	PHEV
Photovoltaic	PV
Renewable Energy Directive	RED
Redpoint Energy System Optimisation Model	RESOM
Tera-watt Hour	TWh
UK Energy Research Centre	UKERC

A Introduction

The period between now and 2030 has become a major focus for energy policy analysis in the UK. The UK government has set out plans and aspirations for decarbonisation in 2030 and the Committee on Climate Change (CCC) has undertaken detailed analysis of what needs to happen in the period immediately preceding 2030 as part of advice to government on the 4th carbon budget. 2030 is regarded as a key staging post on a journey towards deep cuts in carbon emissions in 2050. Many relevant bodies have produced scenarios for 2030 decarbonisation. In this report we review the commonalities and areas of uncertainty and disagreement between these scenarios. The report seeks to relate various visions of what needs to happen by 2030 to the immediacies of current policy and to key decision points that arise over the coming 15 years.

This is important because substantial changes to the energy system cannot be realised over-night. Large investments in power stations, in infrastructure such as transmission and distribution networks, heat networks or pipelines for CCS will need to get onto a critical path that ensures development happens in time. Similarly, roll out of household efficiency, vehicles or appliances will take several years. If scenarios are to become reality policy must ensure that development takes place in a timely fashion. This means taking stock of the time needed for all of the various steps along the way, from initial planning through project development and finance to construction.

This report links 2030 aspirations to more immediate policy choices by identifying the broad areas of agreement in models and scenarios, highlighting divergences and disagreements in these scenarios, identifying the timescales needed between decision and delivery for any of these key developments, identifying other key assumptions or requirements such as learning curves and technology readiness which will determine if and when deployment can happen, and recognising possible finance and public acceptance hurdles.

The following scenarios and scenario sets are considered in this annex:

Scenario Sets	**Selected Scenarios**
CCC 4th Carbon Budget Scenario	
National Grid Future Energy Scenarios 2014	Gone Green
	Low Carbon Life
UKERC Scenarios Update 2011	Low Carbon
DECC-AEA Carbon Plan 2011	DECC-1A-IAB-2A

B Low carbon scenarios for 2030: An overview

B.1 The Committee on Climate Change 4th carbon budget scenarios

The Committee on Climate Change (CCC) was established under the Climate Change Act 2008 and constitutes an independent, statutory body that advises the UK Government on setting and meeting carbon budgets and preparing for climate change (CCC 2015).

In 2011 the CCC set the fourth carbon budget (CCC 2010), covering a period of 2023-27, which committed the UK to a 50% cut in 2025 and a 60% cut in 2030 on 1990 levels (CCC 2013c).

As part of the agreement to set the budget, the Government scheduled a review for 2014. However, changes can only be made if there have been significant changes affecting the basis on which the previous decision was made. (CCC 2013b). To provide the evidence base on which to make this decision the CCC produced two reports that together made up the review. The first part considered the evidence on climate science and international circumstances, concluding there has been no significant change in circumstances as specified in the Climate Change Act and consequently the budget should not and cannot be changed under the terms of the Act (CCC 2013a). The second part reviews the latest evidence on how the budget can be met (CCC 2013b). This exercise included an updated abatement scenario that outlined a variety of cost-effective abatement options capable of reaching the UK's 2050 target.

The updated abatement scenario results in an emissions reduction of 56% by 2025 and 63% by 2030 on 1990 levels (CCC 2013c). These emissions cuts are deeper when compared to the original 2010 budget and are realised by more severe reductions during the 2020s as illustrated by Figure 1. This is achieved by an average rate of GHG reduction between 2012 and 2030 of 3.8% $MTCO_2e$ per annum[1], which increases to 4.3% $MTCO_2e$ per annum between 2030 and 2050 (CCC 2013b).

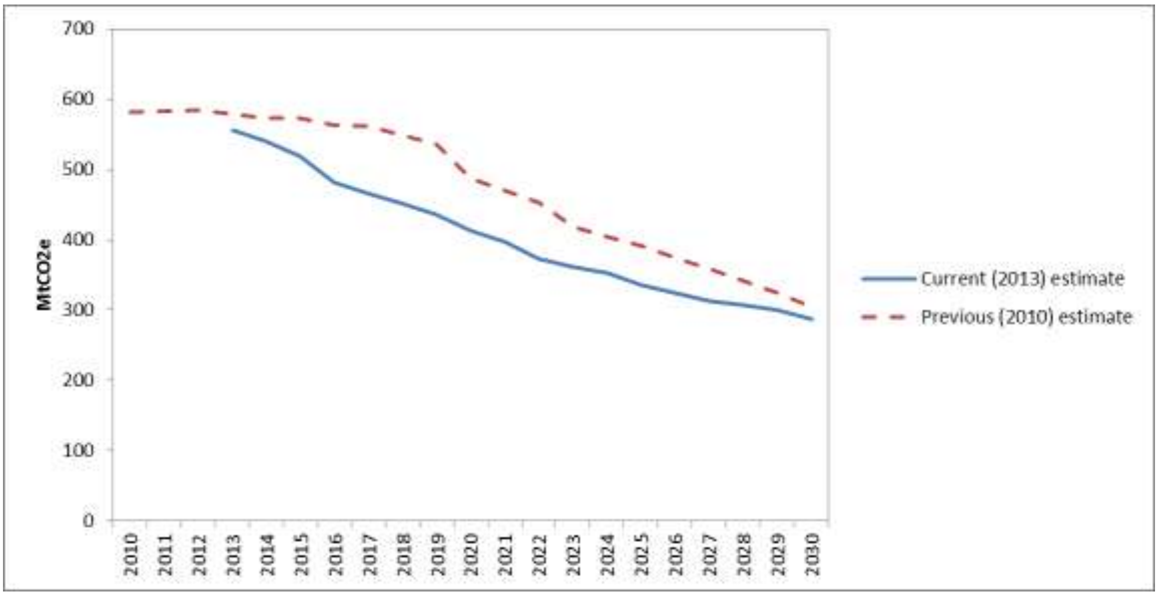
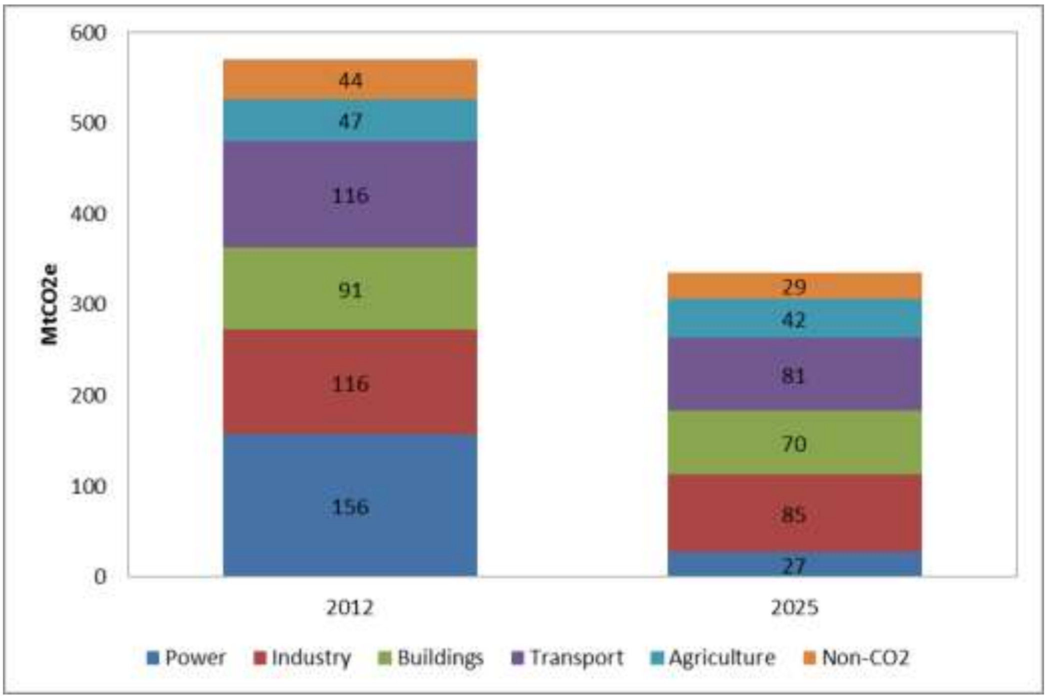


Figure 1:UK estimated emissions reduction trajectory to 2030 to be compliant with CCC 80% reduction pathway (CCC2013c)

[1] Excluding international aviation and shipping

As Figure 1 below illustrates the greatest reduction in emissions by 2025 is expected to come from the UK's power sector, with emissions falling from 156 $MtCO_2e$ in 2012 to 27 $MtCO_2e$ by 2025, an 82% reduction. Across the other sectors the reduction is significantly lower, sitting between 30% (transport) and 11% (agriculture). In the following sections the scale of these emissions reductions for each sector[2] and how these will be achieved will be discussed, highlighting areas of uncertainty, contestation and potential 'branching points'[3] for each sector.



Note: Building sector category is for direct emissions and therefore does not include electricity consumption but energy used for space heating, cooking, hot water etc.

Figure 1: Estimates of the cost-effective level of emissions in 2025 (total GHG by sector) (CCC 2013c)

B.2 Other low-carbon UK 2030 scenarios – overview of scenarios

Three sets of comparator scenarios were selected for comparison with the CCC scenarios and these are; the National Grid Future Energy Scenarios 2014 (*Gone Green, Low Carbon Life*); the UKERC updated scenarios 2011 (*Low Carbon*) and DECC-AEA Carbon Plan 2011 (*DECC-1A-IAB-2A*). All these scenarios (including the CCC) apart from National Grid use the same underlying model: UK MARKAL (Ekins et al. 2013). In addition, a separate DECC commissioned scenario for the UK's heat sector in 2030 was developed by consultancy Redpoint using the Redpoint Energy System Optimisation Model (RESOM) model.

B.2.1 National Grid Future Energy Scenarios

National Grid issues its Future Energy Scenarios on an annual basis. They focus primarily on the time period up to 2035 and their purpose is to help enable decisions to be made on the future development of the UK's electricity and gas networks. This review uses the 2014 iteration of this

[2] These include: power, buildings, transport and industry
[3] These are defined as 'key decision points at which choices made by actors, in response to internal or external stresses or triggers, determine whether and in what ways the pathway is followed' (Foxon et al. 2013 p.146)

series (National Grid 2014) and specifically two of the four scenarios where the UK's carbon targets are expected to be met: *Low Carbon Life* and *Gone Green*. The report outlines them as follows in Table 1.

Table 1: Overview of contextual factors shaping Low Carbon Life and Gone Green scenarios (National Grid 2014)

	Low Carbon Life	**Gone Green**
Economic	Growing UK economy.	Growing UK economy
Political	Short-term political volatility but long-term consensus around decarbonisation.	Domestic and European policy harmonisation, with long-term certainty provided.
Technological	Renewable generation at a local level. High innovation in the energy sector.	High levels of renewable generation with high innovation in the energy sector.
Social	High uptake of electric vehicles but consumers not focused on energy efficiency. 'Going green' is a by-product of purchasing desirable items.	Engaged consumers focused on drive for energy efficiency. This results in high uptake of electric vehicles and heat pumps.
Environmental	Carbon target hit. No new environmental targets introduced.	All targets hit, including new European targets post-2020.

B.2.2 UKERC Phase 2 (UKERC2) Scenarios

In 2011 the UK Energy Research Centre (UKERC) produced an updated set of the Energy 2050 scenarios it published in 2008, in light of numerous policy and model developments having taken place. Ekins et al. (2013) explain that the UKERC2 scenarios were developed using the latest version of the UK MARKAL model, which incorporated some but not all of the changes that had been introduced in the original CCC 4CB abatement scenario and the AEA Carbon Plan scenarios. They also include an updated range of other policy and technology assumptions to match recent developments. The *Low Carbon* scenario where the first four carbon budgets are met, as well as the 2050 reduction target of 80%, is examined here.).

B.2.3 DECC scenarios

The last set of scenarios we use for comparison are those produced by consultants AEA Technology on behalf of DECC for the UK government's 2011 Carbon Plan (HM Gov 2011). This plan replaced the previous Government's Low Carbon Transition Plan (HMG 2009) and was published in December 2011 shortly after the UK government had legislated for the Committee on Climate Change (CCC)'s recommendations for the fourth carbon budget.

The work consisted of two distinct phases, and for the purposes of this study the core run for phase 2 of the modelling, called *DECC-1A-IAB-2A*, is examined. A variety of assumptions are made in this scenario (Hawkes 2011). This AEA scenario is used here for both the power and transport sector, however we use a different DECC commissioned scenario for the heat sector. Instead we use a core run scenario developed by Redpoint, which was included in the recent DECC report *The Future of Heating: Meeting the challenge* (2013c). This scenario was developed using the Redpoint Energy System Optimisation Model (RESOM) as it has a detailed representation of domestic heat demand, heat technologies and networks, which allows exploration of the implications for heat in more detail.

C Scenarios to decarbonise the UK heat sector

C.1 Overview of low-carbon heat sector scenarios

C.1.1 CCC Updated Abatement Scenario

UK heat sector*: *2012 – 2020

By 2020 the CCC scenario sees direct emissions from buildings fall to 80 $MtCO_2$, constituting a 12% fall on 2012 levels[4] and an 18% on baseline projections for 2020 (CCC 2013c).

Despite the residential sector accounting for more than four times the emissions of the non-residential sector in 2012, the total emissions reductions on baseline assumptions for 2020 will mostly be delivered from the non-residential sector, delivering cuts three times as great. Specifically, residential emissions are expected to fall by 3.3% to 71.8 $MtCO_2$ and the non-residential sector by 49% to 8.6 $MtCO_2$ by 2020 on 2012 levels.

In the lead up to 2020 it is expected that the majority of residential sector emissions cuts will be balanced between both renewable heat and achievement of the efficiency measures, however in the non-residential sector there is a much greater focus on emissions reductions from renewable heat, which accounts for approximately 71% of achieved emissions reductions. The general picture is one where both types of intervention play a key role in decarbonising the buildings sector this decade.

UK heat sector 2020 - 2030

By 2030 the CCC scenario sees direct emissions from buildings fall to 64 $MtCO_2$ in 2030, constituting a 30% fall on 2012 levels and 38% on baseline projections for 2030 (CCC 2013c). Heat consumption stands at around 443TWh by 2030.

Residential emissions are expected to fall by 17% to 61.4 $MtCO_2$ and the non-residential sector by 84% to 2.6 $MtCO_2$ by 2030 from 2012 levels. The 2020s see the most dramatic decarbonisation taking place in the non-residential sector. Importantly however, the 2020s see a much more rapid decarbonisation take place in the residential sector than during the 2010s, with over 80% of the 12.8 $MtCO_2$ reductions being delivered in the post 2020 period.

Whilst abatement in the 2010s is largely balanced between abatement from both efficiency and renewable heat measures, the 2020s are much more centred on renewable heat abatement. By 2030, approximately three quarters of buildings sector emissions are achieved through decarbonisation of heat. By 2030, the scenario sees renewable heat deliver 30$MtCO_2$ of emissions reduction on baseline levels. Almost half of this is delivered through large-scale deployment of heat pumps, which delivers a 14 MtCO2 reduction in emissions[5]. By 2030 4 million domestic heat pumps in approximately 13% of homes provide 31TWh[6] of primary energy production in the residential sector and a further 20TWh of primary energy is provided by non-domestic heat pumps (CCC 2013c). Together these account for approximately 12% of building heat consumption in 2030.

[4] Emissions values are taken for 2012 because this is when the CCC values are taken and the 2013 DECC values (DECC 2014a) do not offer the same categorisation as the 'buildings' sector.
[5] It is unclear from the data whether this is for both sectors or just the residential sector
[6] This reference to total heat pump output minus electricity input

District heat is also expected to play an important role providing 30 TWh/year standing at approximately 6% of buildings heat demand by 2030. Whilst the scenario does not reserve any major role for bioenergy, it does attribute a reduction of around 8.5 $MtCO_2$ by 2030 to this group of technologies (CCC 2013c).

Total savings from energy efficiency measures across both the residential and commercial sectors by 2030 from the 2012 level are calculated at more than 10 $MtCO_2$ against baseline levels. Table 2, below, outlines the various different measures that contribute to 7.2 MtCO2 seen in the residential sector. Whilst the majority of these are achieved via cavity, loft and solid wall insulation, both heating controls and behavioural change also contribute to efficiency gains and therefore carbon reductions. To achieve these reductions in the residential sector, it is expected that all lofts and walls are insulated in addition to the installation of solid wall insulation across 3.5 million other homes.

The key outputs from this scenario are summarised in Table 3 and Figure 2.

Table 2: Summary of direct carbon savings by 2030 from the residential sector ($MtCO_2$) (CCC 2013c)

Measure	Old 2010 estimates	Revised 2013 estimates
Solid wall insulation	4.9	2.5
Cavity wall and loft insulation	3.0	2.7
Other fabric measures	0.4	0.7
Heating controls	0.1	1.4
Heating 1 degree centigrade decrease	3.1	2.0
Lighting	-0.4	-1.2
Cold & wet appliances	-0.2	-0.7
Electrical products (e.g. computers, televisions, other appliances)	-2.2	-3.2
Other measures	0.6	3.0
Total	9.3	7.2
Source: CCC modelling		

Table 3: Key estimates for building sector decarbonisation 2012 – 2030 (CCC 2013c)[7]

	2013	2020	2030
Total emissions ($MtCO_2$)*	91**	80	64
Total heat consumption (TWh)	598	443	435

* - These are direct emissions, which include both heat and electricity consumption in buildings

** - Emissions are for 2012

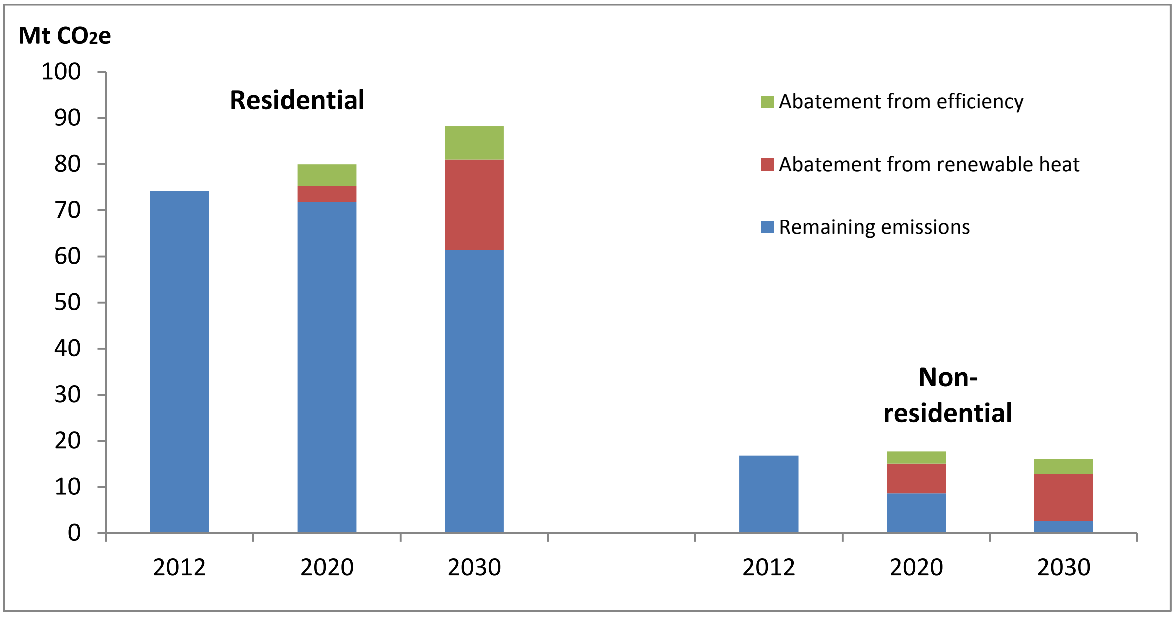


Figure 2: Updated scenario for direct emissions abatement for residential and non-residential buildings (2010, 2020, and 2030) (adapted from CCC 2013c)

C.1.2 National Grid Future Energy Scenarios

C.1.2.1 Gone Green

Heat supply in Gone Green stands at 439TWh[8], with the vast majority of this still coming from gas. The Gone Green scenario places a major emphasises on heat pump deployment largely due to reflecting stronger policy incentives and measures and higher affordability. In total the scenario sees approximately 5.6 million heat pumps in operation by 2030 (Figure 3), responsible for 12.7TWh of electricity demand, together producing approximately 40TWh of renewable heat[9] (Carbon Connect 2014). This accounts for approximately 9% of total heat output in this scenario. It is expected that most heat pumps will be air-source devices, due to the higher cost of installation of ground-source heat pumps. Additionally, it is expected that initially heat pumps will replace oil and electric systems before gas boilers. This is largely because the cost of heat pumps is expected to be more favourable

[7] 2020 and 2030 data also drawn from CCC's own supporting calculations from spreadsheet titled *4CBR heat load updater corrected*
[8] This is taken from Carbon Connect's analysis of the National Grid's RESOM modelling because the FES data does not divide residential and non-residential. It also includes cooking and industrial space/water demands
[9] Calculated as 53TWh listed in Carbon Connect report minus the 12.6TWh of electricity input from NG calculations

versus oil and electricity rather than gas in the medium term. In parallel there is some limited growth of district heating due to policy drivers but growth is limited by the carbon intensity of CHP emissions.

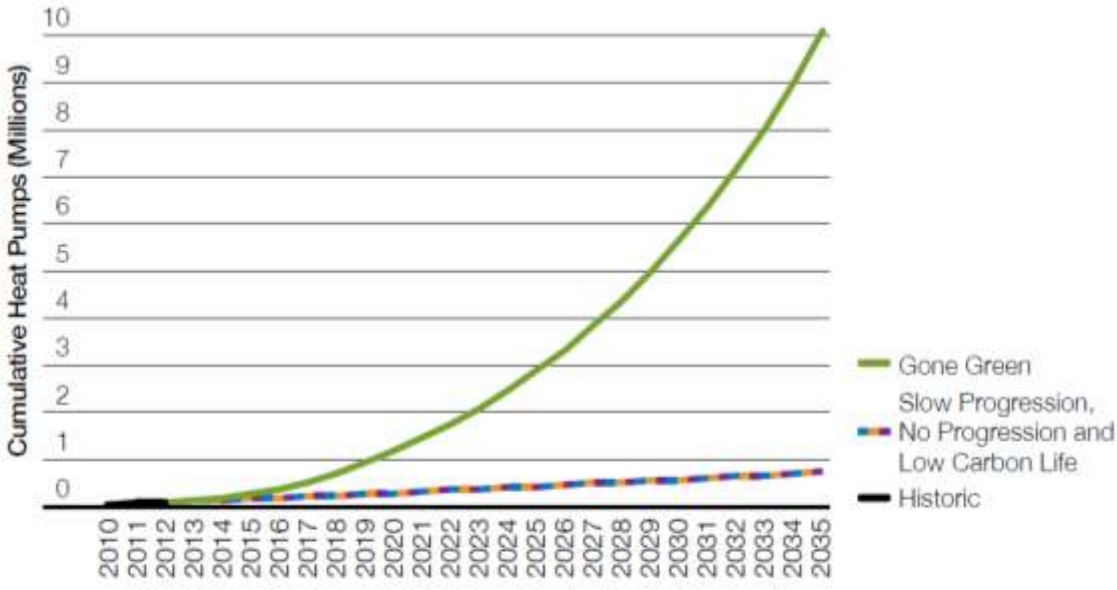


Figure 3: Cumulative heat pump deployment (National Grid 2014)

Whilst Figure 4 includes heat from the industrial sector it provides some illustration of the heat supply mix by 2030, which is still heavily dominated by gas and other fossil fuels.

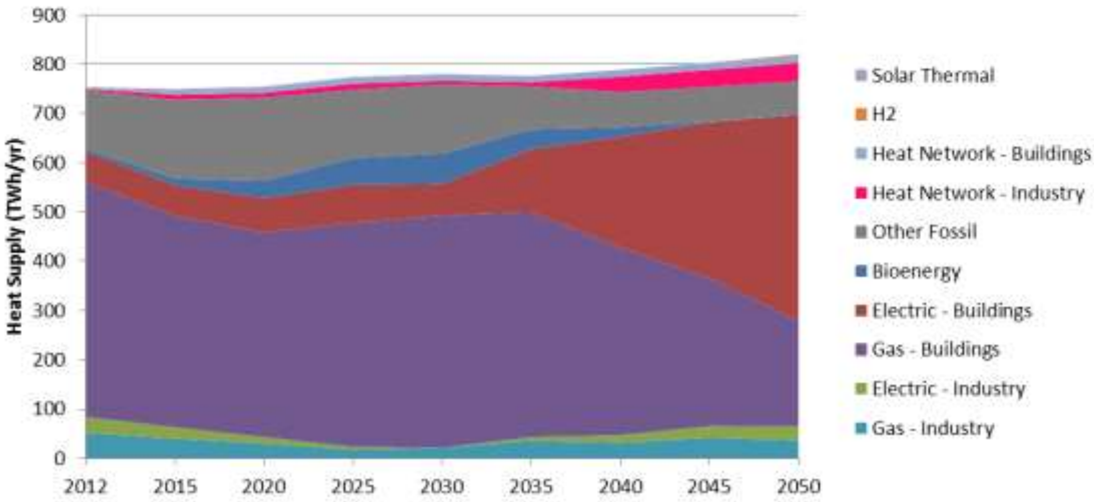


Figure 4: Gone Green heat supply to 2050 (National Grid 2014)

The Gone Green scenario also sees major improvements in the energy efficiency of the UK's housing stock. For new build homes it sees the annual heat demand from each new home falling from 10.3 MWh/yr in 2013 to 5.2 MWh/yr by 2030. This can be attributed to building regulations being 'tightened every four years from 2018, due to an average of a two-year timeline between achieving planning permission and household completion, with regulations pending for 2016' and that 'Passivhaus standards are reached by 2030' (National Grid 2014 p.56) for new build residential.

The scenario also sees major efficiency improvements of building fabric via retrofits, with highest rates of insulation deployment across all the scenarios, although it is expected that loft and cavity market are beginning to reach saturation. By 2030 the scenario sees 18.2 million homes with loft insulation (approx. 16.2 in 2013), 14.8 million with cavity (approx. 13.4 in 2013) and almost 1 million homes with solid wall insulation (approx. 209,000 in 2013) (Decc 2011). Even so it is the replacement of old boilers with new A-rated efficiency is expected to deliver the most significant reduction in gas demand, resulting in a 31TWh heat demand reduction, with the market reaching saturation by 2030. It is assumed that 1.5m new boilers are purchased each year, displacing predominantly non-condensing ageing appliances. Together with the roll-out of insulation gas demand is expected to fall by 49TWh on 2013 levels (Figure 5).

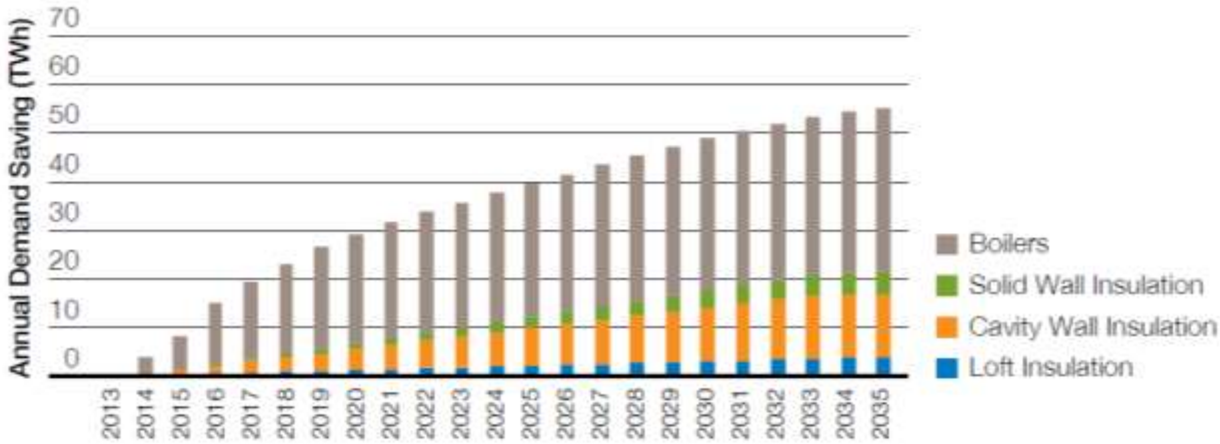


Figure 5: Gas demand savings from residential energy efficiency measures for Gone Green (National Grid 2014)

C.1.2.2 National Grid Low Carbon Life

In contrast to the Gone Green scenario, the Low Carbon Life scenario presents a much more pessimistic outlook for heat pump deployment, seeing only 600,000 deployed by 2030, accounting for 1.5TWh of electricity demand. This is explained by a reduced emphasis on sustainability in this scenario and consequently fewer energy policies designed to promote heat pump uptake. Instead, the scenario sees a much more important role for district heating CHP, with more than a million homes being served by district heat network by 2030 compared to approximately 200,000 at present (National Grid 2014) (Figure 6). This growth is attributed to higher economic growth than in the other scenarios, resulting in more new homes being developed and thus more opportunities for heat networks to be developed at relatively low cost compared to retrofits.

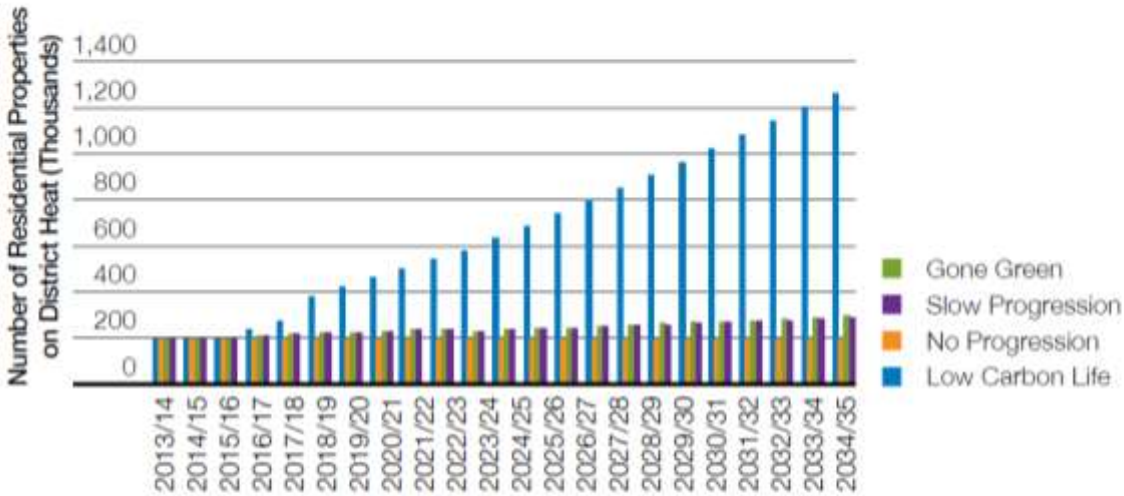


Figure 6: Number of residential properties using district heat

Whilst Figure 7 includes heat from the industrial sector it provides some illustration of the heat supply mix by 2030, which is still heavily dominated by gas and other fossil fuels.

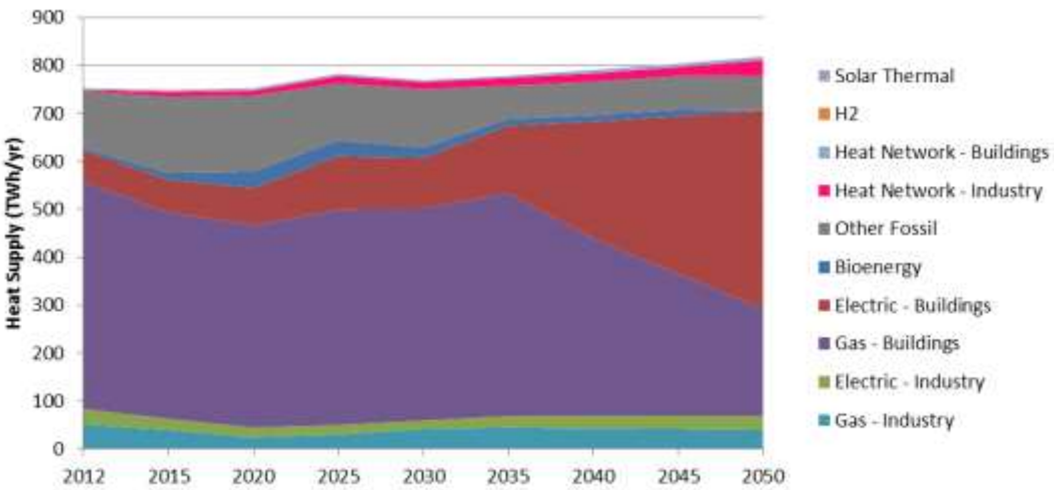


Figure 7: Low Carbon Life heat supply to 2050 (National Grid 2014)

Building performance standards are not expected to rise as much as in the Gone Green scenario, with half the rate of thermal efficiency improvements achieved through building regulations. This sees energy demand for new homes falling from 10.3MWh/yr to 7.6MWh/yr. This scenario also assumes a high rate of uptake for loft and cavity wall insulation, but a low rate of uptake for solid wall insulation, with only 440,000 homes adopting the measure by 2030. Finally, boiler replacements are also expected to make a similarly important contribution to heat demand reduction.

Figure 8 summarises the combined heat energy savings for both National Grid scenarios, illustrating how major efficiency gains are expected in the lead up to 2030 in both scenarios, which are achieved at a steady pace across the period.

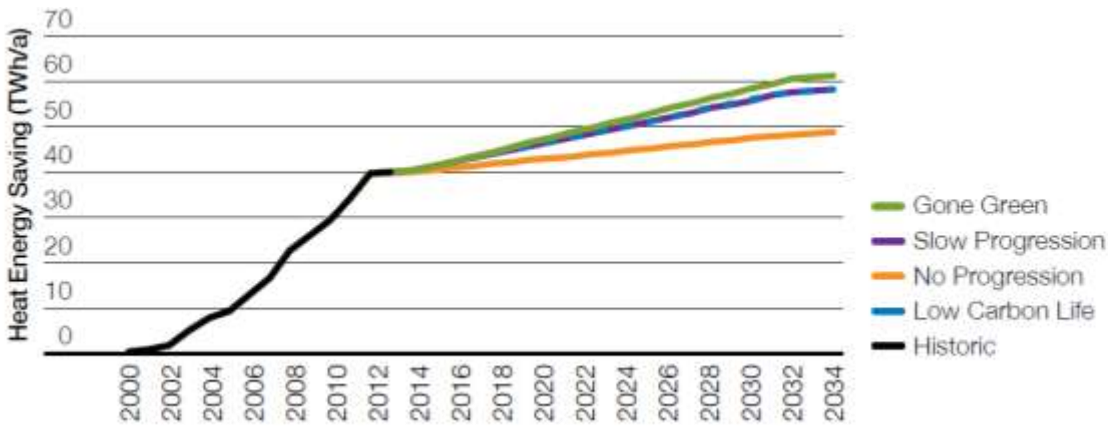


Figure 8: Total residential insulation savings by scenario (National Grid 2014)

C.1.3 UKERC Phase 2 Scenario

Under this scenario service and residential heat consumption reduces to 469TWh by 2030, constituting a fall of approximately 31% on 2013 levels. This is achieved as a result of demand reduction across both sectors, although the largest proportional demand reduction is seen across the service sector (Figure 9 and Figure 10). This is based on a variety of assumptions, for example the Renewable Energy Directive (RED) target for renewable heat being set at 12 % by 2020, a reduction of hurdle rates in the residential sector from 15 to 5 % and annual deployment constraints relaxed by 20%.

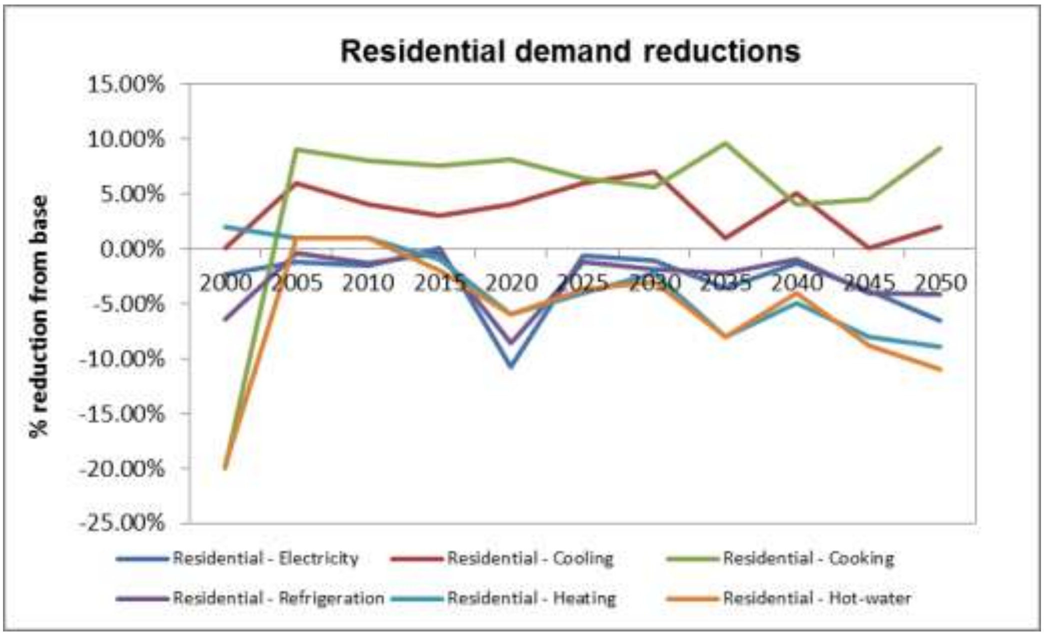


Figure 9: Residential demand reductions from baseline (Ekins et al. 2013)

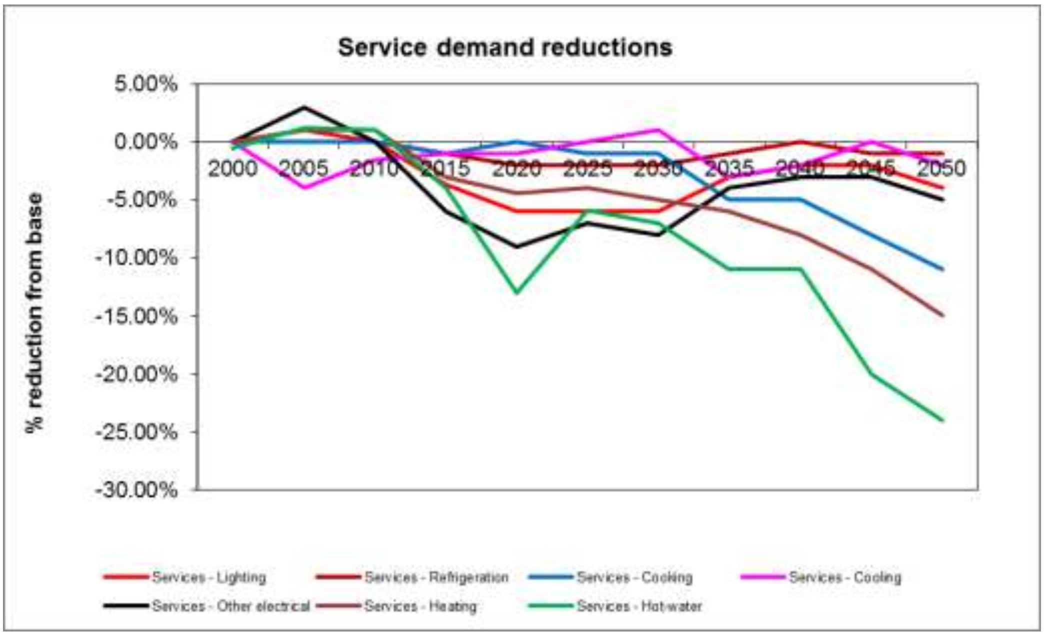


Figure 10: Commercial demand reductions from baseline (Ekins et al. 2013)

The heat mix also changes dramatically during this period. Similar to the other scenarios, a dramatic fall in gas consumption of nearly 50% is seen, falling from 461TWh in 2013 to approximately 243TWh by 2030. Additionally, there is a steady shift towards condensing gas boilers during this period until 2025 when levels of non-condensing increase once more. This is not explained within the modelling.

Whilst gas continues to dominate we find that the remaining half of the UK's 2030 heat supply mix undergoes major change (Figure 11). Like the other scenarios we see a dramatic increase in heat pump deployment, contributing 57TWh of renewable heat in 2030 and accounting for 12% of heat supply[10]. To a lesser extent there is an increase in both district heating and solar thermal, the former growing to 10% of heat consumption and the latter 8%. Both heat pumps and solar thermal see growth from 2015 onwards, whilst district heating grows post-2020. Importantly, whilst some limited district heating already exists in the UK, both heat pumps and solar thermal markets are very small at present. These alternative heating technologies not only eat into the share of gas but also oil and solid/wood fuel, whilst electrical heat remains fairly constant.

[10] This assumes an average COP of 3.1 during the period up to 2030. This based on calculations used by the UKERC team

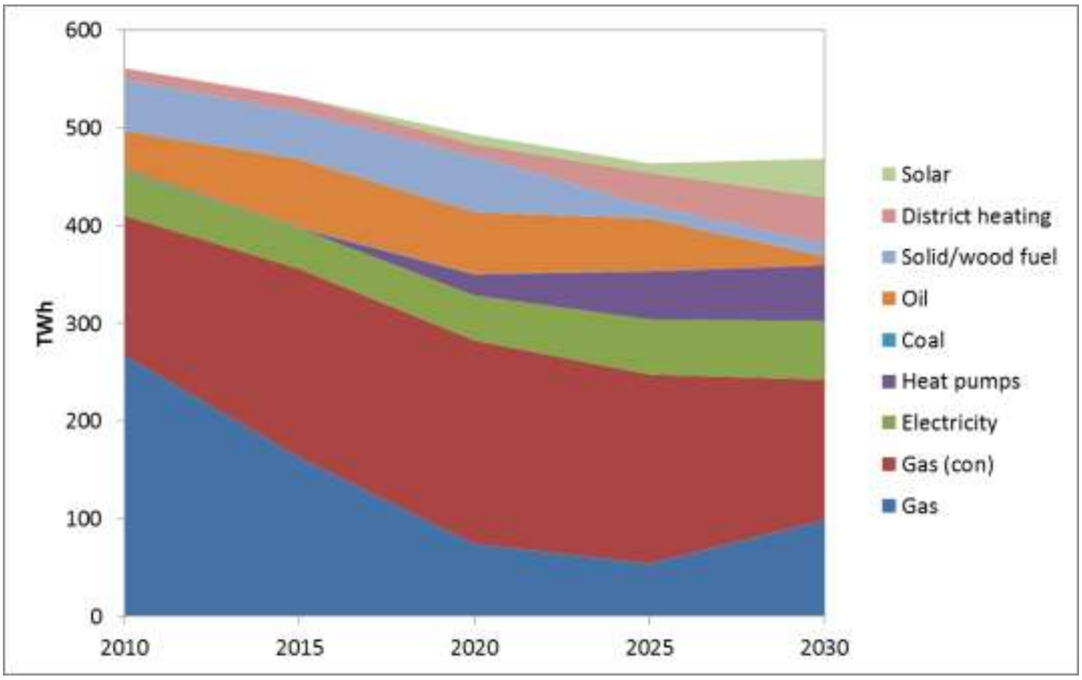


Figure 11: Service and residential sector heat demand for the UKERC Low Carbon scenario (Ekins et al. 2013)

C.1.4 DECC-Redpoint core run scenario

Under this scenario heat consumption from the building sector accounts for 412TWh, a 31% reduction on 2013 levels. We address the residential and non-residential sectors in turn.

C.1.4.1 Residential sector

The RESOM core run shows a similar picture for the domestic sector to that presented in DECC's Carbon Plan, with natural gas remaining the main fuel used in domestic buildings until the 2030s, but reducing thereafter (DECC 2013d; Redpoint 2013). However, unlike the previous DECC modelling and the other scenarios we are examining, the RESOM run reserves an important role for hybrid systems, especially gas boilers used in conjunction with heat pumps. These are adopted relatively quickly, with stand-alone condensing gas boilers being completely replaced by 2030. Initially hybrids generate most of their heat from the gas boiler, supplemented by a small heat pump running at night to take advantage of cheaper off peak electricity. Heat pumps eventually provide the majority of the baseload heat, however the hybrid system means that gas still provides the majority of the heat supply buildings on extreme cold winter days (i.e. 1-in- 20). Interestingly, cooking is not decarbonised in the scenario because whilst it could be electrified, the peaks in demand for cooking coincide with the wider system peak entailing balancing issues and costs.

Whilst heat pumps play the most important role, the scenario reserves a substantial role for heat networks which grow rapidly by 2030 to provide approximately 33TWh/yr of heat (Figure 12). The majority of district heat is supplied by gas sources (approx. 25TWh/yr) through large scale CHP, but complemented with around 5TWh/yr heat from biomass and 3TWh/yr from large-scale marine heat pumps. The growth in hybrid systems, heat pumps and district heating phases out gas boilers entirely by 2030, as well as electric and oil heating.

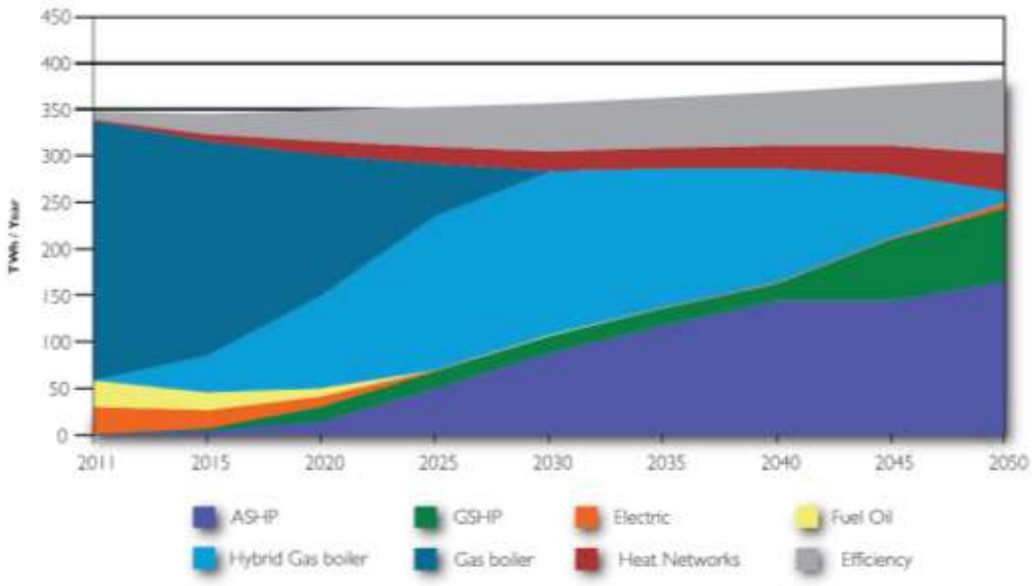


Figure 12: Domestic space heat and hot water output by technology[11] (DECC 2013d)

As Figure 12 illustrates efficiency gains in the residential sector will account for approximately a 50TWh/yr reduction in heat consumption, meaning that demand will fall to approximately 315TWh However, the assumptions underlying this reduction are not obvious from the analysis.

C.1.4.2 Non-residential sector

"The non-domestic buildings show a similar pattern to domestic buildings, with the majority of heat coming from heat pumps by 2050. Gas boilers' share of the heating supply declines sharply between now and 2025, but continues to decline slowly from then on before falling to near zero by 2050. However, gas is still used almost exclusively as a back-up on the peak 1-in-20 cold winter day" (Redpoint 2013 p.24). Similarly we also find that electricity for direct resistive and cooking is phased out almost entirely by 2025 shifting towards gas. We also see a similar growth of heat networks to provide 7% of the heat by 2030 (excluding heat for cooking), focused primarily on urban areas. However, unlike the residential sector the scenario does not see a role for hybrid systems.

[11] Note that the heat generated by an ASHP and GSHP used as part of a hybrid systems is not identified separately in the chart.

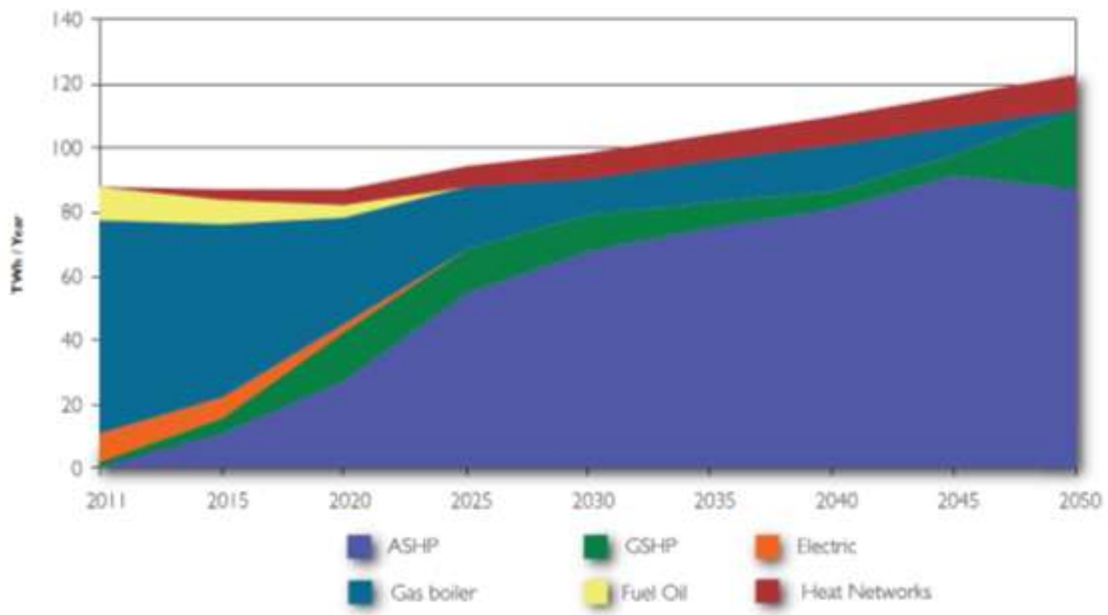


Figure 13: Non-domestic space heat output by technology (DECC 2013d)

C.2 Comparison of scenarios

This section compares the key outputs of the five different scenarios to highlight areas of consensus and convergence versus areas of contestation and divergence.

C.2.1 High-level comparison of scenarios

Table 4: Key indicators for the 2030 heat sector

	2013 baseline	CCC (2014)	DECC-Redpoint (2013)	UKERC2 (2011)	National Grid FES (2014)	
		Updated Abatement (2030)	*RESOM core (2030)*	*Low Carbon (2030)*	*Low Carbon Life (2030)*	*Gone Green (2030)*
Emissions ($MtCO_2$)*	91	64	50**	65	N/A	N/A
Total heat output (TWh)	598	435	412	469	N/A	439

* - Direct emissions

** - excludes CHP emissions

C.2.2 Areas of consensus and convergence

Reflecting on the comparison of the different scenarios for the UK heat sector in 2030 a number of areas of convergence across the comparator scenarios are identified:

- Heat consumption falls by approximately 20-30% across the scenarios by 2030 underlining the important role demand reduction technologies play. Attributed mainly to insulation (loft, cavity and solid wall) of existing stock, the replacement of inefficient boilers and the construction of highly efficient new buildings.
- Remaining emissions reductions are achieved by moving away from gas. Low carbon heating technology deployment 'ramps up'post-2020, however there is still substantial deployment of some technologies pre-2020.
- Gas still expected to be a major contributor in 2030, whether through stand-alone gas boilers or via hybrid gas heat pumps and gas-fired district heating
- Heat pumps are central to decarbonisation with district heating also playing an important role. There is less of a role for small-scale, non-electrically driven technologies such as solar thermal, biomass boilers, biogas and hydrogen.
- Decarbonisation is achieved across both residential and non-residential sectors

C.2.3 Areas of contestation and divergence

- *The Role of Gas:* Gas is expected to still play a pivotal role in UK heat supply in 2030. However, there is disagreement on whether this gas will be used in stand-alone conventional boilers or hybrid heat pumps and district heating networks.
- *Deployment of Heat Pumps:* There are uncertainties about the feasibility of deploying millions of heat pumps by 2030, dependant on installation costs, overall economics and expected lifetimes. Issues with the strain heat pumps would place on distribution networks and generation capacity also create uncertainties on deployment levels, as do domestic insulation levels and the suitability of existing central heating systems.
- *Role of Heat Supply Technologies*: There is significant uncertainty on the deployment levels of other low-carbon heating technologies, with district heating, solar thermal and hybrid heating technologies having different estimates for the extent of deployment, if they are deployed at all. Uncertainties on how these technologies will interact with each other are also present.
- *Energy Efficiency of the UK's Housing Stock:* There are uncertainties surrounding the introduction and extent of new building regulations for low and zero carbon houses, as well as the amount of solid wall insulation which will be installed by 2030.
- *Consumer Rationality:* Due to the necessity of these changes being undertaken by individual owner-occupiers, landlords and other small actors compared with a few larger actors in the supply sectors, there is considerable uncertainty as to whether the models for deployment, following rational economics, will be accurate.

C.2.3.1 Role of gas

All of the scenarios still see an important role for gas by 2030, generally accounting for at least half of building heat supply. However there is some contestation about whether the vast majority of gas is consumed via stand-alone boilers (see National Grid and UKERC scenarios) or via hybrid boiler-heat pumps and district heat networks (see DECC-Redpoint scenario), with gas boilers phased out by 2030. Consequently, whilst gas is expected to still play a pivotal role in the UK heat sector by 2030 there is some disagreement across the scenarios as to which technologies will be used to convert it into heat.

C.2.3.2 Deployment of heat pumps

Most of the scenarios envisage a central role for heat pumps by 2030, with renewable heat from these devices accounting for approximately 9-12% of total heat supply[12]. However, there is some uncertainty about the feasibility of these ambitious deployment levels. The CCC report emphasises that residential heat pumps may not reach 4 million by 2030, instead reaching 1 million as late as 2025 and climbing rapidly to 2.5 million by 2030, resulting in 24 Mt CO_2 less abatement between 2023 and 2027 (CCC 2013c). This is supported by the National Grid's *Low Carbon Life* scenario that sees only 600,000 deployed by 2030 explained largely by a reduced emphasis on supporting energy policies from government. This is compared to the 5.6 million heat pumps included in the *Gone Green* scenario.

The CCC highlights that the exact levels of deployment will very much depend on the capital and operating costs of heat pumps, ongoing improvements in heat pump performance and their long-term durability, issues that were subject to a report from Frontier Economics and Element Energy (2013). However, a wide range of other barriers that are not explicitly dealt with in the modelling may pose a real challenge to realising these ambitious levels of heat pumps deployment. The scenarios typically prefer electrical heat pumps and so one of the biggest issues relates to the additional burden large-scale heat pump deployment will place on the UK's grid (National Grid 2014). Eyre and Baruah (2015) explain that by 2050 'meeting peak heating demand with heat pumps alone would need approximately 40GW of additional electricity generation capacity, much of it low carbon, at an investment cost of approximately £70 billion' (p.12). Another study from Hawkes et al. (2011) presents similar findings where, considering only deployment in highly-insulated houses heat pumps result in a 33GWe increment to peak system demand in the worst-case scenario. This is roughly 40% of current power generation capacity. Naturally, this dramatic increase to peak electricity demand has implications not only for power generation capacity but also electricity grid reinforcement. One potential solution is to install short-term heat storage technologies alongside heat pumps to shift these peaks in electricity demand (Watson et al. 2014). Alternatively, some of the burden could be shifted back to the gas grid by installing gas-fired absorption heat pumps although these represent a generally less mature technology, with few products on the UK market at present (CCC 2013c).

Another grid related issue is that the carbon abatement of electrically driven heat pumps is highly dependent on the carbon intensity of the UK's national grid (Carbon Connect 2014). Should the UK fail to significantly decarbonise its power sector by 2030, abatement from heat pumps will be dramatically reduced as the electricity used to run them carries a high carbon-intensity. Consequently, the move to low-carbon power generation needs to happen before the deployment of heat pumps, not after.

The efficiency of the UK's housing stock also poses a major barrier to wide-scale heat pump deployment (Watson et al. 2014), one which is poorly represented in the scenarios (Carbon Connect 2014). Almost 20% of England's housing stock was built before 1919 (DCLG 2014) with much of this achieving low levels of energy efficiency considering they were built without today's stringent building regulations and technological advances. Heat pumps do not operate very efficiently in

[12] This is for the CCC, UKERC and NG Gone Green scenarios. DECC-Redpoint modelling do not differentiate between stand-alone heat pumps and hybrid systems

homes with high thermal losses and older homes are typically fitted with gas-fired high temperature central heating systems, which are incompatible with heat pumps due to their low temperature output (Delta Energy 2014). Additionally, heat pumps provide relatively low-temperature heat compared to gas boilers and thus require low-temperature central heating systems, which are not commonplace in the UK (Watson et al. 2014). Finally, space is also an important factor considering that most heat pumps require a hot water storage tank, which not all homes have the necessary room for. Ground-source heat pumps also require sufficient land to lay underground working fluid pipes to transfer ground heat into the home.

Not only should forthcoming modelling work be sensitive to these infrastructural constraints on heat pump deployment but policy makers should be aware that the scale heat pump deployment will rely on both policy to stimulate the construction and retrofitting of low-carbon buildings as much as it is on policies to improve the cost-effectiveness of heat pumps.

C.2.3.3 Role of other heat supply technologies

Whilst the scenarios are fairly unanimous in their view that heat pumps will play a key role in decarbonising the UK's heat sector by 2030, there is much less convergence and certainty about the role that some other technologies will play.

Whilst district heating is included in all the scenarios, its relative role is different. The DECC-AEA, UKERC and CCC scenarios all see an important role for district heating contributing between 30 and 50TWh per annum of heat and accounting for somewhere between 5-10% of heat supply. In contrast the National Grid scenarios see a much less important role for district heating, although exact levels are difficult to quantify as they incorporate industrial heat in their calculations.

This divergence in outlook might be explained in part by the uncertainties surrounding district heat deployment in the UK. Watson et al. (2014) highlight that district heating's currently reliance on gas means that emissions can only fall so far and that it 'is unlikely to help reduce emissions once electricity grid carbon intensity falls below 250 g/kWh' (p.20). A shift to bioenergy is problematic considering that the land that would be required to grow the fuel and there are also competing demands for bioenergy from both power and transport sectors (Watson et al. 2014). Additionally, there are also significant sustainability concerns associated with bioenergy use, which continue to be deliberated (Slade et al. 2010). Finally, there are also major challenges regarding the implementation of district heating including (Watson et al. 2014):

- Very high upfront costs of schemes
- Limited availability of finance to Local Authorities to implement schemes
- Lack of relevant skills and knowledge within many Local Authorities to deliver these
- Public resistance due to switching from conventional systems

There is even less convergence across the scenarios for solar thermal. Whilst the UKERC Low Carbon scenario seeing wide-scale deployment post 2015 and delivering 8% of the UK's heat supply by 2030, none of the other scenarios see a substantial role for solar thermal. One of the major barriers to the deployment of this technology is the need for considerable thermal storage to store heat or a back-up source of heating for night time heat demands or days with little sunshine (DECC 2013d). Even so, heat pumps face a similar challenge and these are preferred by the scenarios on the whole.

There is also a wider discussion around the extent to which different heat supply technologies might be integrated with one another or with electricity micro-generation technologies and storage technologies (both heat and electricity). Whilst some of the scenarios account for some degree of device integration, such as DECC-Redpoint's RESOM core run for heat pumps and gas boilers, most technologies are treated independently in the models. This raises questions about the technical, economic and social feasibility of integrating numerous different building-scale energy technologies together and how this might impact upon heat sector emissions.

Focusing specifically on heat pump-boiler hybrid systems the CCC report explains that they could play a role as transitional technologies in the medium term considering that they are likely to be subject to fewer barriers to installation. However, they also warn that 'assuming a hybrid heat pump involves using a gas boiler to meet around 25% of heat demand during the coldest days of the year, the reduction in abatement from substituting all electric heat pumps in our scenario for hybrids would be within the range bounded our low sensitivity of 2.5 million heat pumps in 2030' (CCC 2013c p.73). Therefore, whilst hybrid systems might enable higher penetration of heat pumps, the abatement potential of heat pumps would reduce if they supplanted electrically driven devices. At present there is a great deal of uncertainty in relation to levels of adoption of hybrid heat pumps.

C.2.3.4 Energy efficiency of the UK's housing stock

All of the scenarios make various assumptions about the efficiency of the UK's building stock in the lead up to 2030, which impact not only the level of heat demand reduction but also the cost-effectiveness of low-carbon heat technologies, especially heat pumps. These are predominantly based around rates of construction, building stock turnover and new-build performance standards. The latter presents one area of major uncertainty in the UK. Whilst the UK government has signalled its intention to 'introduce Zero Carbon Homes regulation in 2016 and similar standards for new non-residential buildings in 2019, current proposals leave a substantial margin of uncertainty as to exactly how energy efficient new homes and buildings will be in practice' (Carbon Connect 2014 p.6). Without stringent low-carbon building regulations being put in place within the next couple of years the UK is unlikely to large-scale roll-out of low-carbon building technologies across new-build before 2030 as developers will be predominantly influenced by market forces, which do not typically favour immature technologies.

There is a strong degree of convergence across the scenarios regarding the importance of cavity, loft and solid wall insulation to raise the energy efficiency of the UK's existing housing stock. However, there is some uncertainty around the exact levels of solid-wall insulation uptake. The CCC scenario sees 3.5 million homes with solid wall insulation by 2030, increasing from around 200,000 today. They do however caveat this by saying that deployment may reach only 1 million by 2022 resulting in fewer than 3.5 million homes with the measure by 2030. This is supported by the National Grid *Gone Green* scenario, which sees only 1 million homes with solid wall insulation and only 440,000 under the *Low Carbon Life* scenario by 2030. This uncertainty is mainly centred around the extent to which the final cost of implementing this measure will fall over the coming years, with the CCC's scenario estimating the average cost of carbon abatement from anywhere between £88 to £2,000/tCO2 for external insulation (CCC 2013c). There is also uncertainty about the appetite amongst homeowners to implement such a potential disruptive efficiency measure, especially considering the high upfront cost, with CCC estimating the cost somewhere between £3,600-8,400 (CCC 2013c).

C.2.3.5 Consumer rationality

Much of the criticism of the cost-optimisation models that generate these scenarios focuses on the fact that they do not endogenously account for the fact that energy consumers do not necessarily behave in a neoclassical economically rational way. Unlike the power sector, decarbonisation of the heat sector will be driven primarily by end-use energy consumers such as householders and commercial landlords and/or tenants, rather than large companies that may operate in a more economical rational way.

This can be corrected for to some extent by imposing exogenous constraints on the model, for instance capping the number of devices installed by 2030 or constraining the rate of their deployment. It has been argued however that 'most analyses give little weight to consumer attitudes' (Carbon Connect 2014 p.6) and do not account for the 'bounded rationality' of consumers, which implies that people make decisions subject to constraints on their attention, resources and ability to process information (Sorrell et al. 2000). In addition, 'non-economic factors' that may affect behaviour include nuisance, disruption and perceptions of utility. Examples might include a consumer not installing loft insulation because of the level of disruption to their home. Another might be that an air source heat pump could offer lower cost means of satisfying a household's heat demand by 2030 but the noise they generate is regarded a nuisance and puts the consumer off purchasing one (Watson et al. 2014).

Consequently, the outputs of these models with regards to the adoption of many end-use efficiency options may need to be treated with a significant degree of caution as they do not fully account for the decision making of energy consumers. In the context of meeting the UK's 4^{th} carbon budget policymaking needs to take account of how these behaviours may jeopardise emissions reductions from the heat sector and the types of policies that may counteract these, which may not be financial mechanisms.

C.3 Summary

The scenarios have a significant number of factors in common:

- *Heat consumption falls* by approximately 20-30% across the scenarios by 2030 underlining the important role demand reduction technologies play. Attributed mainly to insulation (loft, cavity and solid wall) of existing stock, the replacement of inefficient boilers and the construction of highly efficient new buildings.
- *Moving away from gas*. Low carbon heating technology deployment 'ramps up'post-2020, however there is still substantial deployment of some technologies pre-2020. However, gas still expected to be a major contributor in 2030, through stand-alone gas boilers or via hybrid gas heat pumps and gas-fired district heating
- *Heat pumps are central to decarbonisation* with district heating also playing an important role. There is less of a role for small-scale, non-electrically driven technologies such as solar thermal, biomass boilers, biogas and hydrogen.
- Decarbonisation is achieved across both residential and non-residential sectors
- *The Role of Gas:* Gas is expected to still play a pivotal role in UK heat supply in 2030. However, there is disagreement on whether this gas will be used in stand-alone conventional boilers or hybrid heat pumps and district heating networks.

Main areas of contestation or uncertainty

- *Deployment of Heat Pumps:* There are uncertainties about the feasibility of deploying millions of heat pumps by 2030, dependant on installation costs, overall economics and expected lifetimes. Issues with the strain heat pumps would place on distribution networks and generation capacity also create uncertainties on deployment levels, as do domestic insulation levels and the suitability of existing central heating systems.
- *Role of Heat Supply Technologies*: There is significant uncertainty on the deployment levels of other low-carbon heating technologies, with district heating, solar thermal and hybrid heating technologies having different estimates for the extent of deployment, if they are deployed at all. Uncertainties on how these technologies will interact with each other are also present.
- *Energy Efficiency of the UK's Housing Stock:* There are uncertainties surrounding the introduction and extent of new building regulations for low and zero carbon houses, as well as the amount of solid wall insulation which will be installed by 2030.
- *Consumer Rationality:* Due to the necessity of these changes being undertaken by individual owner-occupiers, landlords and other small actors compared with a few larger actors in the supply sectors, there is considerable uncertainty as to whether the models for deployment, following rational economics, will be accurate.

D Scenarios to decarbonise the UK transport sector

D.1 Overview of low-carbon transport sector scenarios

D.1.1 CCC Updated Abatement Scenario

UK transport sector*: *2013 – 2020

The CCC scenario sees emissions from the transport sector reduce to 93MtCO_2 by 2020, a fall of more than 20% on 2011 levels and 25% on 2020 baseline projections. The bulk of the remaining emissions are from road transport, which make up 83 MtCO_2 of emissions in the scenario by 2020, which stood at around 110 MtCO_2 in 2011 (CCC 2013c).

An important part of this reduction will be achieved through improvements to the efficiency of conventional internal combustion engine (ICE) vehicles. It is expected that around 40% of the 25 MtCO2 abatement on the projected baseline emissions for 2020 will be delivered in this way. For example, average new conventional car CO_2 intensity will fall to 110 gCO_2/km by 2020, which stood at 133 gCO2/km in 2012 (CCC 2013c). Alongside efficiency gains in ICE vehicles, it is also expected that the late 2010s will see an acceleration in electric vehicles (EV) uptake (this includes both battery electric (BEV) and plug-in hybrid electric vehicles (PHEV)). By 2020 the scenario sees EVs making up 9% of new car sales and 12% of new van sales. Besides ICE and EVs, it is also expected that there will be a greater penetration of biofuel by 2020, accounting for 8% by energy of transport liquid fuel demand by 2020.

In parallel with reduction from technological efficiency gains, the CCC scenario also sees transport energy consumption fall at the hands of behavioural initiatives. The Smart Choices programme sees a 5% reduction in vehicle-km by 2020 (relative to the baseline), achieved through a shift to other less carbon-intensive modes of transport like walking or cycling. Eco-driving initiatives also play a role, which encourage drivers to engage in techniques to reduce fuel consumption. The scenario assumes that by 2020, 12% of cars drivers and 100% of HGV drivers have been trained in eco-driving, resulting in fuel savings of 3% for cars/vans and 4% for HGVs compared to untrained drivers. It is also assumed that the 70mph speed limit will be more rigorously enforced on motorways and major roads by 2020.

UK transport sector 2020 – 2030

By 2030 transport sector emissions have fallen to 68MtCO_2, a fall of approximately 42% on 2013 levels and 57% on 2030 baseline projections. Again the bulk of these emissions come from road transport.

The period sees further improvements in ICE vehicle efficiency, with average emissions reaching 80 gCO_2/km for cars, vans 120 gCO2/km and HGVs around 600 g CO_2/km, together accounting for 17% of the reduction on baseline projections. However, the period is really characterised by the major deployment of EVs. By 2030 it is assumed that the majority (approx. 60%) of new vans and cars sold are EVs, resulting in deployment of 10.7 million ultra-low-emission cars and 1.9 million ultra-low-emission vans, which account for 31% and 40% of the fleets respectively. It is expected that around 60% of EV car purchases will be PHEVs and 40% BEVs, emphasising the need for an extensive recharging infrastructure. This proliferation is founded on the assumption that battery costs will fall dramatically to \$210/kWh for BEVs and \$425/kWh for PHEVs by 2030. They currently stand at around \$725/kWh and \$1,325/kWh respectively.

The period up to 2030 also sees the deployment of hydrogen vehicles, especially for public transport, with 50% of new buses hydrogen fuelled by 2030. With this dramatic increase in EVs and to a lesser extent hydrogen vehicles by 2030 we find they account for a much larger proportion of abatement than they did in 2020, standing at almost 20% of the reduction on baseline projections[13]. In contrast biofuels do not see any growth during the 2020s with their share of total transport energy consumption remaining constant, reflecting uncertainties around sustainability. Finally, the demand management measures delivered pre-2020 are expected to continue but remain at their 2020 levels, meaning no additional abatement is achieved through these measures during the 2020s. One other abatement measure explicitly mentioned pre-2020 is freight logistics and it is assumed that a combination of modal shift, supply chain rationalisation and better vehicle utilisation would result in a 6.5% feasible reduction in vehicle-km by 2030 relative to baseline projections. Together, it is expected that these measures achieve emissions reductions of around 4.5 $MtCO_2$ by 2030.

Summary of scenario

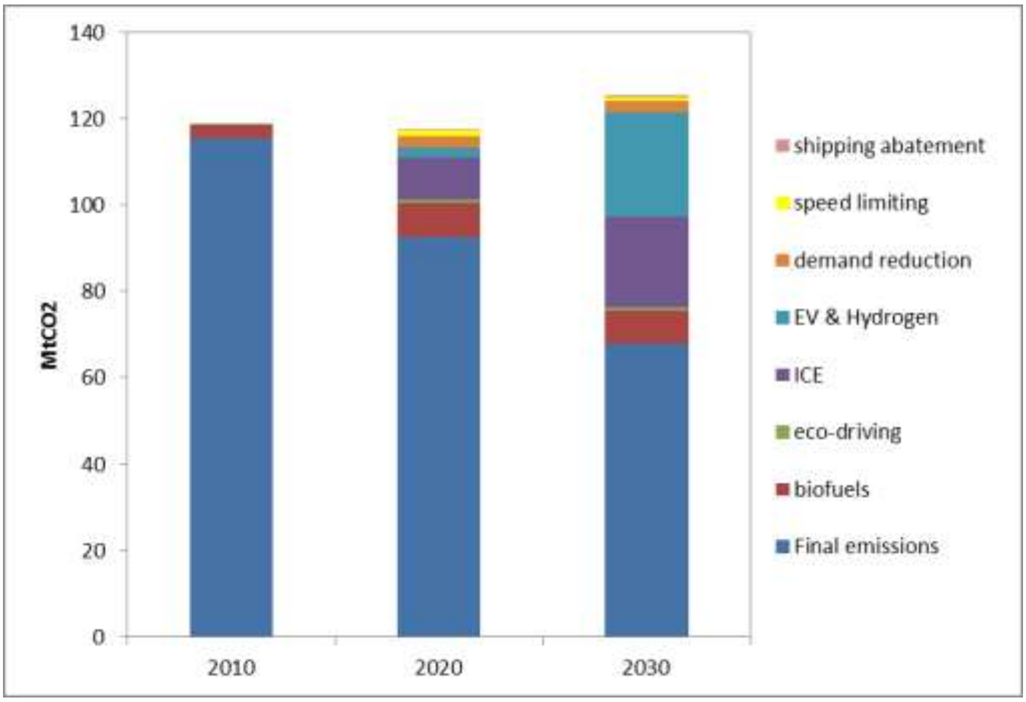


Figure 14: Updated abatement scenario for transport (CCC 2013c)

[13] This value also includes abatement from hydrogen vehicles

Table 5: Key estimates for transport sector decarbonisation 2012 – 2030 (CCC 2013c)

	2013	2020	2030
Total emissions ($MtCO_2$)	117	93	68
Conventional road vehicle efficiency (gCO2/km)	133*	110	80
EVs as % of new sales	2%**	Cars - 9% Vans - 12%	60%

* - value for 2012

** - value taken from the Society of Motor Manufacturers and Traders (SMMT) (2015)

D.1.2 National Grid Future Energy Scenarios

The *Gone Green* and *Low Carbon Life* scenarios are reviewed together, as their outputs are broadly the same. Both scenarios see transport energy demand fall from approximately 620TWh in 2012 to 590TWh and 580TWh in 2030 respectively. By 2030 emissions in *Gone Green* fall to 110 $MTCO_2$ and 84 $MTCO_2$ in the *Low Carbon Life* scenario.

A major focus of the National Grid's scenarios is on the electrification of transport. Both scenarios see a major deployment of electric vehicles, with this attributed to increased government intervention in *Gone Green* and greater disposable income in *Low Carbon Life*, with EVs initially considered a desirable luxury good. By 2020 there are approximately 570,000 EVs (split 29% PEV/71% PHEV/E-REV) growing to 3.19 million EVs by 2030 (split 20% PEV, 80% PHEV/E-REV). This reflects the acceleration in deployment post 2020, as shown in Figure 15. These account for annual demand of 1.4TWh and an Average Cold Spell (ACS) peak demand of 156MW in 2020, with this growing to 8.2TWh and 888MW by 2030. It is expected that due to the current cost of EV batteries and consumer range anxiety, PHEVs and extended range BEVs[14] will achieve higher deployment levels quicker than standard BEVs. Importantly, electrification is restricted to cars and does not happen for larger vehicles in the lead up to 2030.

Despite this rapid growth in electric vehicles they still only account for 5% of all road transport energy in *Low Carbon Life* and 2% in *Gone Green*. It is assumed that the remainder is fuelled by hydrocarbons with no explicit mention is made of other types of fuels, such as bioenergy and hydrogen.

[14] Commonly known as extended-range electric vehicle (E-REV)

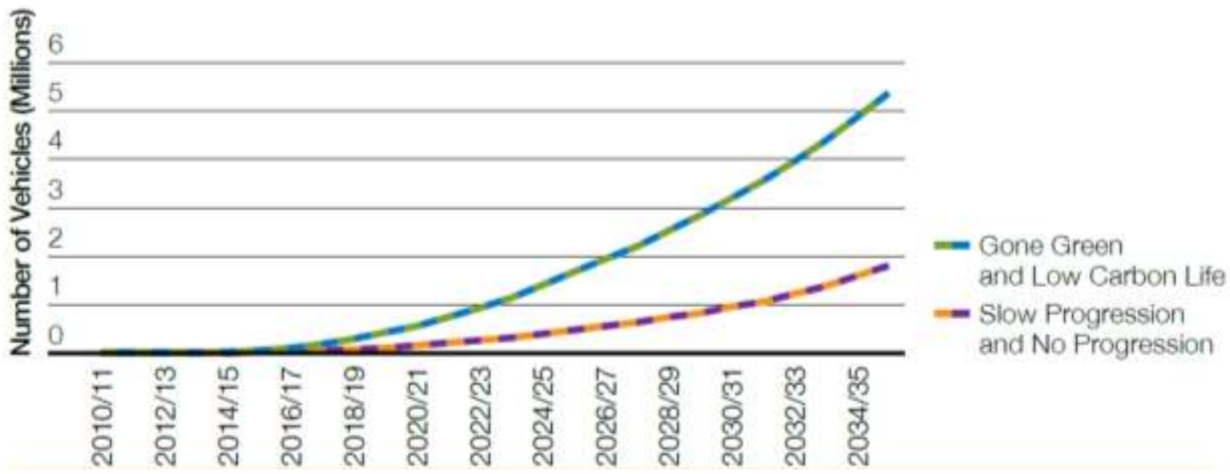


Figure 15: Number of electric vehicles (National Grid 2014)

Focusing on rail, shipping and aviation the following developments unfold:

- Further electrification of the UK rail network, with electricity demand from rail transport growing by 2.5% per year;
- Shipping energy demand remains fairly constant;
- Aviation experiences sustained growth to 2030, after which there is little change.

An overview of transport energy supply is outlined in the figures below (Figure 16 & Figure 17).

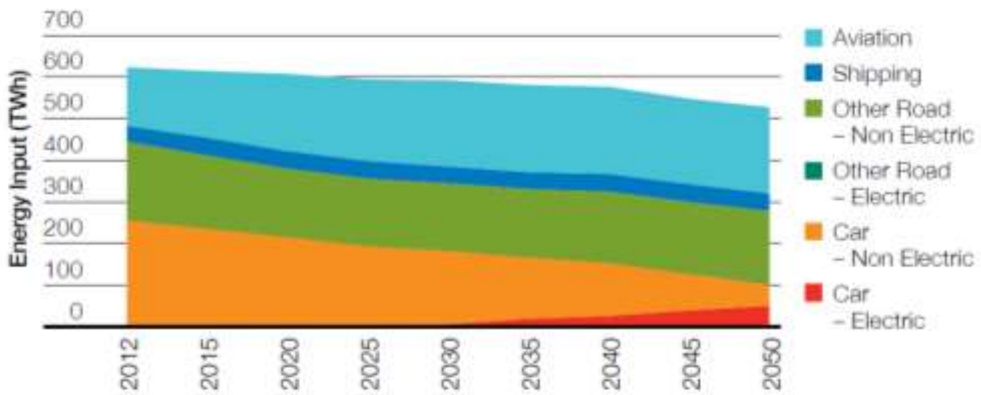


Figure 16: Energy inputs to transport Gone Green (National Grid 2014)

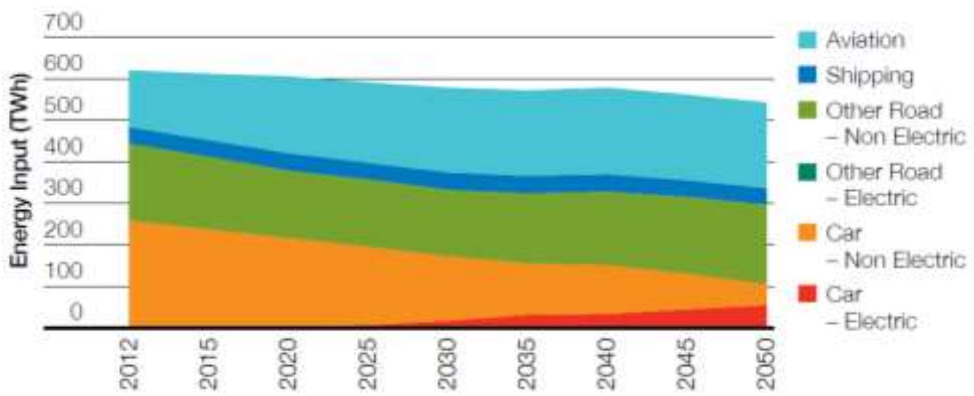


Figure 17: Energy inputs to transport Low Carbon Life (National Grid 2014)

D.1.3 UKERC Phase 2 Scenario

The UKERC *Low Carbon* scenario sees end-use transport emissions reduce to 82MtCO_2, with energy demand falling to 364TWh. In contrast to some of the other scenarios there is much less emphasis on moving away from hydrocarbons and more emphasis on efficiency gains. Consequently, the fuel mix does not dramatically change by 2030, with petrol and diesel still accounting for 82% of total transport fuel demand. However, this share also includes hybrid technologies, which account for a large proportion of cars, as illustrated by Figure 19 & Figure 20. Hydrogen contributes the largest proportion of fuel demand of the alternative fuels, accounting for 9% of fuel demand but its share is zero pre-2025. Electricity grows steadily but slowly throughout the period, reaching 3% of demand by 2030. Moderate growth in bio-fuels is also seen, rising to 5% of demand by 2020 before dropping to 3% by 2030.

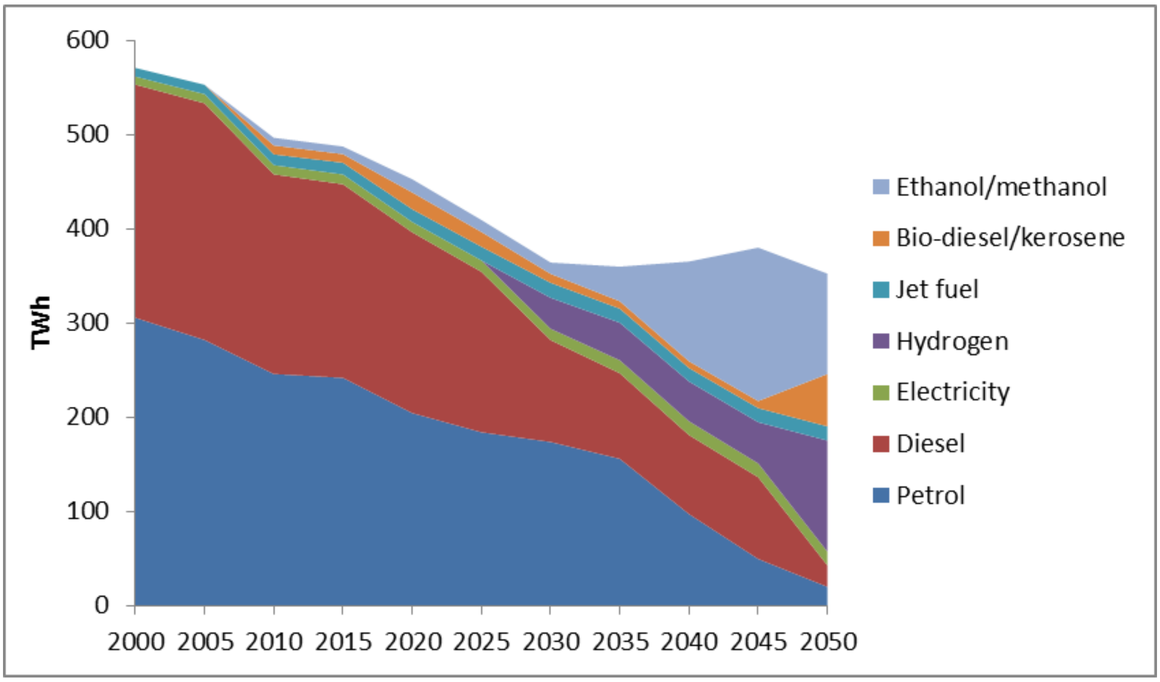


Figure 18: Transport fuel demand (Ekins et al. 2013)

Focusing only on cars illustrates the very important role hybrid vehicles play in the scenario, with all car journeys made in diesel/biodiesel and petrol hybrids by 2030. Their market share grows substantially post-2015. Battery electric vehicles play no part in any of the scenarios due to their relatively high up-front capital costs, which are about a third above the investment costs assumed for a fuel cell powered hydrogen car, as well as the availability of biofuels (Ekins et al. 2013). Neither hydrogen nor E85 biofuel hybrid vehicles play a role before 2030.

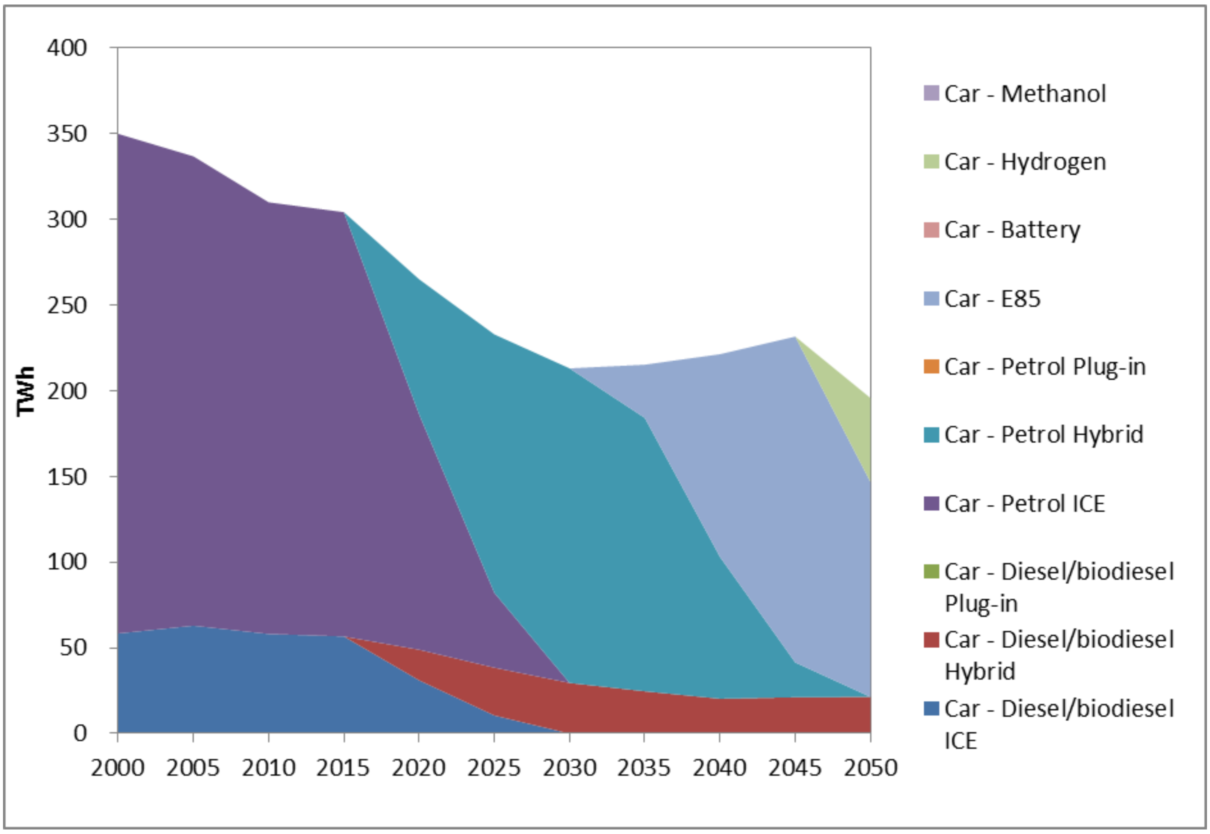


Figure 19: Car transport fuel demand by vehicle type (Ekins et al. 2013)

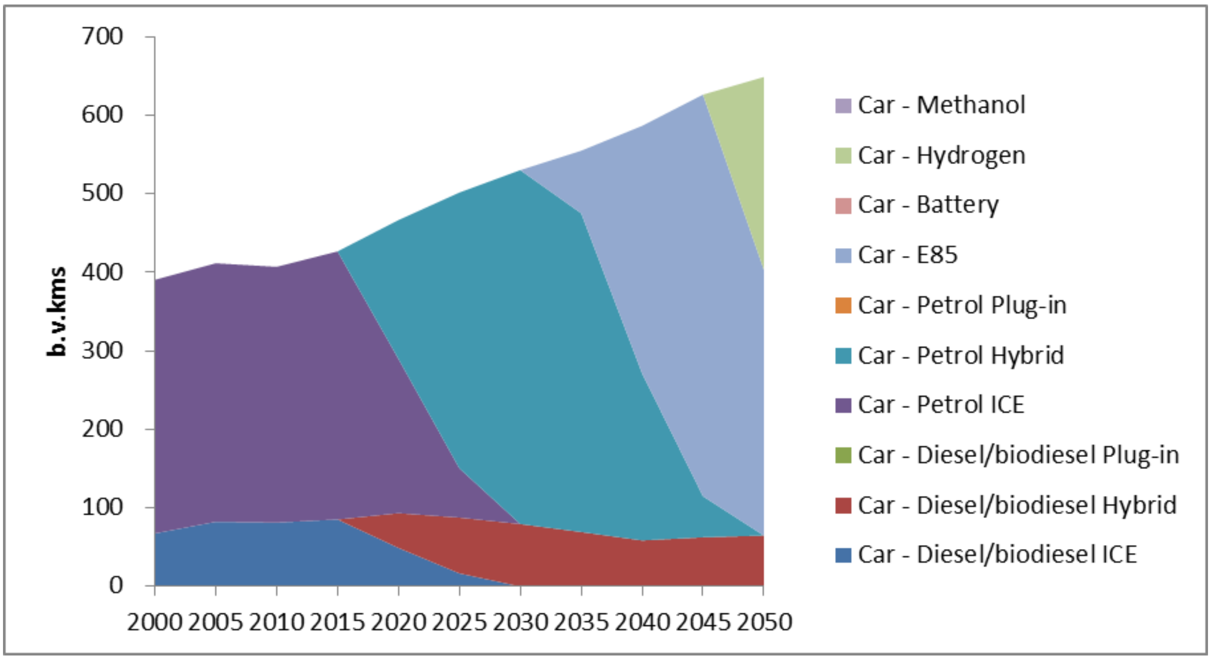


Figure 20: Car transport service demand met by vehicle type (Ekins et al. 2013)

With regard to other road transportation the period sees buses still driven by ICE until 2030 when half of all km travelled are with hydrogen fuelled buses, however these only come online post-2025. In terms of road freight we find that from the early 2010s almost all HGVs are hybrids, which evidently is not the case at the moment. These eventually give way to hydrogen vehicles, which account for 72% of km travelled by 2030. LGVs in contrast are not fuelled by hydrogen under the scenario and unlike HGVs only transition to diesel/biodiesel hybrids from 2025 onwards. Finally, two wheelers remain petrol driven throughout the period. Turning to non-road transport the period sees a greater electrification of rail, whilst shipping remains diesel driven and air travel fuelled by kerosene.

D.1.4 DECC-AEA Carbon Plan Scenario

By 2030 the scenario sees end-use transport sector emissions fall to 63MtCO_2, standing at approximately 70% of the2010 level (Hawkes 2011). This is achieved in large part by vehicle efficiency gains which contribute to a significant fall in transport fuel demand, reaching 317TWh in 2030. Emissions reductions are also achieved from electrification and fuel substitution, although the latter plays a more important role post-2035 when hydrogen and biomass-to-liquids (BtL) attain significant shares. Consequently petrol, diesel and kerosene account for around 77% of total transport fuel demand by 2030. The remaining share is made up of electricity (18%), which grows dramatically throughout the late 2010s and 2020s. Only a small proportion of BtL (2%), ethanol (2%) and hydrogen (1%) (Figure 21).

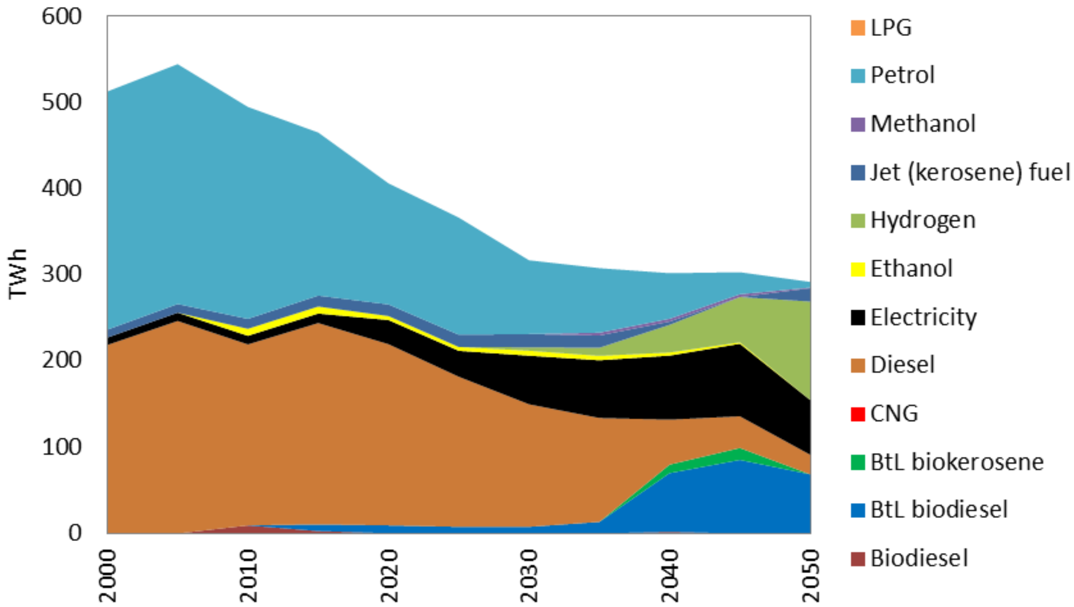


Figure 21: Transport fuel demand by fuel type (Adam Hawkes et al. 2011)

The scale of electrification of transport is much more acute across car transport (Figure 22 & Figure 23). We find that by 2030 no more journeys are made by pure ICE vehicles. Instead journeys are only made by BEVs (44%), hybrid petrol vehicles (41%) and hybrid diesel vehicles (15%). The proportion of electric vehicles in relation to service demand (Figure 23) is much greater than their proportion in terms of fuel demand (Figure 22) on the basis that they are expected to represent a more efficient form of transport than traditional ICE vehicles, meaning they cover more distance (km) per unit of energy (TWh). Hybrid vehicles also take a large share of the LGV and HGV markets, satisfying 100% and 90% of all vehicle kms respectively. Hydrogen accounts for the remaining 10% of HGV journeys.

In contrast we find that hydrocarbons still persist in the other transport sub-sectors, with 74% of bus kms and 100% of two-wheeler kms being fuelled by diesel, whilst 100% of aviation kms fuelled by kerosene. It is also in the aviation sector that we see a significant increase in b.v.kms (+58% on 2010) and demand for kerosene (+34% on 2010) by 2030.

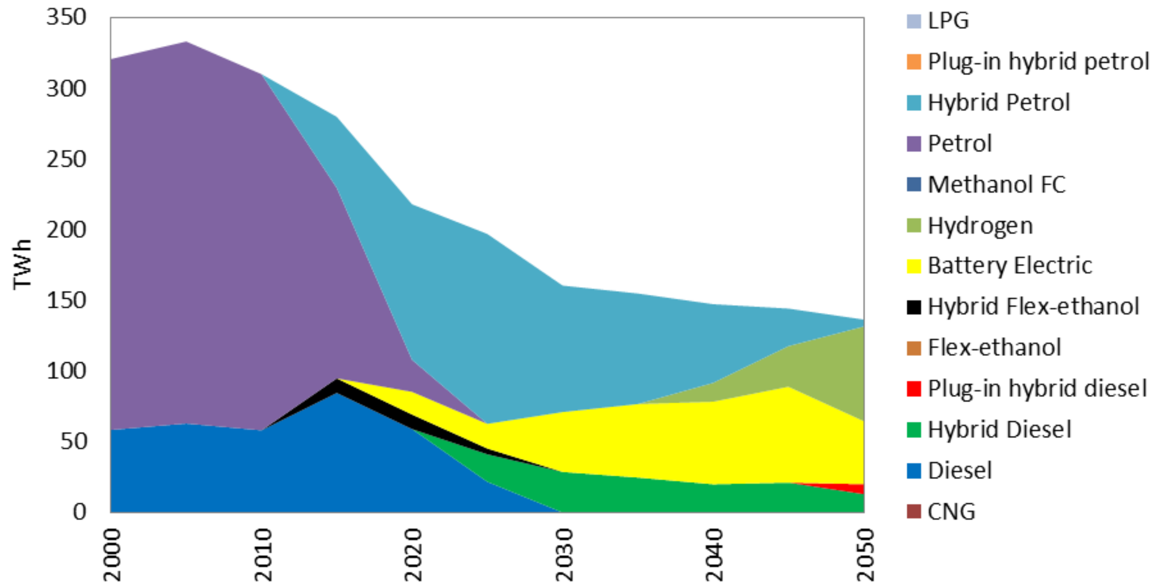


Figure 22: Car transport fuel demand by vehicle type (Adam Hawkes et al. 2011)

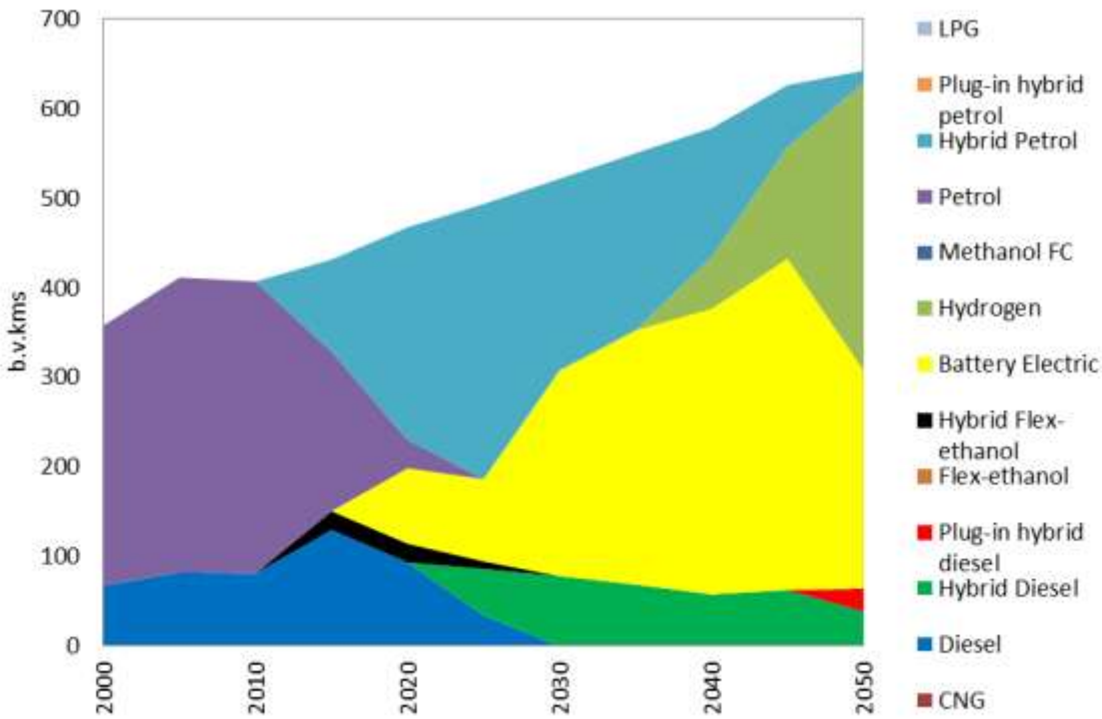


Figure 23: Car transport service demand met by vehicle type (Adam Hawkes et al. 2011)

D.2 Comparison of scenarios

D.2.1 High-level comparison of scenarios

Table 6: Key indicators for the 2030 transport sector

	2013 baseline	CCC (2014)	DECC-AEA (2011)	UKERC2 (2011)	National Grid FES (2014)	
		Updated Abatement (2030)	***DECC-1A-IAB-2A (2030)***	***Low Carbon (2030)***	***Low Carbon Life (2030)***	***Gone Green (2030)***
Emissions ($MtCO_2$)	117	68	63	82	84	110
Total transport energy demand (TWh)	N/A	N/A	317	364	580	590

D.2.2 Areas of consensus and convergence

There are a number of areas of convergence across the comparator scenarios:

- Energy demand falls across the scenarios, although not uniformly
- Share of non-hybrid ICE engines falls dramatically, to zero in some cases (i.e. DECC-AEA, UKERC)
- Electric vehicles (both battery and hybrid) are the dominant alternative fuel
- Hydrogen gains traction pre-2030 in bus and HGV sectors rather than car transport
- A limited role for biofuels (4-8% of total fuel demand)
- Aviation sees an increase in energy demand (not explicit in CCC)

D.2.3 Areas of contestation and divergence

- *Battery vs Hybrid Electric Vehicles:* The relative roles of hybrid vehicles and battery electric vehicles is hotly debated in the scenarios, with one scenario estimating no significant penetration of dedicated (non-hybrid) battery vehicles by 2030, with others suggesting they would play a central role in the 2030 transport mix.
- *Role of Hydrogen:* There is considerable uncertainty over the role hydrogen will play in the future transport system. Some scenarios foresee a major role for hydrogen only after 2030, while others see it providing a more substantive (though still modest) role earlier.
- *Importance of Energy Demand Reduction:* The levels of energy demand in the future transport sector, and the emissions produced, are substantially different between scenarios. Different assumptions are made about vehicle and driver efficiency and modal shifting in the scenarios, which change the final figures in this sector drastically.

D.2.3.1 Fuel prices

The pace and type of transport decarbonisation is very much dependent on fossil fuel prices. The CCC (2013c) report highlights that there is uncertainty around whether fossil fuel prices are likely to, on average, rise or fall during the period up to 2030. Recent history shows sustained oil price rises since 2000 punctuated by sudden price drops coinciding with the financial crisis (c.2008) and a combination of additional/sustained OPEC supply, new North American oil supply and lower energy demand due to weak economic activity (c.2014) (BP 2014; The Economist 2014). Going forward the IEA (2014) takes the view that oil prices are likely to either remain broadly similar or increase significantly in the lead up to 2040, thus reversing the current downward trend. However, there is great uncertainty about the extent to which fuel prices will rise.

Under high fossil fuel prices the CCC work indicates that abatement costs would be lower implying an opportunity to go further in terms of deployment. Additionally, ICE efficiency improvements would also become more cost effective. Should EVs in new car and van sales reach 70% in 2030, and conventional new car efficiency reach 60 g/km on a test cycle basis, emissions from domestic transport would be 4 MtCO2 lower over the fourth carbon budget period" (p.112) versus the core abatement scenario (CCC 2013c).

Should current low prices persist then abatement costs would be greater. The CCC report suggests that EVs may no longer be cost-effective in the 2020s, however their deployment would still be required in order to prepare for a near-zero emissions light vehicle fleet by 2050. They suggest that efficiency improvements, demand-side measures and biofuels would all remain negative or low cost. Consequently, low fuel prices will have an impact on the cost of abatement options such as the deployment of EVs, which could significantly reduce consumer demand for these options unless government implements policy to counteract these falls in cost.

D.2.3.2 Battery vs. hybrid electric vehicles

One important area of divergence between the scenarios is the relative roles for battery electric vehicles versus hybrid electric vehicles by 2030. On the one hand UKERC's *Low Carbon* sees no role for BEVs whatsoever by 2030, relying entirely on hybrids. On the other the DECC-AEA, CCC and National Grid scenarios reserve a central role for BEVs, albeit one that is generally less important than hybrids.

Whilst there seems to be a general consensus that hybrid electric vehicles will be cost-competitive in the lead up to 2030, research has identified a host of barriers that threaten the wide-scale deployment of BEVs. Watson et al. (2014) summarise these as "uncertainties associated with the drivers of consumer decision-making, including the infrastructure, technological and policy uncertainties that impact directly on this process" (p.22) (Figure 24). For instance, both Ekins et al. (2013) and the CCC (2013c) cite high capital costs (e.g. batteries) as a key reason for any potential slow deployment of EVs. In the context of these uncertainties the CCC scenario is sensitive to lower levels of deployment where the share of EVs in new sales reaches only 30% rather than 60% in 2030, which would result in emissions being 14 $MtCO_2$ higher over the fourth carbon budget period. They cite 'constraints on access to overnight charging for tenants, consumer acceptance of EV capabilities may be slower than anticipated, or battery cost reductions may be more gradual than expected' (CCC 2013c p.112) as potential factors. Whilst the CCC scenario assumes that vehicle sales of EVs could ‘catch’ up with the core scenario by 2050, the stock would still contain high-carbon vehicles purchased in the 2030s and early 2040s, thus jeopardising the achievement of the 2050 target.

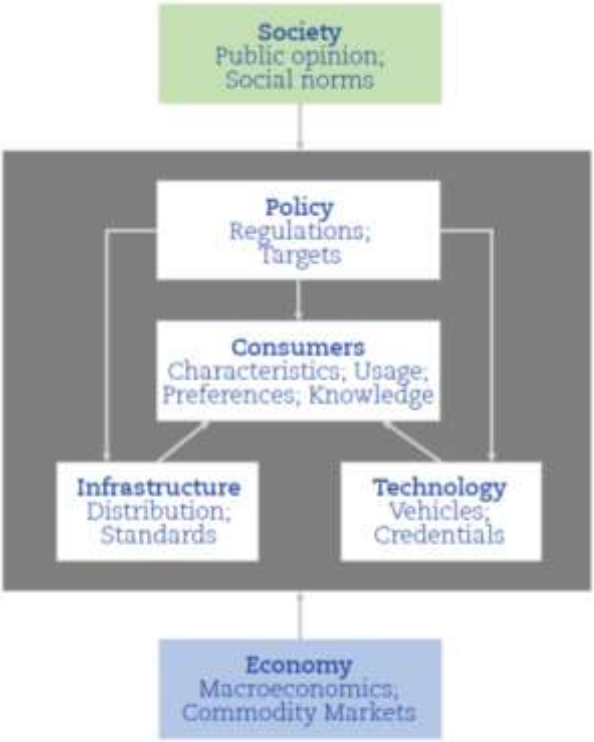


Figure 24: Multiple influences on electric vehicle adoption (Watson et al. 2014)

Government policy could play a key role in avoiding these cost barriers, namely improvements in charging infrastructure (overnight charging and access to public rapid charging), consumer awareness schemes, capital grants for EV purchasing and supporting the development of battery leasing schemes (CCC 2013c). Some schemes are already in place such as the UK government’s Plugged-in Places initiative for installation of EV charge points and electric vehicles grants schemes. Even with such policies simply realising the deployment rates for electric vehicles outlined in the CCC and other low carbon scenarios is extremely ambitious. For example, Watson et al. (2014) illustrate that between 2005 and 2012 annual growth of registrations of Hybrid Electric Vehicles in the UK was at 17.5 per cent. Consequently, under the CCC scenario registration rates of EVs will have to double every year to 2020 (Watson et al. 2014).

D.2.3.3 Role of hydrogen

The different scenarios see different roles for hydrogen by 2030. Whilst some of the scenarios see hydrogen playing a very minor role by 2030 and a more substantial role post-2030 (i.e. DECC-AEA, CCC), the UKERC scenario sees it playing a more important role than purely electric vehicles before 2030, contributing 9% of the total transport supply mix versus 3% in other scenarios.

Similar levels of deployment are outlined by two other recent studies. The first relates to the preliminary phase of UK H2Mobility[15] project (UKH2Mobility 2013). Their findings indicate that through potential early adopters among car and van drivers, it is feasible for uptake of hydrogen vehicles to reach 10% of new sales by 2030. However, this would rely on a refuelling network comprising 65 stations in 2015 growing to 1,150 stations by 2030 with at least one hydrogen refuelling station per local authority district and 'start-up' funding of £420 million (UKH2Mobility 2013). The second is a study undertaken by Element Energy (2013) that 'suggests a 10% market share of HFCVs in 2030 could make an overall share of 60% for ultra-low carbon cars and vans more achievable, though with caveats around vehicle supply and competition for infrastructure support' (CCC 2013c p.100). These conflicting results raise questions about whether the deployment of infrastructure to support hydrogen transportation will be a concern pre-2030 or post-2030.

What is agreed across the scenarios is that it is likely to be larger vehicles such as buses, HGVs and LGVs that will be the first vehicles to adopt hydrogen technology in a low-carbon UK transport sector on the basis that 'battery electric vehicles may be unsuitable (e.g. due to size, weight and cost of the battery required), and if current significant challenges can be overcome (e.g. around hydrogen storage technology)' (CCC 2013c p.101). Whilst niche application is possible, hydrogen fuelled cars are not expected to enjoy wide-scale roll-out before 2040 across the scenarios, although the CCC (2013c) point to potential niche markets amongst car drivers with more demanding duty cycles that longer-range BEVs are unsuitable for and new car buyers without ready access to overnight charging.

D.2.3.4 Importance of energy demand reduction

Whilst all the scenarios acknowledge the importance of energy demand reduction, there is a big difference between the respective falls in transport energy demand. Both the DECC-AEA and UKERC scenarios see dramatic falls in transport energy demand, falling by 36% and 26% respectively on 2010 levels[16]. In contrast the National Grid Gone Green scenario sees a 5% decrease (30TWh) and the Low Carbon Life a 7% decrease on 2012 levels (42TWh). Whilst the CCC does not provide any specific figures on transport energy demand it does emphasise the importance of both vehicle and driver efficiency. Incidentally we find that the non-National Grid scenarios (i.e. those with an emphasis on demand reduction) have lower transport sector emissions. For example, the CCC abatement scenario transport sector emissions are almost half those in the Gone Green scenario (Table 6).

Little information is given about what evidence underpins these divergent views on the role of transport energy demand reduction by 2030 and raises serious questions about the feasibility of this approach in the transport question without further evidence. Examples include improving the efficiency of ICE vehicles, modal shifting and improving the efficiency with which vehicles are driven.

[15] a joint industry and government project to evaluate the potential role for hydrogen in road transport

[16] The DECC-AEA scenario sees a 178TWh fall on 2010 levels by 2030 and the UKERC scenario a 133TWh fall on 2010 levels by 2030. However, transport energy demand starts at a much lower rate (495TWh and 497TWh respectively) compared to the National Grid and UK government statistics which have demand at approx. 620TWh. We assume this is because some transport modes are excluded from the modelling.

D.3 Summary

There are a number of areas of convergence across the scenarios:

- *Transport energy demand falls* across the scenarios, although not uniformly
- *Share of non-hybrid ICE engines falls* dramatically, to zero in some cases (i.e. DECC-AEA, UKERC)
- *Electric vehicles (both battery and hybrid) are the dominant alternative fuel*
- *Hydrogen gains traction pre-2030* in bus and HGV sectors rather than car transport
- *A limited role for biofuels* (4-8% of total fuel demand)

The scenarios also contain the following areas of contestation or uncertainty:

- *Fuel Prices:* The switch to low-carbon transport will depend on the level of fossil fuel prices, and there is significant uncertainty as to the trajectory of fuel prices up to 2030. The effective cost to switch to lower carbon transport will be correspondingly greater as the fuel price trajectory lowers.
- *Battery vs Hybrid Electric Vehicles:* The relative roles of hybrid vehicles and battery electric vehicles is hotly debated in the scenarios, with one scenario estimating no significant penetration of dedicated (non-hybrid) battery vehicles by 2030, with others suggesting they would play a central role in the 2030 transport mix.
- *Role of Hydrogen:* There is considerable uncertainty over the role hydrogen will play in the future transport system. Some scenarios foresee a major role for hydrogen only after 2030, while others see it providing a more substantive (though still modest) role earlier.
- *Importance of Energy Demand Reduction:* The levels of energy demand in the future transport sector, and the emissions produced, are substantially different between scenarios. Different assumptions are made about vehicle and driver efficiency and modal shifting in the scenarios, which change the final figures in this sector drastically.

E Scenarios to decarbonise the UK power sector

E.1 Overview of low-carbon power sector scenarios

E.1.1 CCC updated abatement scenario

UK power sector*: *today - 2020

By 2020 the UK's power sector emissions are expected to have fallen to 64MtCO2, representing a 56% reduction on 2013 levels, with a similar drop in the grid's carbon intensity, falling by 58% on 2012 levels to 211gCO2/kWh**.** Reflecting the Government's latest views in its draft EMR Delivery Plan, the abatement scenario envisages that by 2020 the UK will generate 326TWh of electricity in order to satisfy a final electricity demand of around 300 TWh (CCC 2013c). This indicates that the UK would experience a small drop in electricity generation between 2013 and 2020 of approximately 3%.

Whilst electricity demand is expected to remain fairly constant, the generation mix is expected to change radically in this relatively short space of time. As illustrated by Figure 25 under this scenario the UK's generation mix is dominated by renewables (36%) and unabated gas (35%) generation, with the remainder mostly made up of nuclear (18%) and coal (7%).

To deliver this shift in generation mix the period between today and 2020 sees some important developments. The first is a dramatic fall in unabated coal fired generation compared to 2013 levels (-83%). This is based on number of assumptions including: coal CCS demonstrations would have CO_2 capture applied to all units; more coal capacity to close or face limits on running hours in the face of the Industrial Emissions Directive; the impact of the carbon price; and that lower level of power demand will limit market-pull towards coal generation. Furthermore, it is expected that several coal plants are assumed to convert to run on woody biomass instead of coal by 2020, accounting for approximately 4-6GW of capacity.

The majority of this reduction in coal generation is expected to be offset by a huge increase in renewables generation (+120%), accounted for mainly by the installation of significant amounts of wind during the mid to late 2010s, providing 13 GW of onshore wind and 11 GW of offshore wind by 2020. The report indicates that the availability of sites is not expected to prove an obstacle to growth given that the Crown Estate has granted leases for a total of around 47 GW of capacity. However, there are some concerns that both supply chain capacity and availability of finance could limit roll-out, as well as developer interest more broadly (CCC 2013c).

Another important trend is the 22% increase in unabated gas generation on 2012 levels, suggesting that some new capacity will be added leading up to 2020. The period also sees a small reduction in nuclear (-10%). By 2020 it is expected that approximately 9.5GW of plant capacity will be operational, all of which is in operation now. The CCC assumes that this largely dependent on 3.5 GW of today's nuclear capacity, which were originally scheduled to close by 2020, will have their lifetimes extended by at least five years in line with public announcements (CCC 2013c).

Finally, it is not believed that CCS will be commercially viable by 2020, with only 0.6 GW of demonstration CCS (gas and coal) on-line and generating approximately 5TWh. This is expected to be delivered largely by the projects approved by government in March 2013 as part of its CCS Commercialisation Programme: a gas post-combustion project at Peterhead and a coal oxy-fuel project at Drax. The CCC report explains that:

'*The next step for these projects is to proceed with detailed Front End Engineering Design studies, with a view to take final investment decisions by early 2015. Two projects remain in reserve and several other projects have been put forward for the DECC programme and/or EU funding, some of which may be viable in future, while new projects may also emerge'* (CCC 2013c p.45).

UK power sector 2020 - 2030

By 2030 the scenario sees the power sector's emissions will have fallen to 21 $MtCO_2$, an 87% reduction on 2012 levels and a 67% on the scenario's 2020 levels. This helps to illustrate how the CCC scenario assumes much more rapid decarbonisation of the UK's power sector post-2020 than pre-2020.

This reduction in emissions is impressive in the context of a significant increase in electricity demand associated with the electrification of both heating and transportation, resulting in a 29% increase on 2012 generation levels to 435TWh per annum by 2030. Therefore, the fall in emissions is not achieved by demand reduction but via a significant reduction in the carbon intensity in the UK's power supply falling to approximately 50 gCO_2/kWh, which is 90% lower than the 2012 level and 76% lower than in 2020.

To achieve this reduction in carbon intensity, it is assumed that there is wide-scale investment of low-carbon technologies that are expected to become cost-competitive with fossil fuel technologies or even cheaper in the context of a carbon price. Consequently, renewables account for 46% of the UK's generation mix by 2030 (36% is from wind), with nuclear accounting for 25%, CCS 18%, unabated gas 10% and the remainder made up of coal and other forms of generation. The most significant change to the UK's generation mix during period between 2020 and 2030 is the proliferation of CCS generation, which increases by a factor of 14 to almost 11GW[17] in the 2020s. However, the CCC report indicates that Pöyry have warned of the need for a second phase of pre-commercial deployment before commercial plants can be rolled out in the late 2020s if these levels of generation capacity are to be achieved by 2030 (CCC 2013c).

Another notable change is the 89% increase in nuclear generation, achieved following the addition of between 8 and 16GW of new capacity to the system, the first of which is expected to go live by including EDF's new nuclear plant at Hinkley, four to five 1.3 GW advanced boiling water reactors outlined by the Hitachi's Horizon project and new capacity delivered by the NuGen consortium (CCC 2013c).

The period also sees a 69% increase in renewable generation following an almost doubling of renewable generation capacity from 85GW in 2012 to 140GW in 2030, most of which is wind with approximately 25GW of offshore wind and between 15-25GW of onshore wind in operation.

The other key trend during this period is the 60% fall in unabated gas generation and 95% reduction in unabated coal generation on 2012 levels. It is assumed that this is the result of the mothballing or

[17] Estimate of 5-15GW given in report but an average of CCC's 4 EMR scenarios gives the value of 11GW

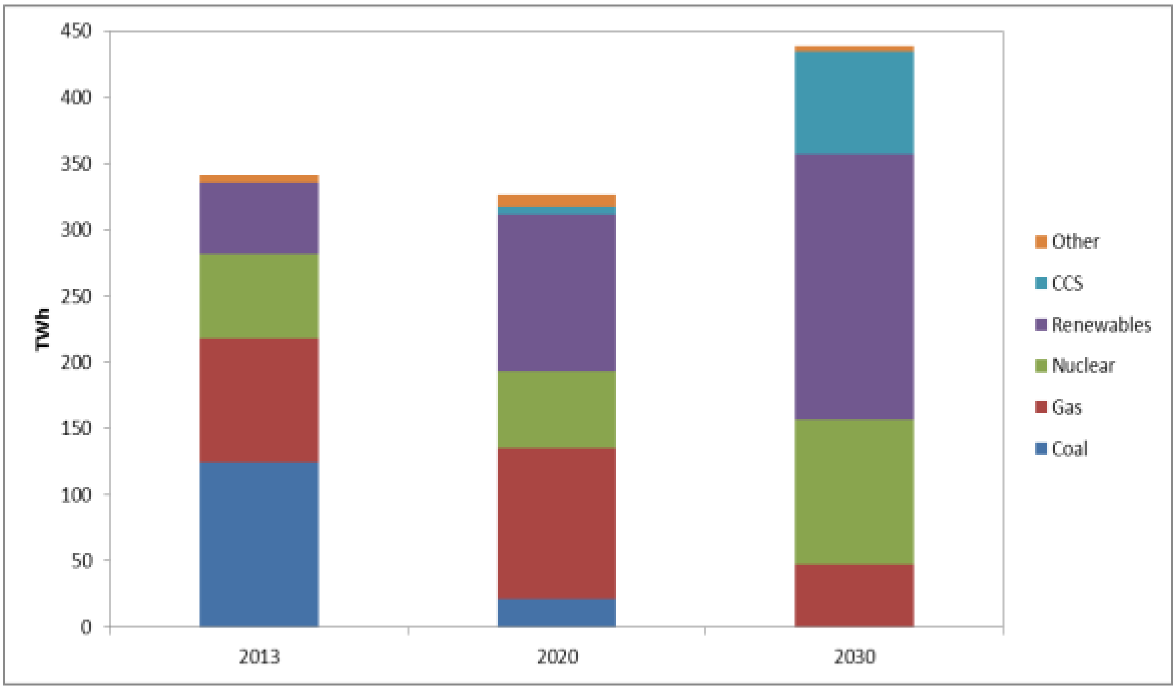
reduced-utilisation of the 38GW of unabated gas and 2GW of unabated coal generation capacity still assumed to be live by 2030.

Summary of scenario

Table 7: Key estimates for power sector decarbonisation 2012 - 2030

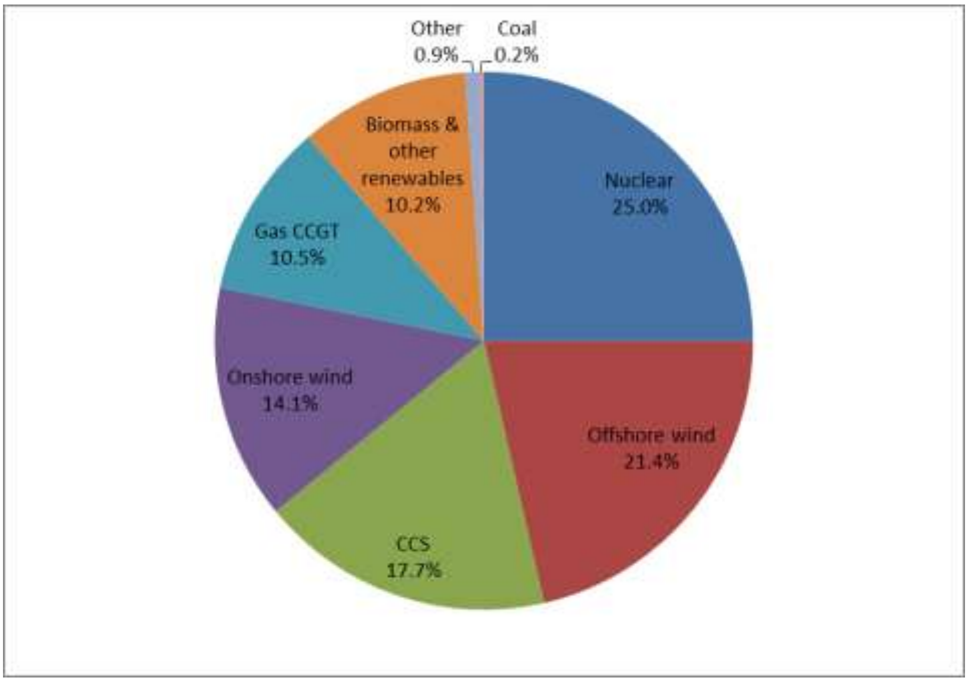
	2013	2020	2030
Total emissions ($MtCO_2$)	145	64	21
Emissions intensity (gCO_2/kWh)	503*	211	50
Total generation capacity (GW)	85	N/A	140
Total power output (TWh)	341	326	435

Note: * 2013 emissions intensity is actually for 2012



Note: The 2030 figures are taken as a proportional average for each of the technology types across the four CCC scenarios developed as part of CCC's *Next steps on Electricity Market Reform* (CCC 2013d) to give values for a central abatement scenario. These scenarios are Ambitious Nuclear, Ambitious Renewables, Ambitious CCS and Higher Energy Efficiency

Figure 25: Abatement scenario electricity generation mix for 2013, 2020 and 2030 (CCC 2013c)



Note: The 2030 figures are taken as a proportional average for each of the technology types across the four CCC scenarios developed as part of CCC's *Next steps on Electricity Market Reform* (CCC 2013d) to give values for a central abatement scenario. These scenarios are Ambitious Nuclear, Ambitious Renewables, Ambitious CCS and Higher Energy Efficiency

Figure 26: CCC's abatement scenario electricity generation mix for 2030 (CCC 2013c)

E.1.2 National Grid Future Energy Scenarios

Low Carbon Life

The scenario sees a major decline in coal generation decline largely as a result of various stations closing due to the Large Combustion Plant Directive (LCPD). This leads to only 2GW of unabated coal fired generation by 2030, a fall from around 20GW on 2013 levels. Consequently, to make up for this reduction in capacity, additional generation is added to the system. Much of this is achieved through the addition of new gas-fired generation capacity, commissioned during the late 2010s and early 2020s. Despite the addition of significant amounts of new gas generation, levels by 2030 are actually lower than today, falling from approximately 31GW in 2013/14 to 25.5GW in 2030 as the closures of old plants outweigh the addition of new ones post 2025.

Besides gas, both nuclear and CCS play a key role by 2030/31 with nuclear accounting for 13GW of capacity and generating 21% of total electricity output and CCS (gas and coal) 10.5GW of capacity and generating 17% of total electricity output. All CCS capacity comes on line from 2021/22 onwards and any new nuclear from 2022/23 onwards.

In terms of renewable generation, both offshore and onshore wind are expected to grow dramatically during the 2010s, with capacity expected to more than double by 2020. Growth levels off post 2025 to reach an installed capacity of 19GW of offshore and 16.5GW of onshore, more than tripling on 2013/14 levels. Together they account for 26.5% of electricity supply.

Solar PV on the other hand is expected to grow even more, with capacity having quadrupled on 2013/14 levels by 2020 to 8.5GW. Growth continues during the 2020s rising to 17GW by 2030, and accounting for approximately 3.5% of electricity supply. Together solar and wind account for almost 30% of electricity supply.

Besides these technologies renewables account for a further 10% of electricity supply, the majority made up of biomass (4.7%) and the remainder (6.4%) made up of other renewables consisting of hydro, pumped storage and marine, anaerobic digestion, landfill gas, sewage, waste and advanced conversion technology. In the scenario biomass capacity almost doubles by 2030, as does the capacity of other renewables.

In the lead up to 2030 Table 8 offers a breakdown of installed capacity levels and Figure 27 provides a breakdown of electricity supply by fuel.

Table 8: Low Carbon Life installed electricity capacity 2013 to 2036 (National Grid 2014)

Installed Capacity Levels

	2013/14 MW	2020/21 MW	2025/26 MW	2030/31 MW	2035/36 MW
Nuclear	9,471	8,981	10,399	12,958	14,091
Coal	20,454	9,797	5,855	1,953	-
Gas	30,760	33,643	32,252	25,659	24,589
CCS	-	-	2,826	10,624	13,624
Onshore Wind	6,727	14,059	16,206	16,610	16,953
Offshore Wind	4,083	9,837	18,697	18,922	18,922
Solar	2,263	8,461	12,520	17,069	22,069

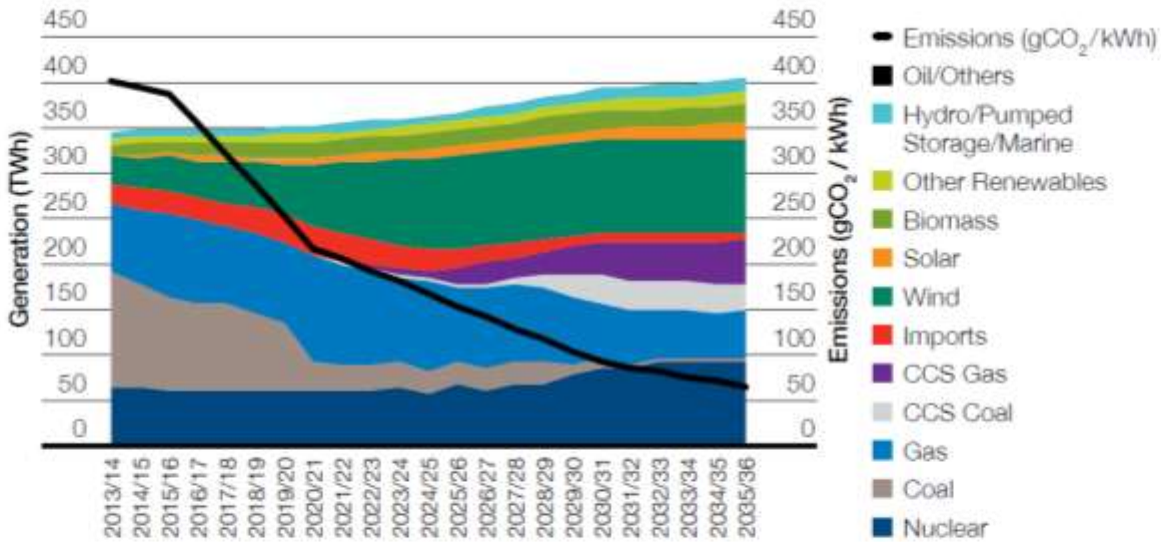


Figure 27: Low Carbon Life electricity generation supply mix 2013 to 2036 (National Grid 2014)

Gone Green

The narrative of Gone Green is very similar to Low Carbon Life apart from a few subtle but important differences. These include:

- A larger capacity of gas fired generation being installed, increasing from 31GW in 2013/14 to 36.5GW by 2025, dropping to 34GW by 2030 as plants begin to close.
- A more ambitious roll-out of wind capacity, reaching 19GW for onshore and 32GW for offshore by 2030, attributed largely to continued growth post-2025.
- A lower deployment of nuclear capacity by 2030 of 9GW, with new capacity coming online only after 2025.
- A much less ambitious roll-out of CCS technology rising to 4.5GW by 2030
- A lower penetration of solar PV, reaching 15.5GW by 2030

In the lead up to 2030 Figure 6 offers a breakdown of installed capacity levels and Figure 28 provides a breakdown of electricity supply by fuel.

Table 9: Gone Green installed electricity capacity 2013 to 2036 (National Grid 2014)

	Installed Capacity Levels				
	2013/14 MW	2020/21 MW	2025/26 MW	2030/31 MW	2035/36 MW
Nuclear	9,471	8,981	6,383	9,022	10,692
Coal	20,454	7,217	3,264	-	-
Gas	30,760	34,085	36,575	33,729	31,904
CCS	-	-	304	4,522	10,964
Onshore Wind	6,727	13,669	18,093	19,149	19,446
Offshore Wind	4,083	12,581	26,587	31,935	35,375
Solar	2,263	7,456	11,394	15,563	20,054

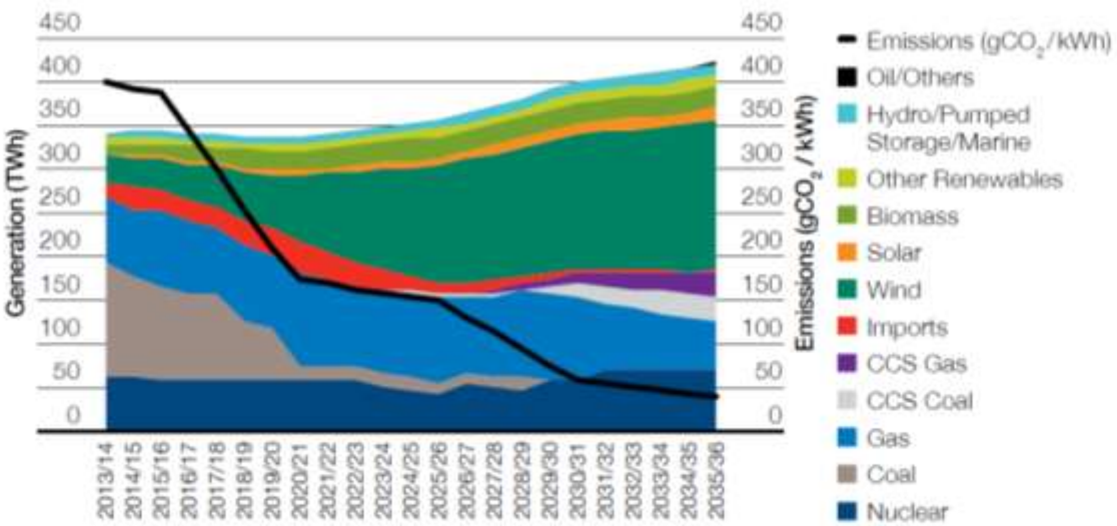


Figure 28: Gone Green electricity generation supply mix 2013 to 2036 (National Grid 2014)

E.1.3 UKERC Phase 2 scenario

In terms of fossil fuel generation, the period up to 2020 is characterised by a fall in unabated coal capacity, dropping to 6GW by 2020, a consolidation of oil capacity, remaining at 1GW, and a significant increase in gas generation, jumping to 33GW. By 2030 all coal and almost all oil capacity is expected to have been decommissioned, whilst gas capacity slowly declines to 29GW. Electricity imports are also expected to double to around 4GW by 2020 and remain at this level until 2030.

In terms of low-carbon generation in the period up to 2020 there is relatively little new low-carbon generation that comes online. Nuclear capacity drops to around 5.5GW as existing plants are decommissioned, however some co-firing CCS and a smaller amount of gas CCS comes online, standing at 2.3GW and 0.4GW respectively. Post 2020 we see new nuclear coming online with capacity almost tripling between 2020 and 2030 to approximately 14GW. Co-firing CCS also experiences major growth, standing at 13GW by 2030.

In terms of renewables the period up to 2020 sees a huge increase in wind generation, rising to almost 20GW, however it is not clear from the scenario materials whether this is offshore or onshore. Growth continues post-2020, albeit at a slower rate, reaching 29GW by 2030. Whilst hydro capacity remains at about 4GW, the only other renewable technology to make a significant contribution is bioenergy, with capacity standing at just above 5GW. Importantly solar PV is not expected to make any contribution by 2030, neither is marine energy.

Figure 29 provides a breakdown of the UK's electricity generation supply mix and Figure 30 the UK's electricity capacity mix between 2010 and 2030.

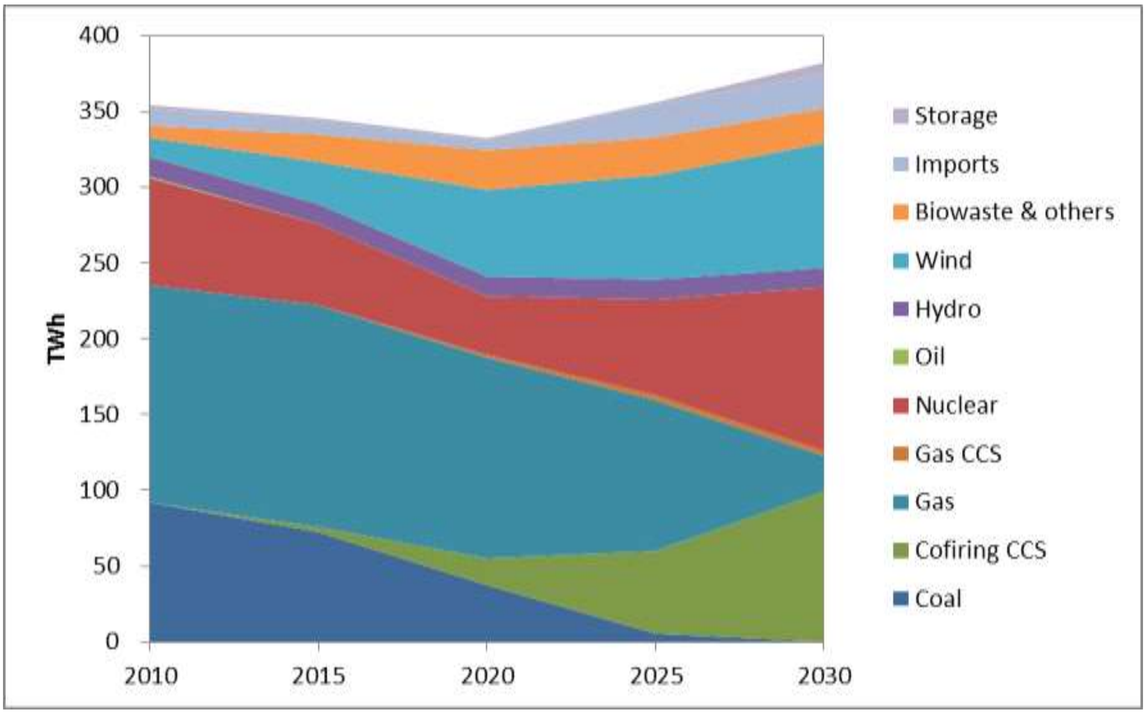


Figure 29: Electricity generation supply mix 2010 – 2030 (Ekins et al. 2013)

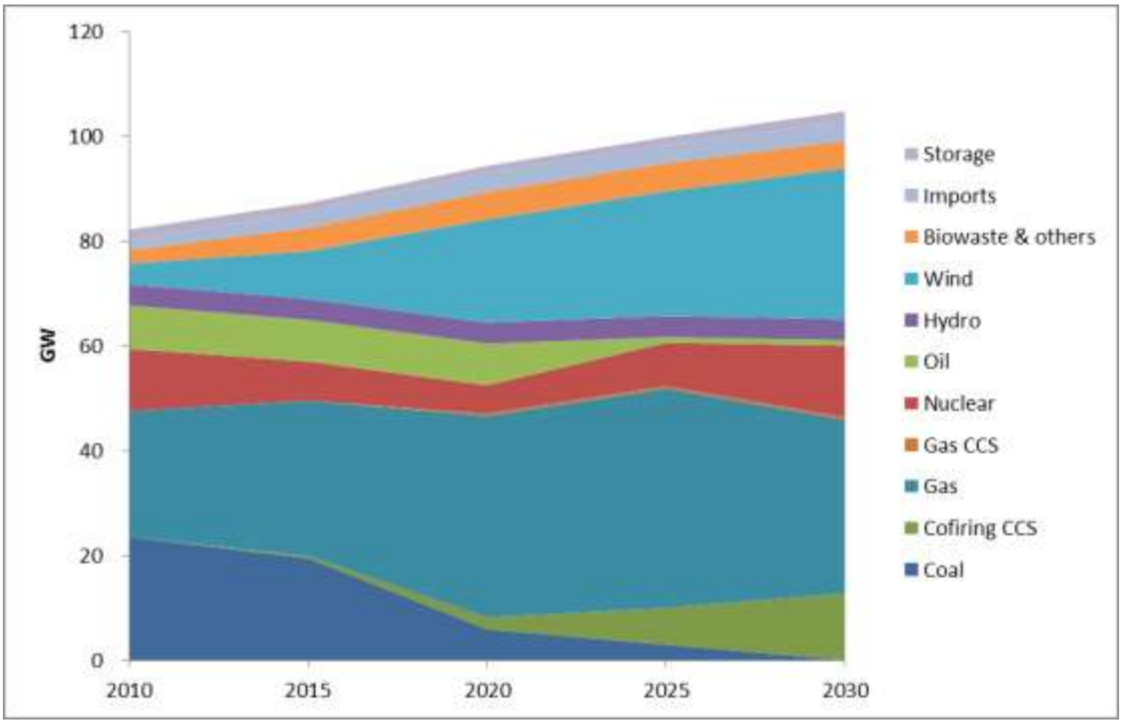


Figure 30: Electricity generation capacity mix 2010 – 2030 (Ekins et al. 2013)

E.1.4 DECC AEA Carbon Plan

This scenario sees a major decrease in unabated coal generation and only a slight decline in unabated gas generation up to 2020. Co-firing, coal and gas CCS coming online in the early 2010s, even despite it not yet being commercially viable. Nuclear generation sees a small fall as some capacity is lost due to decommissioning. In terms of renewables, wind generation sees a significant increase in the lead up to 2020 as capacity reaches almost 30GW. This period also sees an increase in CHP generation, almost doubling to 6GW.

The period between 2020 and 2030 sees many of these same themes continue with a few notable changes. Coal output declines to zero and unabated gas generation falls to 19 TWh, despite 26GW of plant still in operation. This loss of unabated fossil fuel generation is replaced in part by an accelerated roll-out of CCS during the 2020s, increasing from 3.5GW in 2020 to 9GW by 2030. This is also joined by a significant increase in nuclear capacity, as new plants come online, with capacity doubling from 8GW to over 16GW in this period. Whilst wind generation increases at a much slower rate constant during this period, growing to almost 40GW by 2030, the period is marked by a dramatic growth in marine energy, growing from 2.5GW in 2020 to 15GW by 2030.

Figure 31 provides a breakdown of the UK's electricity generation supply mix and Figure 32 the UK's electricity capacity mix between 2010 and 2030.

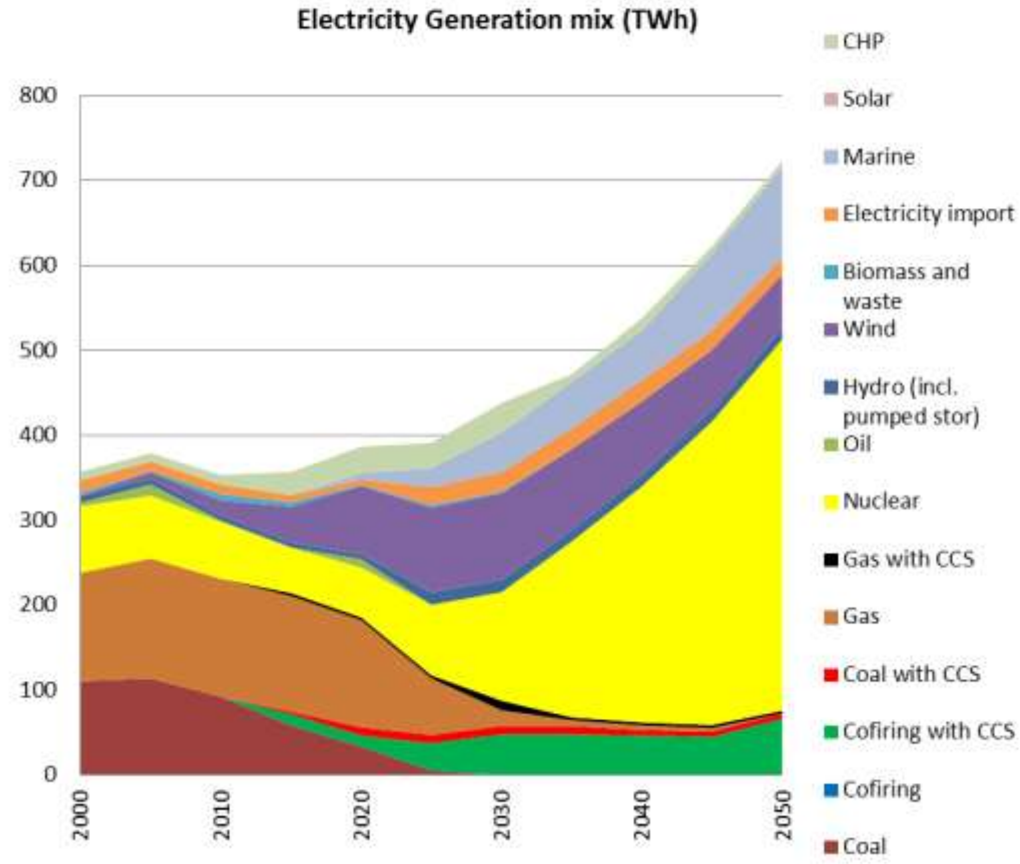


Figure 31: Electricity generation mix 2000 – 2050 for DECC-1A-IAB-2A core run (Adam Hawkes et al. 2011)

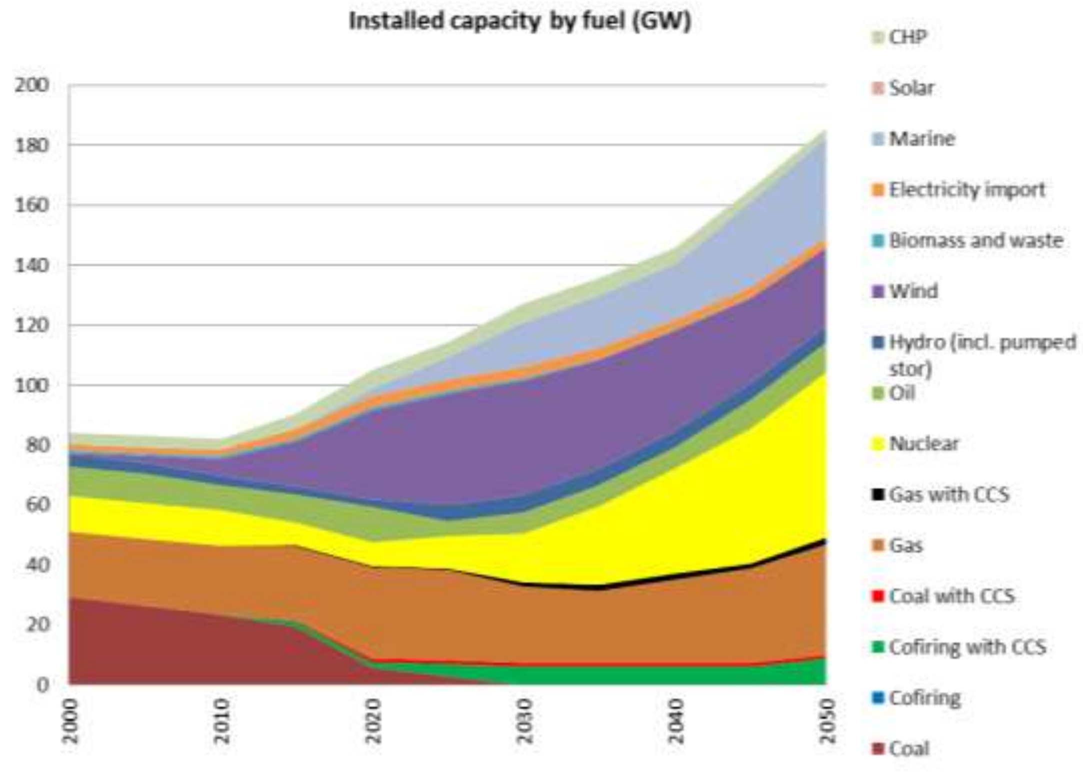


Figure 32: Electricity generation capacity mix 2000 – 2050 for DECC-1A-IAB-2A core run (Adam Hawkes et al. 2011)

E.2 Comparison of scenarios

This section compares the key outputs of the five different scenarios to highlight areas of consensus and convergence versus areas of contestation and divergence.

E.2.1 High-level comparison of scenarios

Table 10: Key indicators for the 2030 power sector

	2013 baseline	CCC (2014)	AEA Carbon Plan (2011)	UKERC2 (2011)	National Grid FES (2014)	
		Updated Abatement	*DECC-1A-IAB-2A*	*Low Carbon*	*Low Carbon Life*	*Gone Green*
Total installed capacity (GW)	85	142	110	105	130	147
Electricity ouput (TWh/annum)	337	435	444	382	403	
Emissions intensity (gCO2/kWh)	500*	50**	90	-3***	57	

* - Approximate value for 2012 quoted in CCC (2013c)

** - CCC also stipulates that an intensity of 100 gCO2/kWh is possible (see Section …)

*** - Negative value due to extensive use of co-firing CCS, which gives negative net emissions

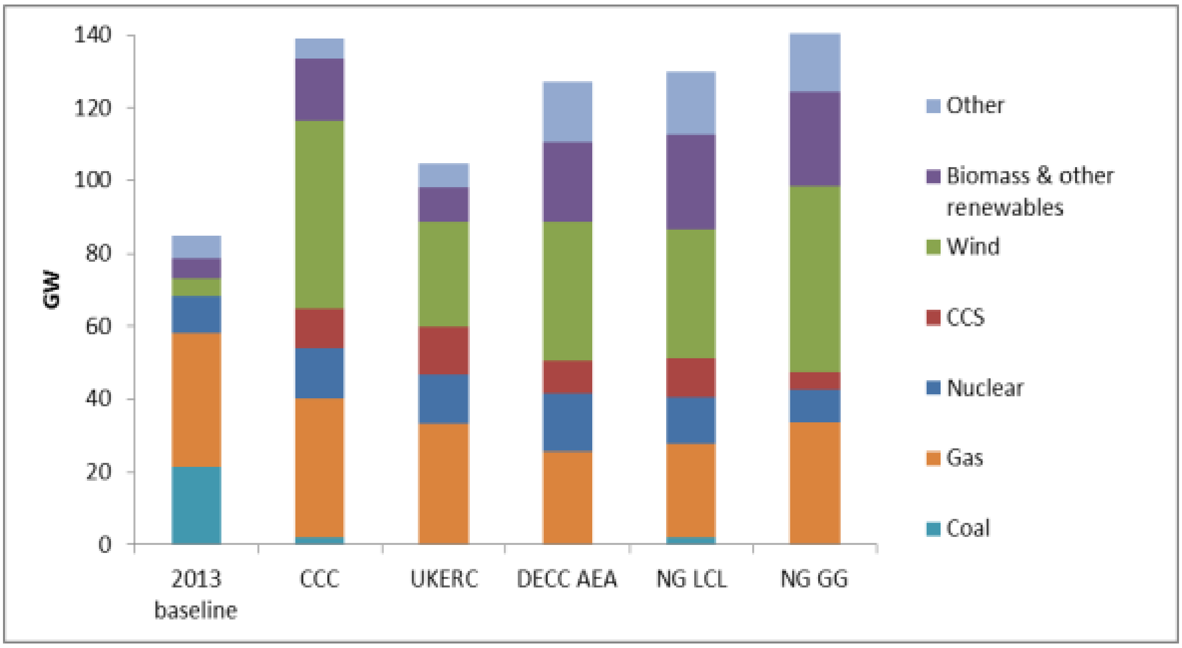


Figure 33: UK electricity capacity across scenarios in 2030

Table 11: UK electricity capacity across scenarios in 2030 (GW)

	2013 baseline	CCC (2014)	UKERC2 (2011)	AEA Carbon Plan (2011)	National Grid FES (2014)	
		Updated Abatement	Low Carbon	DECC-1A-IAB-2A	Low Carbon Life	Gone Green
Coal	22	2	0	0	2	0
Gas	37	38	33	25	26	34
Nuclear	10	14	14	18	13	9
CCS	0	11	13	15	13	5
Wind	5	52	29	30	36	51
Biomass & other renewables	6	17	9	6	26	26
Other	6	5	7	18	10	11
Total	**85**	**139**	**105**	**127**	**130**	**147**

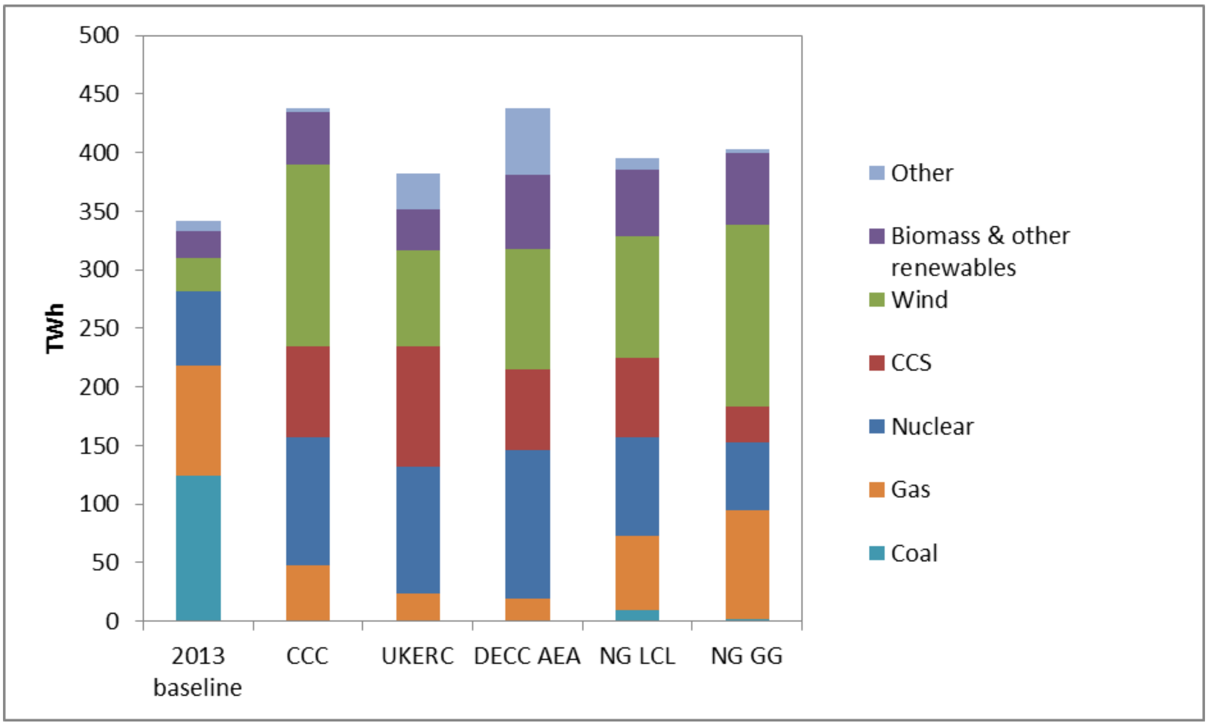


Table 12: UK electricity generation across scenarios in 2030 (TWh)

	2013 baseline	CCC (2014)	UKERC2 (2011)	AEA Carbon Plan (2011)	National Grid FES (2014)	
		Updated Abatement	Low Carbon	DECC-1A	Low Carbon Life	Gone Green
Coal	124	1	0	0	10	2
Gas	94	46	23	19	63	92
Nuclear	64	110	108	128	84	59
CCS	0	77	103	69	67	30
Wind	28	156	82	102	104	156
Biomass & other renewables	23	45	36	63	57	61
Other	8	4	30	58	9	4
Total	**341**	**438**	**382**	**438**	**395**	**403**

E.2.2 Areas of consensus and convergence

- Electricity supply will increase by 2030 (approx. +12-24%) mainly due to growing electrification of both transport and heat
- The CO_2 intensity of power generation falls to less than 100 gCO_2/kWh by 2030
- Unabated coal and oil generation falls dramatically reaching almost zero by 2030
- Unabated gas generation is expected to still play a major role in the UK's electricity supply up to 2030 with approx. 25-40GW online. New capacity additions will also be expected to achieve this level as ageing plants are decommissioned, although exact numbers difficult to determine
- CCS is not expected to be commercially viable until the early 2020s and will account for a modest proportion of capacity by 2030 (approx. 5-15GW)
- Nuclear plays an important role in providing a low-carbon baseline electricity supply with new capacity (at least 8GW) required to come online during the 2020s
- Both new offshore and onshore wind capacity are rolled out extensively in both the late 2010s and early 2020s providing significant capacity by 2030 (approx. 30-50GW)

E.2.3 Areas of contestation and divergence

- *Pace and Timing of Decarbonisation*: There is some uncertainty as to the pace of electricity sector decarbonisation, both within the CCC scenarios and in comparison to the other scenarios. In some scenarios, the UK decarbonises the power sector slower than expected, whereas in others, chiefly the UKERC LC scenario, the power sector actually achieves negative emissions.
- *Renewables - Role of Solar PV and Biomass:* While onshore and offshore wind are central part of all scenarios, the role of solar PV and biomass is more uncertain. The dramatic fall in PV costs over the last few years, after some scenarios were modelled, means that solar PV is underrepresented in some scenarios. There is some divergence around the role of biomass as well.

- *Levelised Cost of Low-carbon Technologies:* There is considerable uncertainty as to the levelised cost of many low-carbon generation sources, as these technologies have not been rolled out before at scale. There are factors, both predictable and unknown, which may affect the costs of deployment of these technologies, which in turn will affect the speed and economics of decarbonisation.
- *Level of Investment Required to Meet 4th Carbon Budget:* Economic modelling to determine the total investment to meet the budget reveals some uncertainties. While all models suggest at least £200million is needed, some suggest that up to £300 million will be necessary.
- *Fossil Fuels - Role of Unconventional Gas and Coal:* The size of the role that unconventional gas could play in a future energy mix is contested, with uncertainties on economics, recovery rates and public acceptance leading to different estimates. The amount of coal generation still operational by 2030 is also a matter of debate, with some work predicting substantial quantities still existing due to low carbon prices and the need for more backup capacity.

E.2.3.1 Pace and timing of decarbonisation

At a broad level the CCC underlines the possibility that UK may make slower progress towards decarbonising as 'conditions for decarbonisation could be less favourable, making a 50g scenario undesirable or unachievable' (CCC 2013c p.54). This could result in the UK achieving a higher power sector carbon intensity of 100 gCO2/kWh by 2030 instead, increasing emissions by around 65 MtCO2 (3-4%) across the fourth budget period (CCC 2013b) (Figure 34). Whilst this slower pace of progress could mean the UK is still able to meet its 4th carbon budget it would mean that it would need to deliver a faster roll-out of low-carbon and renewable technologies after 2030 to meet it 2050 targets. This would translate into an extra 0.5 GW each year on average compared to a 50g scenario (CCC 2013c).

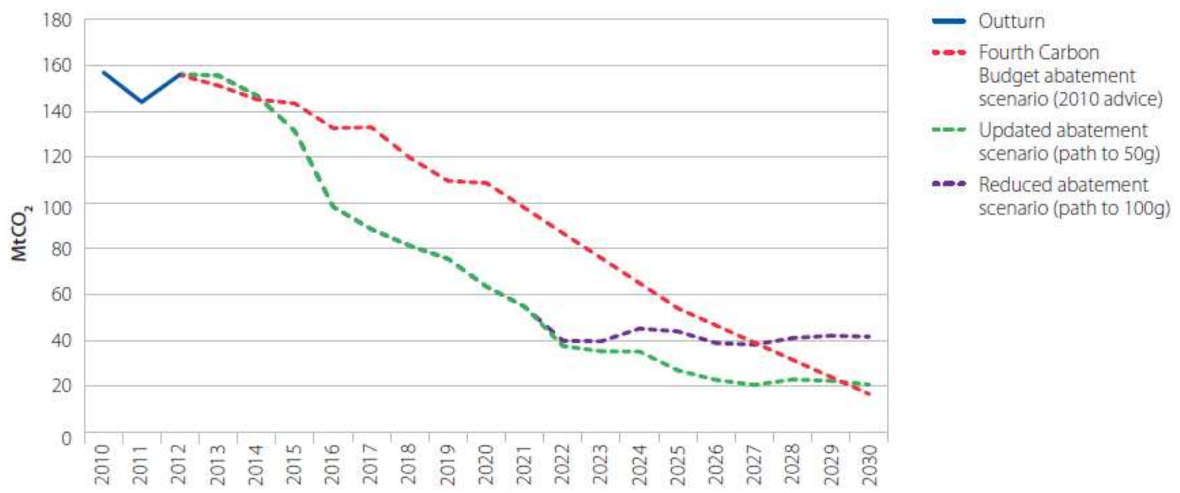


Figure 34: Scenarios for UK power sector emissions (CCC 2013c)

The CCC work attributes such a situation to a variety of developments including:

- Nuclear costs not coming down, or developers are not able to finance projects;
- Failure of CCS to become commercially viable;
- Costs of offshore wind do not fall with deployment;

- Further demand reduction cannot be delivered;
- A risk that coal-fired capacity stays on the system longer than our current assumption; and
- Low gas and/or carbon prices could make unabated gas generation relatively more attractive.

Looking to the other scenarios we find that the *DECC-1A-IAB-2A* core run supports the view that the UK may not reach 62gCO2/kWh by 2030. In contrast however the UKERC *Low Carbon* scenario sees the UK power sector achieving a negative carbon intensity. This means that through wide-scale deployment of biomass with CCS that the power sector actually reduces carbon emissions rather than increase them. Therefore, whilst there is broad agreement that by 2030 the UK's power sector carbon intensity will have to fall by at least 80% on 2012 levels to 100gCO_2/kWh, there is still major uncertainty about whether its carbon intensity will fall significantly further, even to a point where the power sector achieves negative emissions. This therefore raises questions about the pace of the UK's decarbonisation efforts leading up to 2030 and beyond.

E.2.3.2 Levelised cost of low-carbon technologies by 2030

A major area of uncertainty highlighted in the CCC report is the mix of low-carbon energy technologies in operation by 2030. Much of this is attributed to uncertainties around the Levelised Cost of Energy (LCOE) by low-carbon technologies by 2030. Whilst there is a great deal of certainty about the cost per MWh of electricity generated by mature technologies like unabated gas, there is significantly less certainty about the cost of many low-carbon technologies. As illustrated by Figure 35 the estimated range of levelised costs[18] for unabated gas is only £5/MWh (2012 prices), compared to £11/MWh for nuclear, £20/MWh for CCS (gas post combustion), £26/MWh for offshore wind, £33/MWh for onshore wind and £52/MWh for CCS (coal oxy-fuel). In general, the greater the range the less certainty there is about the cost of these technologies in 2030 and thus the role they are likely to play in decarbonising the UK's energy system. Importantly, the upper reaches of each technology's range of levelised costs would put it above the cost of unabated gas by 2030, meaning it is more expensive and potentially less desirable (Figure 35).

[18] This refers to the solid boxes in Figure X and represents the range for high/low capex and central fuel prices (central load factor for wind). Fuel price assumptions consistent with latest DECC
Projections (October 2012). Carbon price rises in line with Carbon Price Floor, to £76/t in 2030; beyond 2030 rises in line with Government 'central' carbon price values
(£147/t in 2040 and £217/t in 2050).

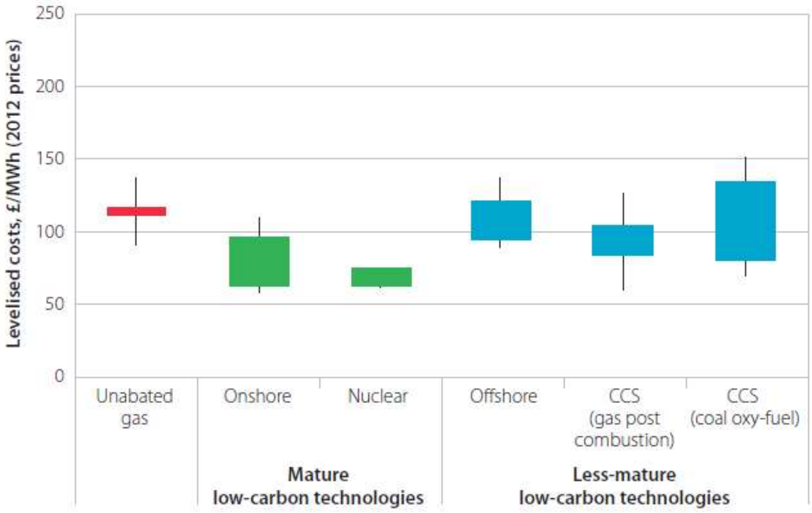


Figure 35: Projected costs of low-carbon technologies by 2030, relative to unabated gas (CCC 2013c)

The UKERC report produced by Gross et al. (2013) included a systematic review of cost estimates both past and present for four key energy technologies in the UK (Figure 36). Looking to 2030 the research presents a much wider range of levelised generation cost estimates for 2030 than presented in the CCC report. For instance, the levelised cost of energy[19] of nuclear by 2030 is expected to range from approximately £25/MWh to above £120/MWh. Similarly the cost of CCGT gas generation is estimated somewhere between approximately £55/MWh to nearly £140/MWh. Whilst technology costs can be expected to fall with time, exogenous factors can overwhelm these processes and disrupt these cost reductions, albeit temporarily.

[19] 'Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatthour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type' (EIA)

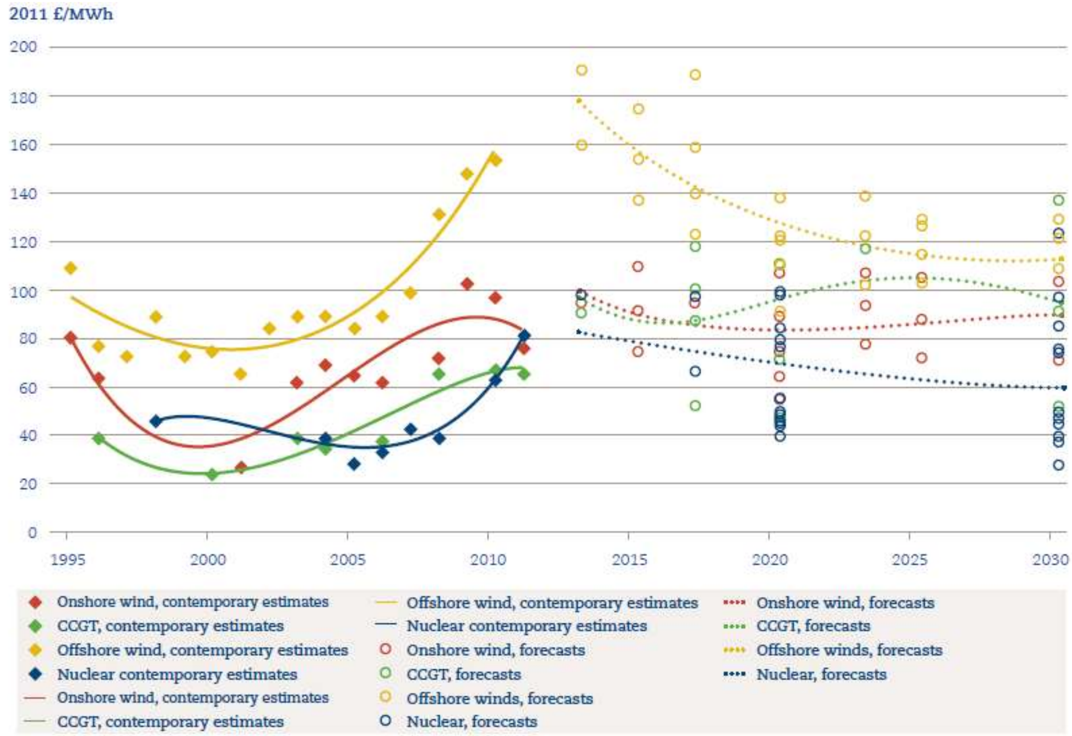


Figure 36: Range of Levelised Cost of Energy (LCOE) estimates, in-year mean and UK-specific forecasts (Gross et al. 2013)

UKERC recently produced its report *UK Energy Strategies Under Uncertainty: Synthesis Report* (Watson et al. 2014). This report discussed a number of key uncertainties for decarbonising the power sector to 2030 and discussed specifically a number of uncertainties relating to the development of technologies that will be key to decarbonising the UK power system by 2030. These are presented in Table 13, and use the framework developed by Blyth et al. (2014) that categorises the uncertainties into three categories:

- **Techno-economic** uncertainties associated with the economic, environmental and technical performance of individual low carbon technologies;
- **Programmatic** uncertainties associated with the wider policy, regulatory and institutional arrangements that could affect the development pathways for these technologies; and
- **System integration** uncertainties arising from the integration of multiple power generation technologies within a low carbon electricity system.

Table 13: Electricity generation technology uncertainties (Watson et al. 2014)

	Techno economic	Programme	System integration
Generic	• Economic & financial viability • Uncertainty over future costs • Market conditions (e.g. future demand and fuel prices)	• Policy commitment and support • Public acceptance • Supply-chains for scaling-up • Skills & knowledge • Innovation co-ordination	• Achieving high levels of electricity system diversity • Adapting supply-side options to demand-side flexibility and innovation
Nuclear	• High capital costs & realising reductions • Long-term waste management • Long build times	• Long-term waste management • Regulatory risks associated with safety requirements	• Adapting to changing base-load profile of supply
CCS	• Realising cost reductions • Regulation of CO2 storage • Integration of CCS component systems and skills	• Variety of technologies could fragment development efforts • Scaling-up technology • Realising cost reductions	• Operating CO2 transport & storage under variable generation profile
Offshore wind	• Realising cost reductions (capital & operating costs)	• Uncertainty over domestic supply chain	• Integration of intermittent generation: need for storage, demand-side response, interconnection etc.
PV	• Potential volatility of international supply chain costs	• Creating stable price support expectations	

In summary, other work indicates that there might be less certainty about the levelised costs of key low-carbon energy technologies by 2030 than presented in the CCC's report but that for each technology there are specific uncertainties that, if managed correctly by government policy, could serve to drive cost reductions over the coming years.

E.2.3.3 Level of investment required to meet 4th carbon budget

Following on from uncertainties in relation to the levelised costs of different energy technologies, it follows that there is some uncertainty around the level of investment required to deliver a low-carbon UK power sector by 2030.

Based on both Pöyry (2013) and Redpoint (2012) modelling the CCC estimate that the total capital costs required to achieve a carbon intensity of around 50gCO2/kWh by 2030 are likely to be up to £200 billion between 2014 and 2030, spread across the full range of technologies outlined in section E.1 (CCC 2013c). Figure 37 gives some indication of which technologies this money will be spent on to achieve a power supply carbon intensity of 50gCO_2/kWh by 2030.

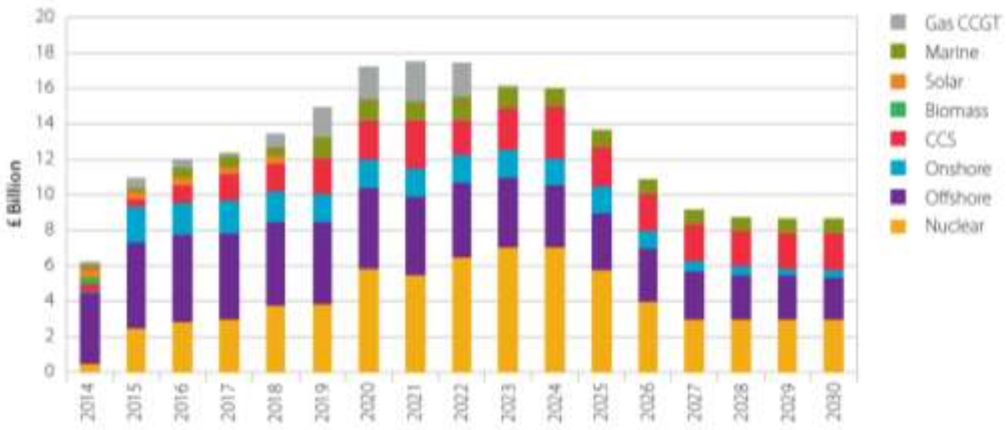


Figure 37: Capital expenditure on low-carbon technologies in CCC 'Higher Energy Efficiency' scenario reaching 50gCO2/kWh by 2030 (CCC 2013c)

Unfortunately the comparator scenarios do not offer much insight into the remaining investment required between today and 2030 to meet the 4th carbon budget. However, comparisons with other modelling work are able to be drawn. For example, based on modelling it did for its EMR Delivery Plan, DECC's *Delivering UK Energy Investment* estimates that approximately £100 billion of further investment will be needed from 2014 to 2020 in the UK power sector to meet its carbon budget, higher than the CCC's estimate of £87.5 billion by 2020. Assuming a similar investment profile to the CCC's during the 2020s, under DECC's assumption total spend may be greater than £200 billion by 2030.

This view is supported by Blyth et al. (2014) who undertook a review of various scenarios to examine whether there will be a sufficient flow of money into the electricity generation sector to finance the renewal of its ageing generation fleet, and the shift towards capital-intensive low-carbon forms of generation. On average the scenarios identified that 5.7GW of new capacity needed to be added annually, which would carry a cost of between £200-300 billion by 2030 (Figure 38). Their work for the UKERC uncertainties project (Watson et al. 2014) indicates that the average amount of investment required is £6.1bn/year (3.4 GW per year of new capacity) to 2020 (Watson et al. 2014). This is expected to increase to £12.3bn (5.7 GW) up to 2030, reflecting the need to expand the construction of capital-intensive low carbon plant, and to account for greater levels of plant retirement, post-2020.

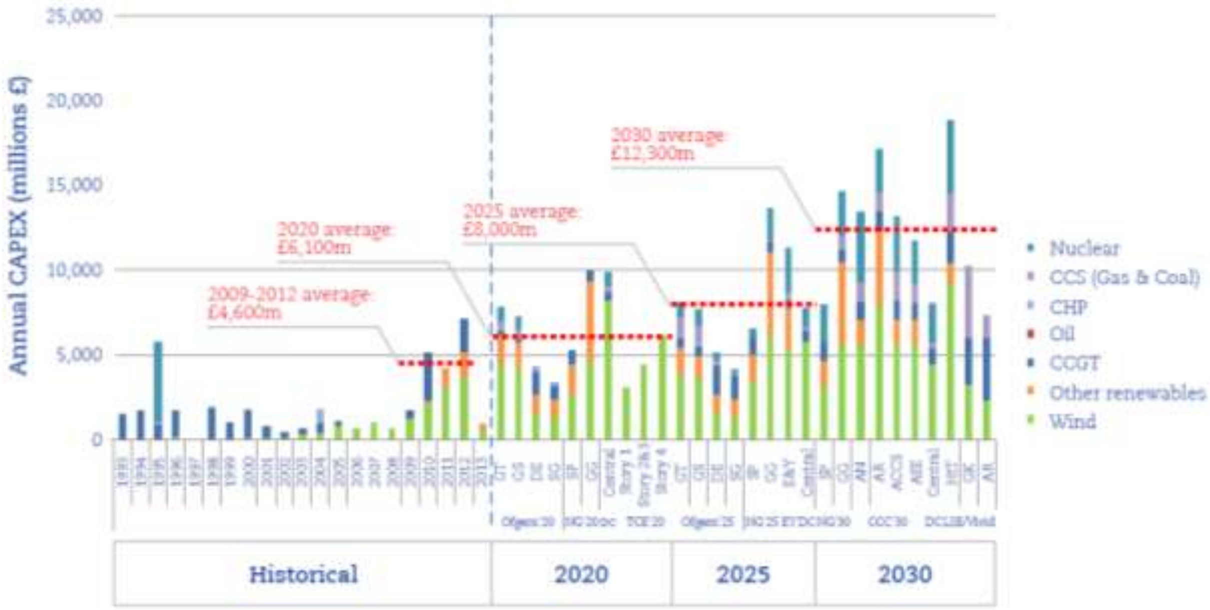


Figure 38: Financial resources required to decarbonise the power sector (Watson et al. 2014)

Whilst there is some agreement at least that the UK is likely to need to invest at least another £200 billion in its power sector between now and 2030, various modelling work suggests that the cost may in fact be much higher, with some estimates reaching more than £300 billion. There is also some major disagreement between the CCC scenario and others reviewed by Blyth et al. (2014) in terms of *when* the this money will need to be invested. The updated CCC scenario envisages that the bulk of this investment will be spent in the early 2020s (Figure 37), rather than the late 2020s (Figure 38), emphasising the need to spend money sooner rather than later.

E.2.3.4 Renewables: Role of solar PV and biomass

The CCC scenario is very clear that both onshore and offshore wind will play a key role in decarbonising the UK's power sector by 2030. However, it is less optimistic about the role that other potentially important renewable energy technologies will play, most notably solar PV and biomass, explaining that at present their costs are sufficiently high that wide-scale deployment is unlikely without major cost reductions and improved deliverability (CCC 2013c). However, it emphasises that these other renewable options could provide important alternatives should other more established or promising low-carbon technologies (e.g. wind, CCS) fail to deliver.

In general terms the CCC scenario attributes approximately 10% of the UK's 2030 electricity supply to biomass, solar PV, marine and hydro, generated from approximately 17GW of capacity[20]. The CCC scenario reserves a significant proportion of this over to biomass conversion (approximately 4-6GW by 2020). With no indication that existing capacity of hydro (1.7GW in 2013[21]) and marine energy (7MW in 2013) (DECC 2014c) will be expanded or reduced, meaning approximately 10GW of solar by 2030. Whilst there is some divergence across the scenarios about the role of biomass in the power sector by 2030, the biggest area of contestation is the role of solar PV.

[20] This is an average across the 4 scenarios presents as part of the CCC's 2013 *Next steps on Electricity Market Reform*, which the CCC's abatement scenario for the power sector is based on

[21] Just natural flow, not pumped storage. Includes both small and large-scale installations

Interestingly in both the AEA-DECC core run and UKERC *Low Carbon* scenarios, there is no solar PV capacity. This is most likely a product of the cost-optimisation modelling work taking place some years ago (c.2010) when the cost projections for solar PV were much higher. Since then the costs of solar PV have fallen dramatically meaning that not only have the prospects for major PV deployment in the UK improved substantially but that significant deployment has already been undertaken. For example, in 2009 solar PV accounted for 27MW (DECC 2014g). However, following extremely strong growth in the market over the past few years capacity grew to 2.8GW by 2030. This is in conjunction with a further 0.6GW under construction, 1.5GW awaiting construction and 1.4GW submitted (DECC 2014b).

Like the CCC scenario, the National Grid's *Gone Green* and *Low Carbon Life* scenarios are much more optimistic about PV deployment. By 2020 they envisage 7.5GW and 8.5GW and by 2030 they see 15.5GW and 17GW of PV deployment respectively. Looking beyond our selected scenarios, this optimism is also shared by the National Grid's *EMR Analytical Report*, which expects 9.3GW -10.7GW solar PV deployed out to 2020. Importantly, this work has formed the basis for DECC's *UK Solar PV Strategy Part 1: Roadmap to a Brighter Future*, which outlines the government's vision for solar deployment.

It is likely that these recent scenarios present a much more positive outlook for PV deployment on the basis that they have been developed much more recently (c.2013-14) than the AEA and UKERC scenarios, during which time PV costs have fallen dramatically and rather unexpectedly:

'*Solar generation costs have fallen substantially since our 2010 advice reflecting reductions in the cost of solar panels (which have fallen by 50% [between 2010 and 2012] (DECC 2013e)), with further cost reductions expected between now and 2020 reflecting further technological and supply chain development. DECC estimates current costs for large-scale solar PV projects to range between £115-130/MWh with costs falling to £65-75/MWh by 2030.*' (CCC 2013c p.41)

If these more optimistic scenarios for solar PV deployment by 2030 are accurate then the UK government will have to give serious consideration to the implications that such a large capacity will have on the wider grid, identifying a strategy to better integrate this intermittent capacity and complement it with other less intermittent low-carbon energy technologies.

E.2.3.5 Fossil fuels: Role of unconventional gas and coal

A detailed analysis of the CCC scenario and a comparison of this with our other scenarios raises some questions about the future role of unconventional gas and traditional coal generation.

The CCC report makes some reference to the emerging shale gas industry in the UK. It acknowledges that despite the uncertainties surrounding the extent of the UK's shale gas reserves and what proportion of this might be cost-effectively recovered, shale gas could make a significant contribution to the UK's gas supply but that it would be unlikely to satisfy the UK's full gas demand and its contribution is unlikely to have a significant impact on gas prices because these are dictated by international markets. The view that shale gas is likely to make an important albeit non-majority contribution to the UK's gas supply by 2030 is also supported by the 2014 National Grid scenarios. Figure 39 indicates that for the two scenarios that meet the UK's carbon budget (*Gone Green* and *Low Carbon Life*) shale gas production could account for between 14 and 32 bcm/year, the former accounting for approximately 20% of gas supply and the latter 30%. Interestingly National Grid's scenarios that do not meet the carbon budgets present a much less optimistic view, with estimates of 6 bcm/year to 0 bcm/year (Figure 44).

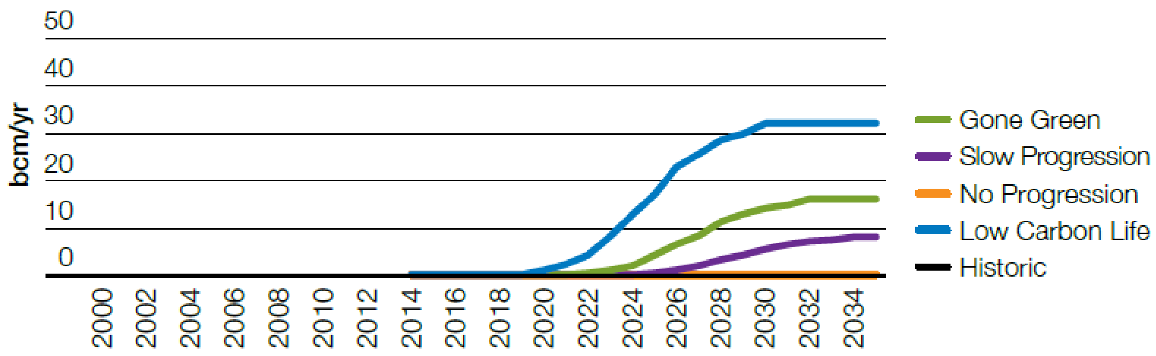


Figure 39: Shale gas projections (National Grid 2014)

Turning to coal recent work undertaken by Gross et al. (2014) warns that a significant proportion of existing capacity could still be operational in 2030**.** On the basis of their modelling they explain that the amount of coal generation still in operation during the 2020s is likely to be primarily a function of the carbon price, in the absence of other policies to constrain the use of existing coal fired power stations. They explain that in their scenarios under a very low carbon price in 2030, up to 9 GW of unabated coal is retained by the model, generating up to 56 TWh of electricity, with power sector emissions of 240gCO2/kWh. Even with the carbon price reaching £75/tonne in 2030 around 5 GW of old coal is retained, generating 8 TWh, emissions in these scenarios stand at 130gCO2/kWh. In both cases the carbon intensity of the power sector is so high that the UK runs a serious risk of missing its 4th Carbon Budget. This suggests that the view of plant operators on the future level of the Carbon Price Support will be a key driver of investment and operating decisions relating to coal out to 2030.

To avoid such a situation they recommend the following, that:

- Government provide a clear trajectory for UK carbon prices in the 2020s and continue to support a strong carbon price through the EU Emissions Trading Scheme.
- Clear signals should also be provided on the availability of CfDs to drive growth in low carbon generation post 2020 and provide confidence to investors.
- Additional clarity for investors is provided if the Emissions Performance Standard is extended to existing coal that becomes IED compliant by 2023. Regulation would need to ensure that by 2030 old coal plants are strictly limited to very low operating hours, or closed.

E.3 Summary

The scenarios contain considerable points of agreement over power sector developments:

- *Electricity supply will increase by 2030* (approx. +12-24%) mainly due to growing electrification of both transport and heat
- *The CO_2 intensity of power generation falls* to less than 100 gCO_2/kWh by 2030
- *Unabated coal and oil generation falls dramatically reaching almost zero by 2030*
- *Unabated gas generation is expected to still play a major role* in the UK's electricity supply up to 2030 with approx. 25-40GW online. New capacity will also expected to be added to achieve this level as ageing plants are decommissioned, although exact numbers difficult

- *CCS is not expected to be commercially viable* until the early 2020s and will account for a modest proportion of capacity by 2030 (approx. 5-15GW)
- *Nuclear plays an important role* in providing a low-carbon baseline electricity supply with new capacity (at least 8GW) required to come online during the 2020s
- *Both offshore and onshore wind capacity are rolled out extensively* in both the late 2010s and early 2020s providing significant capacity by 2030 (approx. 30-50GW)

There are a number of significant areas where the scenarios differ, or where there are more general uncertainties which arise from all scenarios:

- *Pace and Timing of Decarbonisation*: There is some uncertainty as to the pace of electricity sector decarbonisation, both within the CCC scenarios and in comparison to the other scenarios. In some scenarios, the UK decarbonises the power sector slower than expected, whereas in others, chiefly the UKERC LC scenario, the power sector actually achieves negative emissions.
- *Renewables - Role of Solar PV and Biomass:* While onshore and offshore wind are central parts of all scenarios, the role of solar PV and biomass is more uncertain. The dramatic fall in PV costs over the last few years, after some scenarios were modelled, means that solar PV is underrepresented in some scenarios. There is some divergence around the role of biomass as well.
- *Levelised Cost of Low-carbon Technologies:* There is considerable uncertainty as to the levelised cost of many low-carbon generation sources, as these technologies have not been rolled out before at scale. There are factors, both predictable and unknown, which may affect the costs of deployment of these technologies, which in turn will affect the speed and economics of decarbonisation.
- *Level of Investment Required to Meet 4th Carbon Budget:* Economic modelling to determine the total investment to meet the budget reveals some uncertainties. While all models suggest at least £200million is needed, some suggest that up to £300 million will be necessary.
- *Fossil Fuels - Role of Unconventional Gas and Coal:* The size of the role that unconventional gas could play in a future energy mix is contested, with uncertainties on economics, recovery rates and public acceptance leading to different estimates. The amount of coal generation still operational by 2030 is also a matter of debate, with some work predicting substantial quantities still existing due to low carbon prices and the need for more backup capacity.

Appendix 1: Snapshot of present situation in the UK heat sector

Overall buildings emissions accounted for 37% of total UK greenhouse gas emissions in 2012, with direct CO_2 emissions[22] from buildings standing at 91 $MtCO_2$ in 2012 (CCC 2013c). These were split 74 $MtCO_2$ from the residential sector and 17 $MtCO_2$ from the non-residential sector (CCC 2013c).

In 2013 overall energy consumption for heat and other end uses for the residential and service sector reached 743 TWh, with the residential sector accounting for approximately two thirds (69%) of energy demand from these two sectors. There are some important differences between the end use demand and associated fuel use between the residential and commercial sectors, as can be seen in Figure 3. Residential energy consumption is dominated by space heating, followed by water heating lighting and appliances and cooking/catering In contrast the service sector's energy demand is less dominated by space and water heating with larger quantities of cooking/catering, cooling and ventilation (and computing (DECC 2014d).

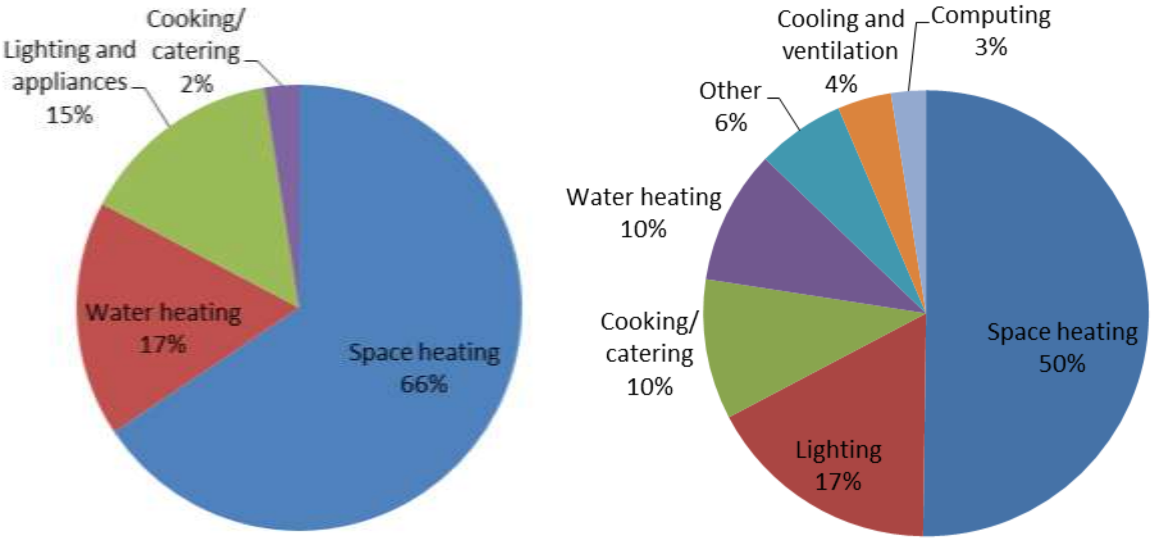


Figure 40: Residential and service sector overall energy consumption for by end use 2013 (DECC 2014d)

As illustrated by Figure 3. heat consumption dominates this sector, accounting for 80% of energy demand in buildings, standing at 598TWh (DECC 2014d). Gas continues to be the most popular fuel to satisfy the UK's buildings heat demand, accounting for 77% of heat supply in 2013, with the remainder being made up of electricity (12%), oil (7%), bioenergy and waste (2%), solid fuel (1%) and heat sold via district heating (1%) (DECC 2014d). Only a very small fraction of the UK's heating needs were met by renewable heating technologies such as solar thermal and heat pumps, providing 2.2TWh and 1.1TWh of renewable heat in 2013 (DECC 2014c).

Taking a sectoral perspective we find that the residential sector accounts for more than two thirds (73%) of UK building heat consumption. The residential sector was dominated by gas, accounting for 79% of heat demand, with electricity (9%) and oil making up most of the remainder (7%) (DECC 2014d). There were also some limited amounts of bioenergy and solid fuel, each accounting for 2% of supply, with almost no district heating (0.1%).

[22] Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity. In buildings this relates to space heating, cooking, hot water etc.

DECC's *The Future of Heating: Meeting the challenge* (2013c) explains that over 95% of UK homes are heated by a boiler, with the fuel type dependent on location. The majority of these are gas boilers with installations in over 24 million homes (88%).86% of centrally heated homes). In recent years there has been a dramatic increase in the number of high-efficiency condensing boilers[23], with regulations in force in England and Wales since 2005 mandating these. Furthermore, there has been a dramatic rise in combination boilers, which instantly heat water as it flows through the unit, effectively removing the need for a hot water storage tank (DECC 2013c). In 2011 approximately a third of residential boilers were standard/back boilers, another third were condensing-combi boilers, with the remainder made up of 'stand-alone' combi (22%) and condensing boilers (11%) (DECC 2014d).

Not all homes are gas heated with 3.6 million homes centrally heated without gas in 2012 (DECC 2014b). Typically, off-grid homes in dense urban environments rely on electrical heating, particularly in housing blocks where there may be limitations on the use of gas for safety reasons. However in rural settings, it is common for off-grid homes to rely on electricity and/or heating oil, with solid fuels and liquefied petroleum gas (LPG) being used to a lesser extent (DECC 2013b).

In the commercial sector the vast majority of heat is also supplied by gas, accounting for 71% in 2013. The majority was made up of electricity (19%), oil (6%), district heat (3%) and bioenergy (1%) (DECC 2014d). The major difference versus the residential sector here is the higher proportion of district heating. Due to the large space and hot water heat demand of commercial buildings, and their appetite for cooling, they are often well suited to supply via CHP. As of 2013 there were approximately 1350 CHP schemes supplying over 1.6TWth to commercial consumers (DECC 2013a).

Whilst moving towards lower carbon fuels can play a key role in decarbonising heat demand another extremely important strategy is reducing the level of heating demand altogether. Two common ways to achieve this is by: 1) improving the energy performance of the construction elements, including insulation, air-tightness and approach to ventilation; and 2) altering the way in which buildings are used, most notably occupants' behaviour and preferences (DECC 2013c). Whilst it is difficult to quantify the latter, we can provide a snapshot of the energy efficiency of the UK's building stock.

In 2013 almost 20% of England's housing stock built before 1919 (DCLG 2014), the majority of which were built during the Victorian era. A similar situation can be found across non-domestic buildings where more than three quarters of non-domestic buildings were built before 1985, with nearly a third of these built before the Second World War (DECC 2013c). In the context of such an old building stock and 'despite national Building Regulations being introduced in 1965, with local standards in existence since the 1930s, we still have a legacy of some of the least thermally efficient housing in Europe' (DECC 2013c p.88). Importantly, approximately 80% of the UK's building stock in use today is expected to still be in use by 2050 (UKGBC 2008),

Some progress has been made in recent years in improving the efficiency of the UK's existing building stock. For instance, as of March 2014 approximately 72% of the UK's homes with cavity walls had cavity wall insulation (13.8 million) and 69% of homes with lofts had loft insulation (>+125mm)(16.4 million) (DECC 2014h). Furthermore, we also find that as of 2011 almost 92% of UK

[23] A typical increase of efficiency can be as much as 10-12% over non-condensing boilers (DECC 2013c)

homes had double glazing (DECC 2014d). However, there is still the opportunity for further efficiency gains, not only in raising these insulation and double glazing levels but in applying other efficiency retrofit measures. For example, only 3% of the homes in the UK with solid walls had solid wall insulation in 2013 (Decc 2011).

Appendix 2: Snapshot of the present situation in the UK transport sector

Consumption from the transport sector represented 36 per cent of total final consumption of UK energy products in 2013, consuming 621TWh (Prime 2014). This sector emitted 117MtCO_2 in 2013, accounting for approximately 25% of UK emissions covered by carbon budgets (DECC 2014a). The vast majority of these emissions were associated with road transportation. Figure 16 illustrates passenger how road transport accounted for 46% of total energy consumption, followed by road freight (27%), domestic air transportation (23%), domestic rail (2%) and water (2%) transport. Almost all passenger transportation energy consumption was via cars (93%) and road freight energy consumption was split between HGVs (61%) and LGVs (39%) (DECC 2014d).

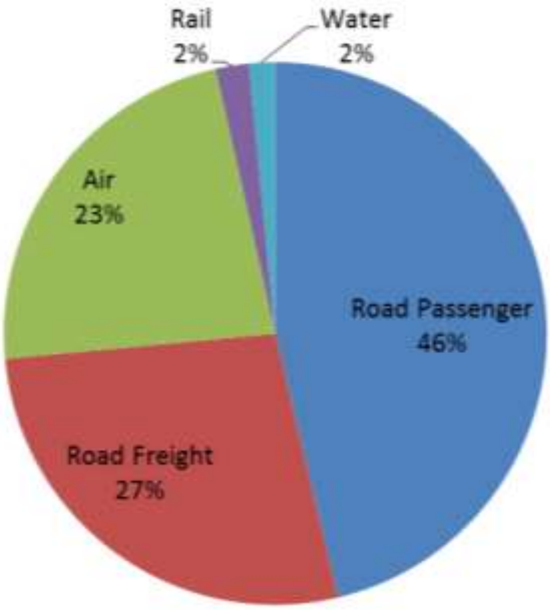


Figure 41: Transport energy consumption by type of transport 2013 (DECC 2014d)

Like in the buildings sector, reducing the greenhouse gas emissions of transport can be achieved in three key ways: 1) decarbonising transport fuels, 2) improving the efficiencies of vehicles and 3) altering user practices to reduce transport demand. With regards to the first of these almost all transport energy consumption (approx. 97%) was derived from petroleum products, with only 2% coming from bioenergy and 1% from electricity (DECC 2014d). National Grid (2014) estimate that 'approximately 9,000 electric vehicles are on the road today: 63% Pure-electric (PEV), 37% Plug-in hybrid (PHEV)/Range-extended (E-REV)' (p.88) equating to an annual demand of 16.75GWh and a peak demand of 2.38MW.

Turning to the second and third decarbonisation approaches (i.e. efficiency improvements and reducing transport demand) the UK has seen some progress in this regard over recent years. Between 2000 and 2012 energy consumption by the transport sector has decreased by approx. 20TWh (Prime 2014). Importantly however this was largely driven by improvements in efficiency rather than by reduced demand for transport services. Prime (2014) explains that had there been no efficiency savings between 2000 and 2012, energy consumption in 2012 would have been 649 TWh, approximately 23TWh higher than the actual level of consumption (Prime 2014).

Figure 17 illustrates how the energy intensity[24] of UK transport has changed in recent decades. Since 2000 we find that the road passenger transport sector has recorded the largest fall in energy intensity, which has translated into a significant reduction in energy consumption given the large number of passenger vehicles on the UK road. Assuming that there was negligible change in road transport demand, DECC estimate that these efficiency gains resulted in a fall of 38TWh in road passenger energy consumption.

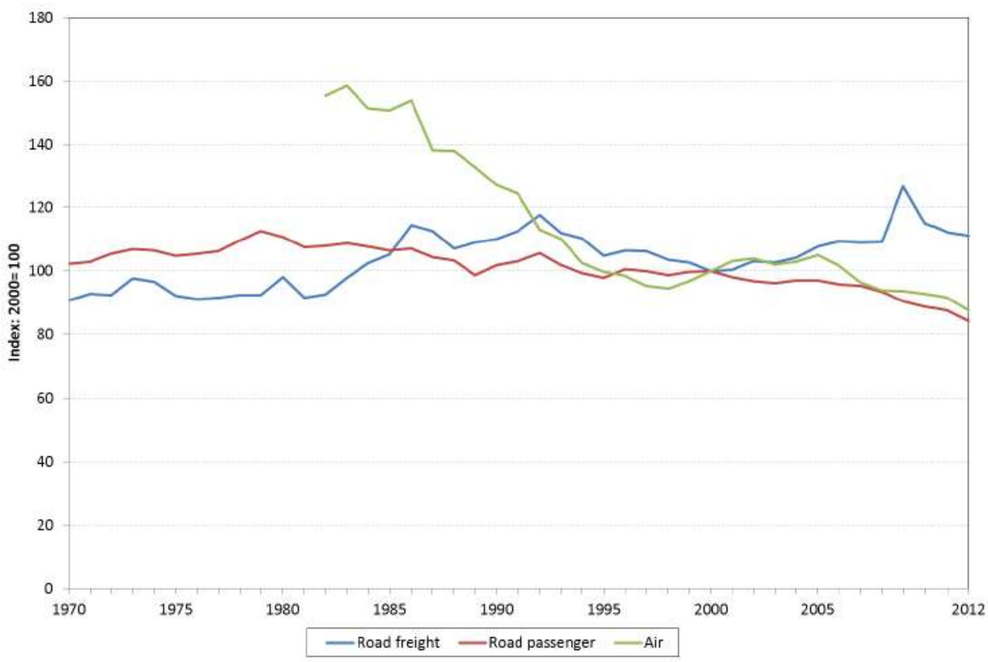


Figure 42: Energy intensities for road passenger, road freight and air transport (between 1970 and 2012) (DECC 2014d)

[24] By looking at the relationship between energy consumption and distance travelled or load carried it is possible to measure energy intensity. For road passenger transport, energy intensity is measured in terms of consumption per passenger kilometre. To take into account of the weight carried, road freight transport intensity is measured in relation to freight tonne-kilometres. Air transport energy intensity is measured as energy consumption per passenger kilometre. (Prime 2014)

Appendix 3: Snapshot of the present situation in the UK power sector

In 2013 UK power sector emissions stood at approximately 145 $MtCO_2$ (DECC 2014a)[25] and it was estimated that in 2012 the UK's emissions intensity stood at approximately 503 gCO_2/kWh (CCC 2013c)[26].

In terms of generation the UK's total electricity generation capacity stood at 85GW in 2013 (DECC 2014f) delivering an output of 341TWh[27] (DECC 2014e). The vast majority of this was from coal (36%) and gas (28%) , with the majority of the remainder made up of nuclear (19%) and wind (9%). Small shares were given over to bioenergy (5%) , hydro flow and storage (2%), other thermal[28] (1%) and oil (<1%)(Figure 29)

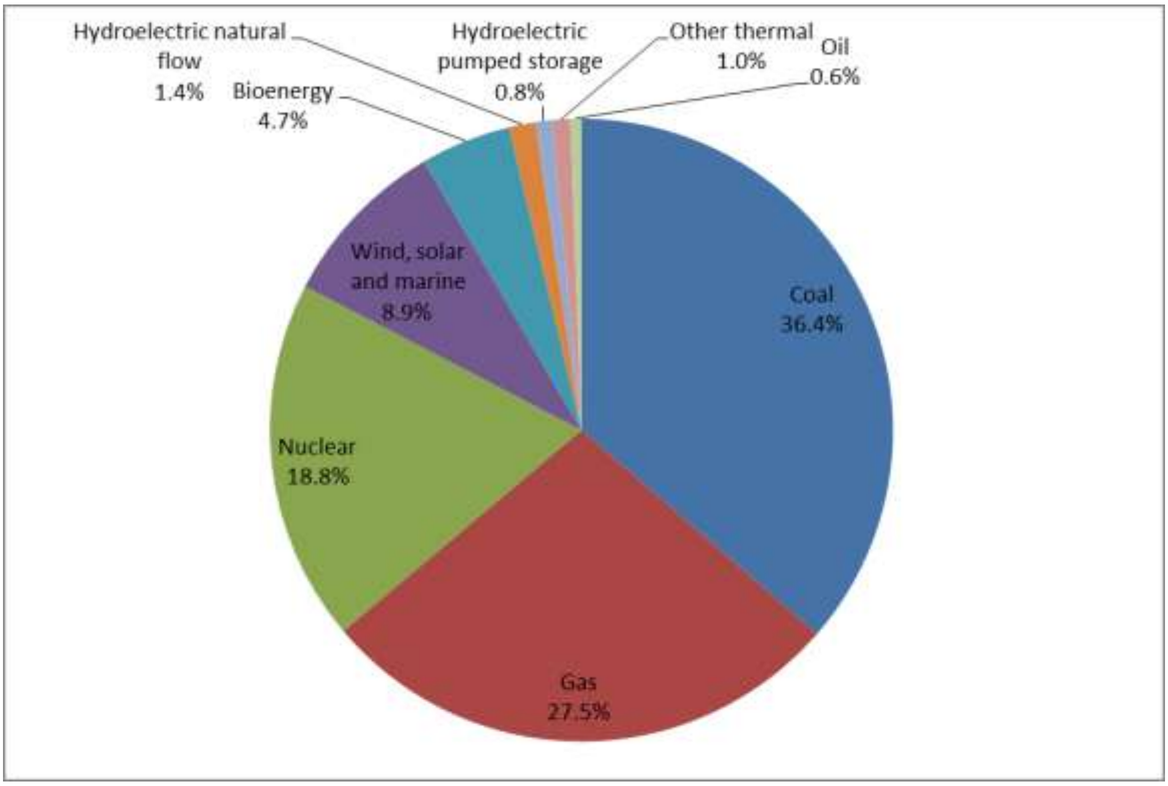


Figure 43: UK power supply mix 2013 (DECC 2014e)

[25] This is a provisional figure for power stations (not all energy supply as defined by DECC's methodology) and may be subject to change.
[26] A provisional value for 2012 taken from Figure 2.2. on p.38 in CCC (2013c)
[27] Total generation supplied to grid minus electricity used on works but includes pumping
[28] Other thermal sources include coke oven gas, blast furnace gas and waste products from chemical processes.

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