HM Government

2050 Pathways Analysis

Response to the Call for Evidence
March 2011

Part 2

Contents

Part 2A: Changes made to the 2050 Calculator

The 2050 Pathways Analysis report published in July 2010 was structured in two parts. The first dealt with the methodology and the findings; the second set out, for each sector of the Calculator, the detailed assumptions underpinning the trajectories in the 2050 Calculator. It was on the detail of these trajectories in Part 2, that the Call for Evidence largely focussed.[22]

As a result of the large number of high quality submissions we received during the Call for Evidence, we have made a number of revisions to the assumptions in the 2050 Calculator.

This section of the report now provides detailed information on the amendments to the Calculator. Where the assumptions and context remain the same as the July report we have not repeated the information here, and this report should be read alongside Part 2 of the July report.[23] We ultimately hope to merge the updates with the text of the original report, thereby providing one document with all the relevant assumptions as contained in the latest 2050 Calculator.

Changes to the inputs to the 2050 Calculator

In summary, the key changes we have made mean:

- We have four new sector choices in the Calculator offering users of the Calculator additional choices about the options for reaching our long-term aims. These include a choice of fuel being used in carbon capture and storage power plants (solid and gas); a disaggregation of industry into two levers, one showing size of the industrial sector in the UK, the other the emissions intensity; a breakdown of the land-use and agriculture sector into two levers, one showing land-use management, the other showing livestock management; and a new biomass power plant option.
- In one sector, international shipping, we have added three additional scenarios to allow further choice. These illustrate the impact of alternative levels of shipping activity, although international shipping emissions are not currently included in the UK's 2050 emissions reduction target. These scenarios are place-holders at this stage and the aim is to refine them as more evidence becomes available.
- We have amended some of the boundaries of the choices, for example by updating the 'Level four' where appropriate; and by updating some of the fixed assumptions in existing trajectories. For example, the offshore wind Level 4 now reflects a higher capacity than the previous version of the Calculator; and some of the assumptions around bioenergy yields and conversion processes have been revised.
- We have updated the 5-day balancing 'stress test' to better reflect empirical evidence, and added a 1-day stress test. These tests explore whether pathways would cope with extra demands for electricity in different weather conditions.

22 See Annex A for the list of Call for Evidence questions.

23 HM Government (2010) *2050 Pathways Analysis* http://decc.gov.uk/2050

Changes to the outputs of the 2050 Calculator

In terms of outputs, the changes we have made to the Calculator affect three key areas: gas, biomass and electricity grid balancing.

By making gas CCS an available technology option, natural gas can now be more easily accommodated into a successful pathway to 2050, as emissions associated with the fuel can be more effectively abated. This can be seen in Pathway 15 in Part 1A.

The changes to the biomass conversion rates have a small but important impact on the amount of energy that can be produced from domestic biomass sources. Because we have revised down the efficiencies associated with converting raw biomass to liquid and gaseous fuels, conversion to solid usable form becomes increasingly appealing. This is explored in more detail in illustrative Pathways 8, 9, and 10.

Finally, the new and more stringent balancing test means that successful pathways which may previously have met the target without requiring backup measures are now required to consider the implications of much more difficult weather conditions. The effect of this, particularly on pathways with a high dependence on renewable generation, is looked at in illustrative Pathways 1, 11 and 12.

Changes to the web tool

The revised 2050 web tool reflects these changes to the underpinning data. Some presentational improvements have also been made.[24] These include:

- A clearer distinction has been made between Levels 1-4 and choices A-D in the web tool, so that selecting a scenario D is not considered to be equivalent to choosing a Level 4 trajectory, in terms of ambition or effect. The 'difficult rating' metric has also been removed as it conflated the two.
- Each sector in the web tool now has a link added which takes the user through to a one-page summary of the sector. This provides more information on the sector than the pop-up box which appears in the web tool, but aims to be sufficiently brief to engage people whilst they are operating the Calculator.
- Further advice has been added, for example, users are now informed if they have over-supplied a particular type of energy, and we have added Sankey diagrams to indicate energy flows; and we have added a basic visual representation of the amount of land associated with each energy supply choice.

24 http://2050-calculator-tool.decc.gov.uk/

2A.A Hydrogen

Hydrogen is an energy carrier, and like electricity has potential applications across our future energy system. In particular, hydrogen has a high energy-to-weight ratio and is emissions-free at the point of use, burning with oxygen to produce only water. This, and the continued development of fuel cell technologies, means that hydrogen's potential in the low carbon energy future, especially in transport, is widely recognised.

Hydrogen is abundant, but as it is rarely found on its own it must be separated from hydrogen compounds such as hydrocarbons and water. Doing this requires energy, and the source and process used for extracting hydrogen is important in accurately measuring the emissions from its use. The 2050 Calculator contains assumptions on the production of hydrogen for transport, and these have been revised based on responses to the Call for Evidence.

Call for Evidence

The July 2010 version of the 2050 Calculator modelled the use of hydrogen within the more ambitious domestic transport trajectories. Hydrogen was anticipated to fuel up to 20% of passenger miles by 2050. The Calculator also contained an unvarying assumption that all transport hydrogen was produced via water electrolysis, at a constant efficiency of 50%.

The July 2010 report also highlighted other potential roles for hydrogen, including grid-balancing and heating. These were not modelled in the Calculator, but are considered by industry to be feasible.

In the Call for Evidence we asked whether the Calculator represented a comprehensive treatment of the future UK energy and emissions systems. Hydrogen was the only area highlighted by respondents to the Call for Evidence as under-represented within the Calculator. Particular issues raised in the responses, as well as in an expert workshop held in November 2010, included grid-balancing, production assumptions and heating. The responses also suggested that the Calculator's assumptions on transport applications were too narrow, although responses here were less unified.

Grid balancing

Several respondents pointed to the potential for hydrogen to be used to help smooth the challenges of balancing the electricity grid where significant levels of intermittent electricity generation are included. Respondents included Bryte Energy, the UK Energy Research Centre, Johnson Matthey and the Centre for Alternative Technology.

To better highlight balancing issues across the Calculator, we have added a new one-day weather stress test and revised the existing five-day test to more closely reflect empirical weather data (see Section 2A.C 'Electricity Balancing').

We are continuing to explore how to highlight balancing and energy security within the Calculator, including through the inclusion of short-term supply and demand patterns. As this work is taken forward, we will investigate how hydrogen can be reflected within this sector.

Production assumptions for transport hydrogen

As set out above, the July 2010 version of the Calculator assumed all hydrogen used in transport would be produced via electrolysis. This contrasts sharply with hydrogen produced today for industrial applications, where electrolysis accounts for only a small share of total production. The lead production source is steam methane reformation (SMR), which consumes natural gas. On the basis of the evidence received, we have revised this assumption in the updated Calculator.

Calculator assumptions about hydrogen production in the near-term

For the short and medium term, the 2050 Calculator now models SMR as the dominant production route for transport hydrogen. This reflects the fact that SMR is a commercially viable platform with substantial capacity. It also acknowledges that, prior to grid decarbonisation, SMR may represent a lower emissions source of hydrogen than grid-based electrolysis.

As a commercially mature technology operating at high efficiencies, no efficiency improvements have been projected for SMR, except in the case of distributed production where some learning and standardisation is anticipated. In particular, as production at the forecourt, or at a municipal level, reduces the costs and challenges of transporting hydrogen, distributed SMR is expected to play a key role, acting as a stepping-stone technology by helping to establish and expand a viable refuelling infrastructure.

Calculator assumptions about hydrogen production in the longer-term

Longer term, the Calculator phases out both central and distributed SMR in favour of production from decarbonised electricity. By 2050, the Calculator expects electrolysis to be the sole source of hydrogen for transport, with a revised maximum efficiency of 77%, approximately 10% higher than today's best demonstrated efficiencies.

There is good reason to expect electrolysis to be significantly higher for transport applications than it currently is for industrial uses: electrolysers are anticipated to become commercially competitive in the latter half of this decade, and on-site electrolysis would also remove the need to transport hydrogen from central facilities to road-side refuelling stations.[25] Efficiencies are also expected to improve, especially if electrolysers are deployed at scale and for grid balancing.

To reflect this, a steady increase in electrolysis' share of hydrogen production is modelled from 2020 to 2050. Prior to this, a faster rate of growth is projected in-line with the electrolysis scenario in the recent industry report: *A Portfolio of Power Trains for Europe*.[26] In the revised 2050 Calculator, electrolysis becomes the dominant production route for hydrogen for transport in 2032, and the sole production route by 2050.

25 US Department of Energy, (2009). *Hydrogen Production Roadmap: Technology Pathways to the Future*. See also: US National Renewable Energy Laboratory, (2009) *Current State-of-the-Art Hydrogen Production Cost Estimate using Water Electrolysis*.

26 McKinsey and Company, (2010) *A Portfolio of Power Trains for Europe: A Fact-Based Analysis*

CCS

The development of CCS technology holds significant potential for hydrogen production. Pre-combustion processes, such as coal gasification, produce hydrogen from hydrocarbons or coal and water, combusting the hydrogen and sequestering a high percentage of the resulting carbon. It is anticipated that CCS plants may be a source of both electricity and hydrogen, and so could be able to supply both electricity and transport energy demands.

We will explore ways of accurately modelling hydrogen's extraction from CCS processes, with the aim of being able to include this in a later iteration of the 2050 Calculator.

Figure A.1: Production share of hydrogen for transport applications

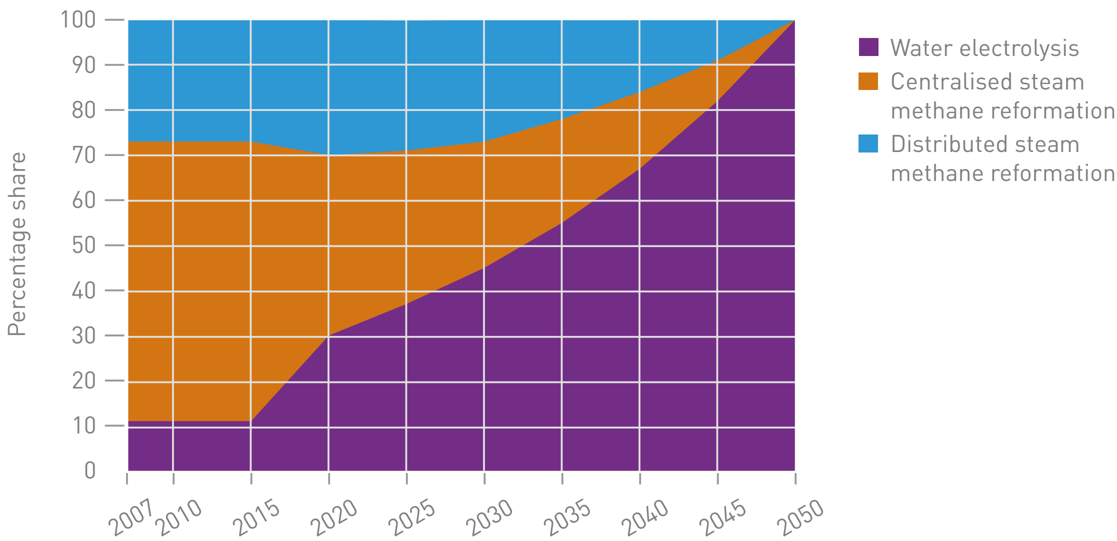


Table A2: Hydrogen production method, efficiencies

Description	2010	2015	2020	2025	2030	2035	2040	2045	2050
SMR – Central	72.0%	72.0%	72.0%	72.0%	72.0%	72.0%	72.0%	72.0%	72.0%
SMR – Distributed	68.0%	68.0%	68.0%	69.3%	70.6%	72.0%	72.0%	72.0%	72.0%
Distributed water electrolysis	65.0%	65.0%	65.0%	66.9%	68.8%	70.8%	72.8%	74.9%	77.0%
Hydrogen production method, share									
Description	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
SMR – Central	62%	62%	40%	34%	28%	23%	17%	9%	–
SMR – Distributed	27%	27%	30%	30%	28%	23%	17%	9%	–
Distributed water electrolysis	11%	11%	30%	37%	45%	55%	67%	82%	100%

Fuel cell buses

The July 2010 version of the 2050 Calculator anticipated hydrogen fuel cells in cars and vans, but not in buses or HGVs. Whilst there would be significant storage challenges and weight penalties for HGVs, buses could be early adopters of hydrogen given they are captive fleets, and both long range and short refuelling times are desirable to operators. The transport section of this report (Section 2A.I 'Transport') sets out the new assumptions on the roll-out of hydrogen fuel cell buses.

2A.B Including a fuel choice in Carbon Capture and Storage

Carbon capture and storage (CCS) is the process through which carbon dioxide may be captured from large sources of emissions such as fuel combustion and stored securely in geological formations, preventing it from being emitted into the atmosphere. In this sector we specifically consider the future application of CCS technology to the large scale power generation sector. CCS applied to industrial processes is considered in the industry sector.

Call for Evidence

In the 2050 Pathways Analysis published in July 2010 we set out four alternative trajectories for the development of fossil fuel power generation combined with CCS between now and 2050. The 2050 Calculator included only coal and solid biomass as the fuels for CCS; this was a simplifying assumption and the July report acknowledged that CCS may use other fuels including natural gas and biogas. See section H, page 174 of the July report.

CCS was a sector that attracted interest in the Call for Evidence with around 40 respondents commenting on the technology, many of them in depth. In general there was support for the inclusion of CCS within the Calculator and the view that CCS may have a key role to play in facilitating the continued use of fossil fuels in the medium and long term.

Many respondents noted that the 2050 Calculator was overly simplistic in including only coal and biomass CCS, and suggested that we also include gas CCS in order to improve the comprehensive scope of the Calculator. We have responded to the Call for Evidence feedback by modelling gas CCS within the Calculator alongside coal CCS; and by dividing coal CCS into pre-combustion coal CCS and post-combustion coal CCS. Both coal and gas CCS can use biomass if it is made available as solids and gases respectively.

The updated Calculator now contains two different levers for the user to set:

(i) Four different levels of effort of build of CCS generation plant (Levels 1-4)

(ii) Four different scenarios for the relative proportions of solid fuel (coal) CCS and gas CCS (Trajectories A-D).

This revision provides more choices to the user and better reflects the possible range of future technology options.

Several respondents noted that pre-combustion CCS technologies are a potential future source of hydrogen, as a 'secondary' fuel which can be used in balancing and back-up. Hydrogen production is discussed in Section 2A.A Hydrogen. In addition, respondents noted that fossil fuel power generation with CCS can be combined with the co-firing of biomass (termed 'bioenergy with carbon captive and storage', BECCS) in order to lead to negative emissions, as was discussed in the July 2010 Analysis.[27] This feature was already in the July 2010 Calculator for solid biomass and is it now available for both solid and gaseous biomass.

27 HM Government (2010) *2050 Pathways Analysis*, pages 35, 176, 236-7.

Context

As noted by several respondents, there is currently very little technical data on CCS due to the absence of functioning commercial-scale CCS plants. In particular, there are very few long term estimates for how the CCS power generation sector could develop over time. The CCS trajectories presented here are therefore estimates based on the evidence available and will need to be revised over time as new evidence emerges.

The Levels

The Levels for CCS build rates

In the revised 2050 Calculator we have assumed that at least initially coal and gas CCS technologies are likely to be strongly interdependent. CCS is a novel technology and for the foreseeable future it can be expected that CCS plants will learn best practice from each other and that power generation companies will make decisions about building CCS plants by choosing between the gas CCS or coal CCS options, not by making decisions about their development in isolation. There will also be competition for suitable sites for new CCS power stations, which will need to be located with access routes for CO_2 pipelines, in particular to the North Sea coast, in order that carbon dioxide can easily be transported to its final storage destination. Gas CCS and coal CCS will also be competing for shared support frameworks and project financing within a single policy framework.

It is therefore assumed that the development and supply chains of gas CCS and coal CCS will be linked. The Calculator retains the total CCS levels of effort at the same levels as those which were presented in the July 2010 version for coal CCS alone, maintaining the same build rates and cumulative capacity. The result is that even if the relative proportions of gas CCS to coal CCS are varied at any particular level, the total build rates and total capacity reached will remain the same for each level. This means that the majority of the earlier assumptions which were outlined in the July 2010 publication still apply.

Pre-combustion and post-combustion coal CCS

There is sufficient technical data about pre-combustion and post-combustion coal CCS that these technologies have now been modelled separately in the 2050 Calculator. The combined capacity of both technologies equals the total coal CCS capacity. The relative proportion of the two technologies at any time point is fixed within the Calculator. This approach was taken based on the view that, initially, post-combustion would be used more for new build as cautious generators would prefer it as it allows them to keep familiar pulverised-coal steam-generation technology, and as time moves on there could be a move to pre-combustion coal CCS, as this probably has greater technical potential for improvement and cost reduction.

The Calculator still only models a 'generic' gas CCS as we are not currently in a position to be able to say how either pre-combustion or post combustion gas CCS may be taken up in the future, with reports referring to gas CCS without specifying post or pre-combustion. We will provide this level of detail in future updates if new evidence becomes available.

Level 1 and the CCS demonstration projects

Level 1 for CCS only assumes that four demonstration projects are built and that there is no commercial-scale rollout. The build rates and timing of the demonstration projects have been updated to reflect the announcement in November 2010 that the CCS demonstration programme will be open to projects on gas-fired power plants as well as coal-fired power plants. The mix of projects assumed to form the demonstration programme are an estimate only and do not reflect Government's desired project mix:

- Two post-combustion coal CCS plant: 0.4 GW (one in 2014, one in 2018)
- One pre-combustion coal CCS plant: 0.45 GW (in 2018)
- One gas combustion CCS plant: 0.45 GW (in 2015)

All capacity figures used in the Calculator are gross capacity, i.e. the net capacity plus the 'parasitic' own-energy use of both the plant and the CCS equipment.[28] Level 1 provides the fixed baseline for the subsequent Levels 2–4, as it is assumed that roll-out of the demonstration plants occurred as planned in all scenarios.

The trajectories for the coal and gas fuel choice

The four trajectories modelled in the updated Calculator for the relative proportions of coal CCS and gas CCS are:

Trajectory A: All coal CCS (plus the 1 gas demonstration project)

Trajectory B: Two-thirds coal, one-third gas CCS (additional to the demonstration projects)

Trajectory C: One-third coal, two-thirds gas CCS (additional to the demonstration projects)

Trajectory D: All gas CCS (plus the 3 coal demonstration projects)

Quantities of carbon dioxide captured and emitted

One point noted by respondents is that combustion of gas leads to fewer grams of CO_2 per unit of energy than coal and hence releases fewer than half the carbon emissions of coal.[29] CCS technologies are currently considered to have similar levels of capture efficiency, estimated here to be 90%, in which case gas CCS would both capture and emit less carbon dioxide than coal CCS.[30] This has implications for the transport and storage infrastructure required at CCS power stations, with coal CCS plants likely to require access to greater volumes of pipeline and storage.

28 Base plant own use requirements are taken directly from Mott MacDonald (2010) *UK Electricity Generation Costs Update*; these remain constant across all technologies and over time. The load factors are as per DECC assumptions and remain constant across all technologies and over time. The unabated plant thermal efficiency is from Mott MacDonald (2010) *'ibid'* 'First of a kind' data until 2020 in line with internal DECC data relating to the demonstration plants; at 2020 'Nth of a kind' data for unabated plants followed by further 10% efficiency improvement by 2050 (DECC assumption). Up to 2020 the CCS equipment own use requirements are taken from Redpoint (2009) *Carbon Capture and Storage demonstration: analysis of policies on coal/CCS and financial incentive schemes report* for coal demonstrations and a DECC assumption for the gas demonstration. From 2020 onwards the CCS equipment own use requirements are taken from Mott MacDonald (2010) *'ibid'*, using 'first of a kind' data at 2020, 'Nth of a kind' data at 2030, and a further 10% efficiency improvement by 2050 (DECC assumption).

29 Coal contains 319g of CO_2 per kWh of energy, whereas gas contains 185g of CO_2 per kWh of energy. DECC (2010) *Guidelines to GHG Conversion Factors for company reporting*.

30 IPCC (2005) *Special Report on Carbon dioxide Capture and Storage*.

At present there remains significant uncertainty around the challenge of storing carbon dioxide and it is difficult to quantify this constraint. It is considered that at least initially the construction of carbon dioxide transport and storage would be an equal constraint on gas and coal CCS due to the need to build new pipelines and identify storage locations. It is likely that several CCS plants would share the same pipelines and access to the same storage location, regardless of whether they are gas or coal CCS plants. Levels 1–4 in the 2050 Calculator therefore are limited by the combined build rates of all CCS plants.

It is estimated that the UK has access to at least 10 Gt of carbon dioxide storage in the UK continental shelf, which is around 80 years' worth of emissions from current coal power stations, so total storage capacity is unlikely to be a constraint in the short and medium term. It is possible that in the long term gas CCS would be viewed more favourably due to the lower volumes of carbon dioxide required to be disposed of and the lower final CO_2 emissions.

Total capacity and output levels

Although the total capacity of CCS generation at each level is the same as in the July 2010 publication, the electricity output varies slightly, being slightly greater for gas CCS based on the technical assumptions made.

Only the trajectories for Levels 1–4 for the 'all coal' and 'all gas' scenarios are shown in figure B.2; the mixed coal/gas scenarios have intermediate trajectories. The cumulative capacity and generation outputs for all levels are listed in Tables B.1 and B.3 below:

Table B1: Cumulative capacity of CCS power stations (both gas CCS and coal CCS; GW)

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	0.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Level 2	–	–	0.9	1.7	4.4	10.1	17.6	25.1	32.6	40.1
Level 3	–	–	0.9	1.7	6.6	16.6	26.6	36.6	46.6	56.6
Level 4	–	–	0.9	1.7	11.7	25.7	40.7	55.7	70.7	85.7

Figure B.2: Trajectories for electricity generation from CCS power stations

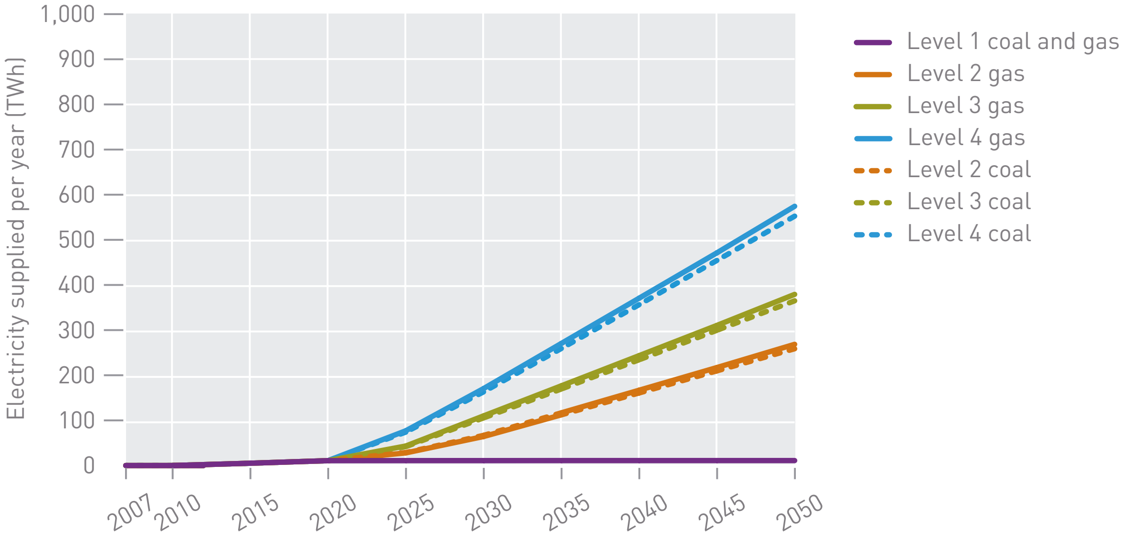


Table B3: Electricity produced per year from CCS power stations (TWh)

(A) All coal

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	5.1	10.8	10.9	10.9	11.0	11.0	11.0	11.0
Level 2	–	–	5.1	10.8	27.9	64.2	112.2	160.7	209.7	258.7
Level 3	–	–	5.1	10.8	41.8	105.4	169.5	234.2	299.5	364.9
Level 4	–	–	5.1	10.8	74.0	163.1	259.3	356.3	454.4	552.4

(B) Two-thirds coal: one-third gas

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	5.1	10.8	10.9	10.9	11.0	11.0	11.0	11.0
Level 2	–	–	5.1	10.8	28.2	65.0	113.7	162.8	212.1	262.0
Level 3	–	–	5.1	10.8	42.3	106.9	171.9	237.3	303.2	369.7
Level 4	–	–	5.1	10.8	75.0	165.6	263.0	361.1	460.0	559.7

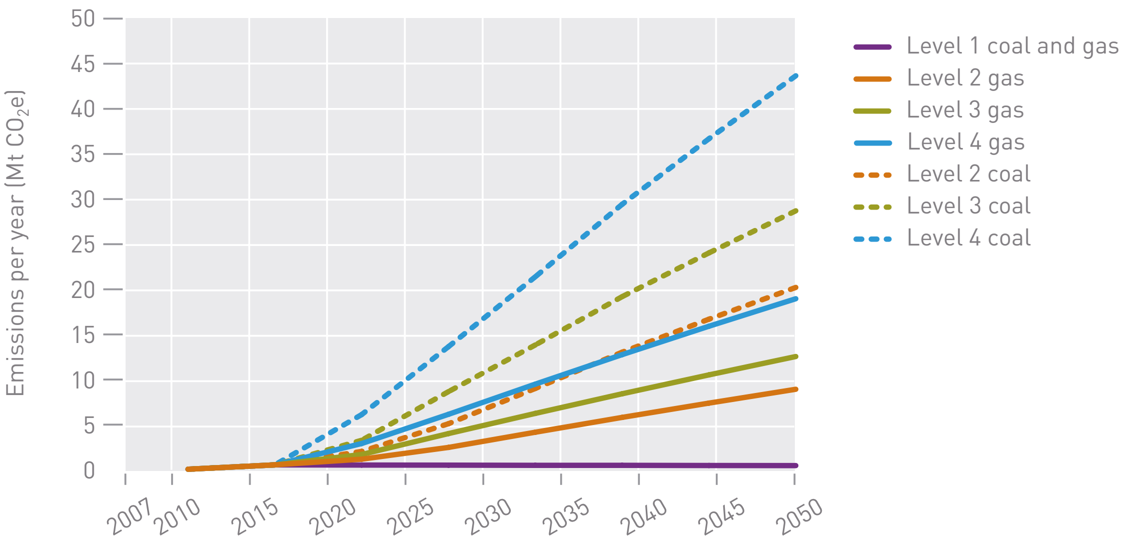
(C) One-third coal: two-thirds gas

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	5.1	10.8	10.9	10.9	11.0	11.0	11.0	11.0
Level 2	–	–	5.1	10.8	28.5	65.9	115.2	164.8	214.6	265.3
Level 3	–	–	5.1	10.8	42.8	108.4	174.3	240.4	306.8	374.4
Level 4	–	–	5.1	10.8	76.0	168.0	266.7	365.9	465.6	567.0

(D) All gas										
	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	5.1	10.8	10.9	10.9	11.0	11.0	11.0	11.0
Level 2	–	–	5.1	10.8	28.7	66.8	116.7	166.8	217.1	268.5
Level 3	–	–	5.1	10.8	43.3	110.0	176.6	243.5	310.4	379.2
Level 4	–	–	5.1	10.8	77.0	170.4	270.4	370.7	471.1	574.3

The carbon dioxide emissions vary depending on whether more gas CCS or coal CCS is chosen, and based on the assumptions modelled in the 2050 Calculator. Once again, only the emissions for Levels 1-4 for the 'all coal' and 'all gas' trajectories are shown here; the mixed coal/gas trajectories have intermediate emissions[31]:

Figure B4: Remaining emissions from gas CCS and coal CCS power stations



31 Note: the emissions shown here include a small amount of N_2O and CH_4 as well as CO_2

2A.C Electricity balancing

Context

In the July 2010 report we set out an analytical approach to electricity balancing – see section P 'Electricity Balancing', page 227. Following feedback from the Call for Evidence as well as new in-house analysis, we are implementing several changes to the section. We hope that these updates will contribute to an on-going informed debate around electricity balancing challenges. The low carbon transition to 2050 is likely to trigger new electricity demand and supply patterns and, with it, new balancing challenges.

The July 2010 report addressed the issue of electricity balancing via three steps:

1. A five-day stress test was used to test the capacity of pathways to address potential electricity balancing challenges during adverse weather conditions. Some renewable supply technologies are more intermittent than conventional electricity supply technologies like gas-fired or nuclear power stations, and can trigger balancing challenges. Also, electrifying demand sectors such as heating or transport can further accentuate the range of electricity demand across the day.

   Energy demand and supply need to match at all times. This includes periods of stress, such as significant cold spells in winter (leading to spikes in heating demand) coinciding with a prolonged drop in wind over the whole of the UK and North Sea (leading to troughs in electricity supply). We need to ensure that all pathways to 2050 are capable of maintaining security of supply.

   The July 2010 report's electricity balancing test put forward a five-winter-day stress scenario. This entailed a wind lull in combination with an increase in heating demand. It assumed that over the five-day period onshore wind capacity dropped 33%, offshore wind capacity dropped 43% and heating demand increased 20% from its seasonal average.

   The output of the five-day stress test is a calculation of the percentage of total electricity capacity used during the five-day period under the assumptions of the chosen pathway. Pathways that include higher ambitions for wind supply and/or electrification of heat demand show more stringent electricity balancing challenges, which in some cases can surpass 100% of overall capacity.

2. To counteract possible shortfalls in generation during the five-day stress test (reaching 100% of overall capacity), the July 2010 version of the 2050 Pathways Calculator provides four levels for 'Storage, demand shifting, backup'. These four levels describe different combinations of interconnection with the European mainland, domestic pumped storage capacity, electricity demand side shifting via electric car batteries and other storage opportunities. Section P of the July Report outlines these options in greater detail. As electricity storage and demand shifting capacities are increased to more ambitious levels, the generation shortfalls identified by the stress test are progressively reduced and the electricity balancing challenges can be mitigated.

3. If a chosen pathway still presents an electricity capacity shortfall during the five-day stress test after the storage and demand shifting assumptions have been applied, the 2050 Calculator automatically balances the system via unabated open cycle gas-fired power stations. As gas is seen as the most flexible electricity generation source, it is implemented as the final backup electricity generation source to ensure the grid balances during adverse weather conditions. Thus, all pathways have different assumptions on storage, interconnection and demand shifting imposed by the user, as well as different amounts of back-up unabated gas-fired capacity automatically provided by the Calculator to address any shortfall during the stress test period.

Call for Evidence

The Call for Evidence generated a good response on electricity balancing. We welcome the very broad group of respondents (around 25), who provided detailed ideas, comments and criticism of our electricity balancing approach. The most common theme was that the 2050 Pathways Analysis should address daily, hourly and even half-hourly levels of analysis. There was concern that some scenarios only worked because demand was assumed to be flat across each day and more analysis should be undertaken. Other respondents were concerned that the levels of back up capacity required were significantly underestimated in the pathways and the 'five-day test' methodology was not sophisticated enough to explore this important issue.

We agree that the five-day stress test in the July report was a first, rather simplistic, approach to this important and complicated issue. Following the responses, as well as further internal analysis, we have implemented several changes to the electricity balancing approach. We believe these changes increase the robustness of the electricity balancing analysis of the 2050 Pathways Calculator, however we acknowledge that significant further analysis would be necessary to address fully the concerns of respondents. At the end of this section we set out the further work which may be possible and desirable to incorporate into future updates to the 2050 Calculator. The changes made to this version of the Calculator can be categorised as follows:

- A more comprehensive balancing test calculation;
- A revision of the five-day stress test;
- A new one-day stress test; and
- More prominent visual presentation of electricity balancing as an output of a chosen pathway.

More comprehensive balancing test calculation

The revised electricity balancing stress tests in the 2050 Calculator reflect in greater detail the interlinkages between different parts of the electricity system. They also describe in more detail how the system could address the challenges. We will discuss these under the categories of supply sector changes, demand sector changes and emissions changes.

Supply sector changes

- In the updated stress test, other renewable sectors besides onshore and offshore wind are included in the analysis. Solar, wave power and micro-wind are now separately modelled within the balancing test and have separate generation assumptions for the stress test periods (these assumptions are set out below).
- Any excess electricity generation within a chosen pathway is presumed to assist the electricity balancing effort during the stress test period. This implies that excess generation within chosen pathways cannot be presumed to be available for exporting throughout a whole year.
- Availability of thermal plant capacity during winter times is now more precisely included in the stress test assumptions. It is presumed that maintenance activities are carried out in such a way that thermal plant load factors over the winter period are higher than their annual average. The maximum load factor is different for each power-generation category, but it is presumed to reach 90% for all thermal plants by 2050. Table C1, below, shows our assumptions on maximum load factor capacity for the different power generation categories leading up to 2050.

Table C1: Thermal plant – availability for winter peak

	Description	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
I.a	Gas: combined cycle gas turbine	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
I.a	Oil-fired	80%	81%	82%	83%	84%	85%	87%	88%	89%	90%
I.a	Coal/Biomass	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
I.b	CCS	–	–	50%	63%	77%	90%	90%	90%	90%	90%
II.a	Nuclear	75%	76%	78%	80%	81%	83%	85%	87%	88%	90%

Demand sector changes

- UK external temperatures during the stress test periods are taken from the National Grid's 'Composite weather variable'.[32] The coldest five-day and one-day periods from 2000 until 2010 are taken as reference cases for the new stress tests.
- Heat peak demand now takes into account user choices made in the pathway on insulation and average home temperatures.
- Commercial heat demand is separated from domestic heat demand. National Grid gas demand data shows that during cold weather spells domestic gas demand increases more sharply than commercial heating demand. The new stress tests incorporate this separation of the two sectors. The percentage increase in commercial heating demand is assumed to be only 80% of the percentage increase of domestic heating demand during the stress test periods.
- Air conditioning demand is presumed to be zero during cold periods, with all data centre heat being diverted towards commercial heating.
- Heat pumps are assumed to be less efficient under extremes of temperature compared to average UK conditions. Thus the new stress test has reduced heat pump efficiency assumptions during the five-day winter stress test. This aspect of heat pumps was mentioned in several Call for Evidence responses.

32 http://www.nationalgrid.com

Emission changes

- Finally, emissions from the unabated gas-fired power stations, used to provide back-up capacity, are added to the overall national CO_2 emissions. It is presumed that half of these stand-by gas-fired powerplants are of the closed cycle design (CCGT) and the other half of the open cycle design (OCGT). If stand-by gas capacity is necessary for a selected pathway to overcome the stress-tests, then these emissions are accounted for in the overall national emissions. For the purposes of calculating the emissions, it is assumed that such a stress test occurs once a year.

Revision of five-day stress test

This more comprehensive approach to calculating an electricity balancing stress test leads to several changes to the existing five-day winter stress test outlined in the July 2010 report. Also, more detailed analysis of empirical wind supply and heating demand data led us to alter the assumptions of both available renewable electricity capacity, as well as heat demand increases during the adverse weather conditions.

The revised five-day stress includes the following new assumptions:

- Onshore wind capacity drops to 5% of installed capacity (an 83% drop from average output). This is taken from Poyry wind data 2000-2008.[33]
- Offshore wind capacity drops to 5% of installed capacity (an 85% drop from average output). Also taken from Poyry wind data 2000-2008.
- Small-scale wind capacity drops by 83% from average output, following the drop in onshore wind (Poyry).
- Electricity generation from wave capacity drops by 43% from average output. This presumes that during a five-day wind lull wave energy gradually declines over the period, due to the drop in wind.
- Solar capacity drops by 80% from average output. This is in line with variations in sunshine during winter periods.
- The efficiency of air source heat pumps is assumed to drop by 10% and ground source heat pumps by 1%.
- Overall temperature in the UK during the five-day period is presumed to be minus 1.4 degrees (based on the average temperature across the UK over the coldest five-day period over 2000-2010, using National Grid's 'Composite weather variable').

A new one-day stress test

To address the concerns expressed by several Call for Evidence respondents that more short-term balancing requirements need to be addressed by the 2050 Pathway Analysis, we included a second stress test. This new one-day stress test attempts to model severe adverse weather conditions during a one day period in winter. The following assumptions are made:

- Onshore wind capacity drops to 2.8% of installed capacity; a 92% drop from average output (Poyry).
- Offshore wind capacity drops to 2.7% of installed capacity; a 91% drop from average output (Poyry).

33 Poyry (2009) *Impact of intermittency: How wind variability could change the shape of British and Irish electricity markets*

- Small-scale wind capacity drops by 92% from average output (Poyry).
- Solar capacity drops by 80% from average output.
- Electricity generation from wave energy is not presumed to decline.
- The efficiency of air source heat pumps drops by 10% and ground source heat pumps by 1%
- Overall temperature in the UK during the one day is presumed to be minus 1.85 degrees.

More prominent visual presentation of electricity balancing as an output of a chosen pathway

An additional visual alteration has been made to the 2050 Pathways Web tool. The new electricity balancing stress tests as well as the Level 1-4 choices on storage, interconnection and back-up are now together in the same section on the right-hand side of the 2050 Web tool. The purpose of this is to show that the electricity balancing challenges should be seen as an output of a chosen pathway, giving more prominence to the energy security implications of a pathway alongside its emissions implications.

The pathways analysis section (1A) of this report describes the balancing challenges under different 2050 pathways.

Further work on electricity balancing

The technical and market requirements to ensure the electricity system balances at all times will clearly change in the face of new sources of demand and supply. The Government recognises that 2050 balancing analysis will need to be both deepened and broadened. DECC will continue to carry out analysis on the physical need for balancing technologies (including backup, storage, demand response and interconnection), but also ensure that the market structure reflects these physical requirements. In particular, the Electricity Market Reform White Paper to be published later in 2011 will set out Government action to enable new technologies, including demand response, storage and interconnection, to enter the market effectively.

The 2050 Pathways Analysis indicates that the build-up of renewable generation technologies twinned with a greater role of electricity in the heating sector is likely to create significant electricity balancing challenges. The revised electricity balancing approach set out in this report is still high level. Call for Evidence respondents identified two main issues on electricity balancing which will necessitate further research and analysis to address: other electricity storage and heat storage. These are areas which are not yet incorporated in the revised 2050 Calculator, but could in the future become significant in the electricity balancing system of the UK.

Other forms of electricity storage

Several Call for Evidence respondents questioned whether we should be more specific about which other electricity storage options besides pumped storage and electric car batteries might become relevant for the UK in the future. We acknowledge that other technologies may come on stream. Most prominently mentioned in the Call for

Evidence is the future possibility of using hydrogen as an electricity storage option. Hydrogen as a potential electricity storage option is dealt with in more detail in the hydrogen section of this publication (see Section 2A.A).

Other potential electricity storage technologies are being discussed and could make contributions in the future. These include ideas around utilisation of used-car batteries in designated storage areas ('battery parks'), gravel energy storage, flywheels or compressed air energy storage. This is in no way a comprehensive list of potential electricity storage technologies – it is a fast-moving and innovative area, which we will need to continue to monitor.

Heat storage

Increase in heat demand is particularly marked during brief cold weather conditions in the UK. These spikes in demand are covered by a robust gas storage and delivery infrastructure in today's energy system. If electrification were to play a more prominent role in the heating sector of the future, these spikes would need to be addressed by a similarly robust infrastructure.

Storage of heat for domestic purposes could play an important role in managing demand from this sector. Opportunities might lie in smoothing heat demand spikes via domestic and/or community heat storage options. Several options were mentioned in the Call for Evidence. For instance, a possible 'smarter' form of heat storage could involve an integrated solution that combines multiple sources of energy and storage (e.g. hot water). This could help meet the wind intermittency and peak heating challenges. More sophisticated home and/or community heat storage solutions might emerge over the coming decades. These could have the potential to substantially mitigate future balancing challenges.

2A.D Bioenergy conversion processes

Raw biomass has to undergo a conversion process before it is transformed into usable liquid, solid or gaseous fuel – from complex chemical procedures to simply drying out. In the course of these processes there is an associated level of efficiency loss, the severity of which is dependent on both the physical state the biomass is converted from, and what it is being converted to. For example, the process of converting dry biomass and wastes (such as crops and collected straw) to solid hydrocarbons has a lower associated energy loss (and therefore higher efficiency) than converting that same dry biomass to a gaseous fuel.

Call for Evidence

In the July 2010 report we set out our assumptions on conversion efficiencies for different bioenergy processes. For more details on these, see section F, page 160 – 162 of the July report.

The bioenergy and waste chapter was one of the most popular topics for comment in the Call the Evidence. Over sixty responses were received with a bioenergy angle – a significant proportion of the total – with many respondents making at least a passing reference. In light of the submissions received, we examined and made changes to our assumptions in two areas:

- The efficiencies associated with converting biomass into usable hydrocarbon fuels;
- The calorific content of woody biomass.

The evidence we received during the Call for Evidence made a number of points. Some respondents questioned the inclusion or omission of certain conversion technologies from the Calculator. Specifically, it was questioned whether biomass torrefaction should have been accounted for, and whether gasification should have been left out (given its relative immaturity). Some detailed responses focused on the efficiency figures we had used in our conversion fixed assumptions, and cited new data which suggested that updates would be needed to paint a more accurate picture. Finally, one respondent highlighted an error in our fixed assumptions on the calorific content of woody biomass.

For this update we have adjusted both the data and treatment of biomass conversion technologies in the Calculator, and have corrected the woody biomass figure. Evidence on other aspects of bioenergy was also considered – see Part 2B of this report for more details.

Drivers and enablers

Technologies available

Biomass torrefaction is a thermo-chemical treatment where the biomass loses around a fifth of its mass, but only 10% of its energy content. It was not explicitly mentioned in the July 2010 report, which some organisations suggested was an error given the benefits from its practical application are under thorough investigation by a number of energy companies. Torrefaction was in fact considered in the previous report, but had been accounted for within the category 'various mixed dry biomass to homogenous dry solid fuel conversions' (a process with 90% efficiency). This may have led to confusion. We are happy to clarify that both the updated and previous versions of the Calculator considered torrefaction as being one of the available technology routes.

A small minority of respondents suggested that gasification was not a sufficiently mature technology to be considered in the Calculator. However, we believe that given the technological progress made so far and the 40-year timeframe of the Calculator, inclusion of gasification is legitimate. Research literature indicates that although gasification has yet to be demonstrated at a large-scale level, there are already a series of successful small-scale demonstration projects taking place. An NNFCC roadmap looking at the technology suggests that entrained flow gasification plants capable of processing up to 3,000 tonnes of biomass per day could be online before 2015.[34] This is a significant scale of activity, and it is quite possible to imagine this improving further out to 2050.

We did not receive any responses suggesting we had missed other significant technology options that could affect our treatment of biomass conversion.

Improvements over time

A point noted by a number of respondents was that our treatment of conversion technologies lacked subtlety by maintaining the efficiency figures as fixed from 2010 through to 2050. Having reviewed the evidence, we agree that there is a good case for separately capturing the potential improvements which can be made in these areas over the next ten years. As a result, the Calculator now includes a set of fixed assumptions for conversion efficiencies from 2010 to 2019 and a separate set for 2020 to 2050. We have not assumed any further improvement beyond 2020 because it is increasingly difficult to predict with any level of certainty, and the closer a process is to its theoretical maximum efficiency, the less cost-effective and achievable further gains are likely to be.

Conversion efficiencies

The new efficiency numbers for each conversion process are set out in Table D1. Further details for these assumptions can be found on pages 161 and 162 of the July report.

Table D1: Efficiencies of bioenergy conversion processes

Process	2010-19 efficiency	2020-50 efficiency	Reference/comments
Various mixed dry biomass to homogenous dry solid fuel conversions (e.g. via torrefaction)	90%	95%	Increased figure for 2020 onwards based upon E4Tech Call for Evidence response suggesting that many larger power and heat applications will simply use chips as these are cheaper – with conversions therefore approaching 100% efficiency.

34 NNFCC (2009), *Review of Technologies for Gasification of Biomass and Wastes, E4Tech*

Process	2010-19 efficiency	2020-50 efficiency	Reference/comments
Dry biomass and waste to liquid hydrocarbons	37%	45%	This is a weighted average efficiency score for 2nd generation ethanol and biomass-to-liquids (BTL) plants. These figures are derived from E4Tech analysis on 2nd generation ethanol.[35]
Dry biomass and waste to gaseous hydrocarbons	58.5%	66.2%	On the basis of a recent study, we agree that there is potential for increasing the efficiency level because of improved bio synthetic natural gas processes.[36] However, this technology is only likely to be sufficiently mature to achieve these rates from 2020.
Wet biomass and waste to gaseous hydrocarbons	75%	85%	Previous modeling exercises have used 75% as the best estimate for current efficiency levels[37], but manufacturers expect improvements of around 10% over the next decade.[38] The previous version of the Calculator used 80% throughout the time period.
Wet biomass and waste to liquid hydrocarbons	31.8%	38.2%	These figures have been reduced to take into account the heterogeneity of UK wet feedstocks, and therefore the efficiency losses involved in sorting and processing them. Domestic wet biomass could come from a wide range of sources including manure, sewage sludge, food waste and macro-algae.
1st generation crops to liquid hydrocarbons (e.g. esterification)	31%	31.6%	See July report. Original figure of 31% derived from conversion of oil seed rape, seen as the most likely source of 1st generation fuel and bioethanol production.
2nd generation energy crops to solid hydrocarbons	90%	95%	See 'various mixed dry biomass to homogenous dry solid fuel conversions.'
2nd generation energy crops to liquid hydrocarbons	37%	45%	See 'Dry biomass and waste to liquid hydrocarbons'.
2nd generation energy crops to gaseous hydrocarbons	58.5%	66.2%	See 'Dry biomass and waste to gaseous hydrocarbons'.
Gaseous waste to gaseous hydrocarbons	100%	100%	See July report, no change.

35 E4Tech, (2009) *Focus for Success*, report for the Carbon Trust

36 E4Tech (2010) *Potential for bioSNG production in the UK*, Available at: http://www.nnfcc.co.uk/

37 NERA/AEA (2009) *The UK Supply Curve for Renewable Heat*, report for DECC

38 SOAS (2004) *Feasibility Study for a Central Anaerobic Digestion Plant in Aberdeenshire*, Available at: http://www.aberdeenshire.gov.uk

Biomass calorific content

In the first version of the Calculator, we made an error in the stated calorific value of woody biomass. Sheet VI.a in the Excel version of the Calculator gives the calorific value of wood as 13.7 GJ/odt[39] (3.8 TWh/Modt). This was too low, as the calorific value for 'oven dry' wood is in fact 18.6 GJ/t. The 13.7 GJ/t figure is the calorific value of a tonne of 'as received' wood, which is effectively 75% wood and 25% moisture. We have now amended this in the Calculator.

Trajectories for bioenergy and waste

We have not made any alterations to the four trajectories considered in the Calculator. These each represent different combinations of options for converting the raw biomass resources generated by various lever in the Calculator into different proportions of usable fuels.

- Trajectory **A** is a 'mixed' trajectory, with energy crops used to make liquid biofuels, all remaining dry biomass used as solid fuel, and all wet biomass used to make gas.
- Trajectory **B** uses energy crops and dry biomass as solid fuel, with all wet biomass directed towards production of gaseous hydrocarbons.
- Trajectory **C** uses all available resources to make liquid fuel.
- Trajectory **D** uses all resources to make gas.

These four trajectories effectively represent proxies for the prioritisation of biomass resources in the Calculator, as the physical state of the biofuel is a key determinant of its final destination. As the 2050 work is designed to allow users as much flexibility as possible in manipulating the whole energy system, the Calculator does not make any assumptions on the prioritisation of bioenergy by sector, and represents converted biomass as being directly substitutable with the fossil fuel equivalent (i.e. biogas with natural gas, liquid biofuel with oil, and solid biofuel with coal). In the Call for Evidence, respondents were broadly happy with this approach, with the proviso that the Government notes the importance of prioritisation and sustainability in its long-term strategy for biofuels. The Government agrees that these are factors of significant importance, and it is hoped that the 2050 analysis will in the future help to throw light on these issues.

39 Odt = oven-dried tonne

2A.E Biomass power generation

Solid biomass is being burnt in many power stations today as a low-carbon alternative to coal. Solid biomass can come from a range of sources, such as energy crops or wood, but often needs to be converted before being used in power plants (see Section 2A.D Bioenergy conversion processes). The 2050 Calculator treats solid biomass as a substitute for coal power generation, and so solid biomass electricity generation can occur when solid biomass production is selected in the Calculator's bioenergy levers. However, in the July 2010 version of the Calculator, biomass power generation was limited by the availability of coal power generation, rather than existing as a category of power plant in its own right. As a result, solid hydrocarbon capacity (coal/biomass) was assumed to decline to 1.3 GW by 2025 based on dedicated coal plant retirement rates. This had the result of limiting biomass electricity generation to 1.3 GW per year from 2025 to 2050.

Call for Evidence

A number of respondents in the Call for Evidence highlighted the importance of biomass used for electricity generation and argued this should not be phased out with coal plant retirement, but rather that a new option should be provided where plants dedicated to biomass combustion were constructed. The National Farmers Union and Orchard Partners London Ltd highlighted the potential role of electricity generation from solid biomass. Biomass electricity generation is an existing technology which is already deployed in the UK.

In response, for this update we have re-examined these assumptions and created a new choice in the 2050 Calculator. This will allow the user to choose to generate electricity from biomass by either maintaining the existing biomass plant capacity or by building new plants.

The context

Electricity generation from biomass fuel without CCS was limited in the July version of the 2050 Calculator to 1.3 GW from 2030 to 2050. This was because biomass is treated as a substitute for fossil fuels and solid biomass was treated as a substitute for coal, when available.[40] The solid hydrocarbon (coal and biomass) retirement rate was held as a constant and based on the retirement rate of coal plants.[41] This is shown in Table E1 overleaf:

40 Coal and solid biomass are a substitute given the same energy content. So, 1kg of coal is not considered equivalent to 1kg of biomass but 1TWh of coal is considered equivalent to 1TWh of biomass. The original biomass extracted also faces conversion losses before it is used as a direct substitute. Please see Section 2A.D of this report.

41 Closure rates for coal 2016-2025 are the average rate in the Updated Energy Projections (summer 2010) from DECC.

Table E1: Solid hydrocarbon installed capacity in July 2010 version of the 2050 Calculator, cumulative (GW)

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Solid hydrocarbon capacity	23.0	23.0	15.8	8.6	1.3	1.3	1.3	1.3	1.3	1.3

This approach meant there was no option for the user to choose to build solid biomass electricity generation plants. Biomass power generation is a technology which has already been deployed.[42] In 2009 the UK had 400 MW installed capacity of dedicated biomass plants, and 255 MW capacity of biomass co-firing plants, which can burn both coal and biomass.[43] DUKES data shows co-firing plants used 6.88 TWh (591 ktoe) of biomass input fuel in 2009.[44] The new version of the Calculator allows the user the option to choose electricity generation from biomass.

Current treatment of bioenergy in the 2050 Calculator

Bioenergy is a scarce resource with a wide number of potential applications in energy using sectors. The Calculator simulates the first issue by providing feasible trajectories for bioenergy supply options from: domestic waste, agriculture, marine algae and imports. The use of biomass in transport, power-generation, heating and industry will depend on the cost of the technology and competing de-carbonisation pathways. Therefore, in the absence of costs, the Calculator makes a simplifying assumption by not assuming where biomass will be used. Instead, biomass is treated as a perfect substitute, in terms of energy content, for fossil fuels where:

- Solid biomass substitutes for coal
- Liquid biomass substitutes for oil, petrol, aviation fuel and diesel
- Gaseous biomass substitutes for natural gas

It is assumed biomass will be burnt ahead of fossil fuels in sectors which demand hydrocarbon fuel. A pertinent choice for biomass is therefore which form to convert raw biomass into in order to substitute different fossil fuels. The conversion assumptions are discussed in Section 2A.D Bioenergy conversion processes.

The drivers and enablers

National carbon reduction targets and EU level agreements provide important drivers for the use of bioenergy in electricity generation. The EU's Renewable Energy Directive sets an EU target of 20% of energy from renewable sources by 2020. The Renewables Obligation scheme incentivises the generation of electricity from renewables. Under the banded Renewables Obligation (RO) approach, different biomass-to-electricity processes qualify for different incentives.[45]

Support for all renewable technologies, including biomass, is currently under review as

42 Installed capacity of 655 MW includes dedicated and co-firing plants, taken from DECC (2010) *The Renewable Energy Statistics database/Biomass plus co-firing operational in 2009*. https://restats.decc.gov.uk

43 DECC (2010) *The Renewable Energy Statistics database/Dedicated Biomass and co-firing operational in 2009* https://restats.decc.gov.uk/app/reporting/decc/datasheet

44 *Digest of UK Energy Statistics* – Chapter 7, Renewable sources of energy – Chart 7.1, conversion from ktoe to TWh was taken as 1.163e-2

45 HM Government (2010) *2050 Pathways Analysis*. See table F1 in Chapter F: Bioenergy and Waste.

part of the periodic RO Banding Review. New support levels will be announced later this year and come into force from April 2013.

Electricity generated from biomass occurs both within dedicated biomass plants, where the single feedstock is biomass, and in mixed and dual-fire plants where the feedstock can be varied. For mixed and dual-fire plants the main driver will be the relative costs of biomass and the fuel it is substituting, although the maximum level of biomass used is frequently constrained by the technical capability of the boilers in the plant.

For dedicated biomass plants, the investment in new capacity will similarly be driven by the price of biomass as well as the availability of suitable sites. Planning constraints and technical constraints, such as air quality, may affect short-term build rates; but the consensus at an experts workshop held in December 2010 was that in the long-term, the main constraint was the total bioenergy supply to the UK, both UK-grown and imported.[46] The maximum supply of solid biomass available in the Calculator is therefore used to limit the Level 4 trajectory.[47]

The Levels

We have added a new lever to the Calculator with four trajectories for biomass electricity generation installed capacity. The user's choices for this lever combined with the choices for the supply of biomass will provide a range of new outputs for low carbon electricity generation.

Three drivers are modelled within the one lever, which together give the total installed capacity of biomass and coal fired electricity generation:

- New build dedicated biomass plants
- Current coal plant stock retirement rate
- Conversions or change in feedstock of current coal plant stock.

Each of the drivers is addressed below and we begin by describing the baseline, which is used in the Level 1 trajectory.

Baseline

The Level 1 installed capacity of 600 MW is the sum of dedicated biomass plants installed in 2009 (397.9 MW) and 192.5 MW currently under-construction.[48] Co-firing is not included in this baseline because these plants are captured in the Calculator in mixed and dual fuel coal plants under the coal trajectory.

New build dedicated biomass plants

New build trajectories will be driven predominantly by the relative cost of biomass compared to other fuel sources and power generation. Level 4 therefore uses all available biomass under the most heroic scenarios of domestic biomass production

46 An industry workshop on biomass electricity generation, was held at DECC in December 2010

47 Minimum levels of solid biomass are automatically allocated to the following sectors: industry, heat, agriculture. The remaining solid biomass is available for use in suitable power plants.

48 We have assumed a baseline of 600 MW in 2010 to account for those projects under construction. However, installed capacity in 2010 will not be at this level. This is a simplifying assumption. Figures for current installation and under construction taken from: *DECC (2010) Renewable Energy Statistics database*, https://restats.decc.gov.uk

and biomass imports. Levels 2 and 3 derive annual build rates from economic modelling and international comparisons. The trajectories are based on the following assumptions:

Table E2: Biomass electricity generation levels and assumptions

Level	Annual build rate (linear from 2010)	Evidence
Level 1	0	Baseline assumption of no further biomass build
Level 2	180 MW	Sinclair Knights Merz (SKM) analysis high ambition scenario (average from 2010-2030)[49]
Level 3	300 MW	Maximum historical dedicated biomass power generation build rates (Sweden and Italy achieved 285 MW p.a., 2000-06)[50]
Level 4	550 MW	Maximum available solid biomass (in the Calculator) used for electricity generation after minimum demand from agriculture, heating and industry is accounted for.[51]

Applying the linear trajectories above to 2050 gives the following levels for installed capacity:

Table E3: Biomass electricity generation installed capacity, cumulative (GW)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Level 2	0.6	1.5	2.4	3.3	4.2	5.1	6.0	6.9	7.8
Level 3	0.6	2.1	3.6	5.1	6.6	8.1	9.6	11.1	12.6
Level 4	0.6	3.35	6.1	8.9	11.6	14.4	17.1	19.9	22.6

The assumptions of load factor, thermal efficiency and parasitic load:

- Load factor = 90%, according to the expert workshop held in December 2010
- Thermal efficiency = 35% [52]
- Parasitic load, the energy the plant needs to generate electricity = 5%

49 Sinclair Knights Merz (2008) *Quantification of the constraints of the growth of UK renewable energy capacity*

50 International Energy Agency (2010) *Renewables information – Solid Biomass net electricity generation*

51 Maximum available biomass is 638 TWh based on heroic levels of imports and domestic production and converting most biomass into solid biomass (where technically feasible) and minimum demand from heating, industry and agriculture. To reach this level would involve a trajectory of 558 MW per year but this was rounded down to 550 MW given the heroic levels of effort.

52 The conversion of biomass into useful format is already accounted for in the Calculator, for example converting straw and wood to input fuel is assumed to have a 10% conversion loss, see Section 2A.D. Therefore there is no need to account for the fuel conversion within this calculation.

Current coal plant stock retirement rate

The coal retirement rate baseline has also been adjusted based on further evidence from DECC's Updated Energy Projections (UEP).[53] The changes are set out in the table below:

Table E4: Coal plant remaining capacity following retirement of plants (GW)[54]

Plant type	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal	28.1	28.1	22.8	16.5	8.0	1.2	0.0	0.0	0.0	0.0

The conversion of existing coal power plants to biomass may hasten the use of coal in the existing fleet, since rather than retiring, plants are converted and their generating life is extended. The output of both the coal retirement and biomass installed capacity is a single trajectory for both biomass and coal electricity generation, since the Calculator treats both as substitutable solid hydrocarbons. The user's choices on biomass supply will determine the fuel mix. In a scenario where a high level is selected for biomass electricity generation but a low level for bioenergy production or import, then the biomass plants are assumed to burn unabated coal instead of biomass.

Coal plants may also switch to biomass, because of either an increased use of biomass input fuel or a full conversion to a dedicated biomass plant. To take account of this effect and avoid inflating installed capacity of biomass power plant in the medium term (2015-2030), when biomass increases and coal retires, we have increased the coal retirement rate as outlined below.

Conversions or change in feedstock of current coal plant stock

This should not be considered as a hastening in the retirement of coal power plants but rather accounts for the effects of switching in existing coal power plant stock from coal to biomass feedstock. Evidence from the industry workshop in December 2010 suggested the rate of conversion is difficult to quantify, since there is currently no clear inclusion/exclusion criteria to classify a plant's conversion from coal to biomass electricity generation. Conversions could include a slight tweaking to boilers or a whole plant conversion, and due to this wide range of possible conversions there was little confidence in a minimum or maximum rate of conversion. Support for conversion within the RO is currently being considered as part of the 2013 RO Banding Review and this is likely to determine the rate of uptake. Therefore, in the absence of further evidence we have increased the coal retirement rate by 0.5 GW, 1 GW and 2 GW in total for Levels 2-4. This produces the installed capacity of coal plants under different trajectories as set out in Table E5.

53 DECC (2010) *Updated Energy Projections*. Taken from a high fossil fuel price scenario. http//:www.decc.gov.uk/en/content/cms/statistics/projections/projections.asp

54 Closure rates for coal 2010-2025 are taken from 2010 UEP projections from DECC applied to 2010 figures (assumed to be DUKES figure for 2009). The annual closure rate between 2025 to 2030 is taken as the average UEP closure rate between 2010-2025. The baseline figure of 28.1 GW installed capacity for 2007 includes both dedicated coal plants 23 GW, plus 95% of 5.4 GW of dual fuel oil and coal/biomass plants are assumed to be from solid hydrocarbons (coal/biomass). The figure of 5.4 GW is from the 2007 figure of 6.9 GW of mixed and dual-fired plants minus 1.5 GW assumed to be gas fired.

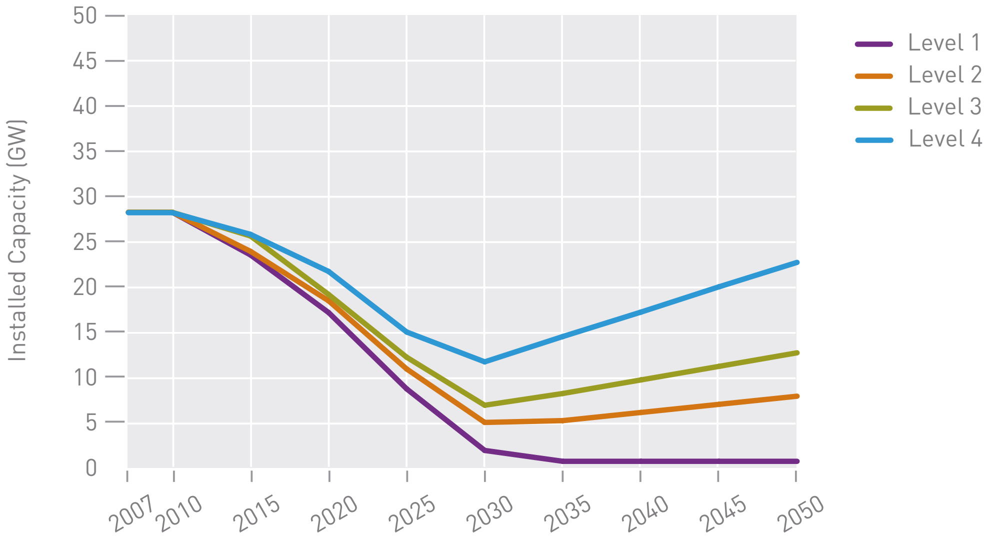
Table E5: Installed capacity of coal plant stock under the four levels (GW)

Level	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
1	28.1	28.1	22.8	16.5	8.0	1.2	0.0	0.0	0.0	0.0
2	28.1	28.1	22.3	16.0	7.5	0.7	0.0	0.0	0.0	0.0
3	28.1	28.1	22.3	15.5	7.0	0.2	0.0	0.0	0.0	0.0
4	28.1	28.1	22.3	15.5	6.0	0.0	0.0	0.0	0.0	0.0

The feedstock (coal-biomass mix) will be determined by the user's choices of biomass supply, where solid biomass is assumed to be used before coal where available.

The trajectories which result from the combination of these choices produce U-shaped curves, for Levels 2-4 reflecting the initial coal retirement and subsequent biomass uptake. These are shown below:

Figure E6: Solid hydrocarbon (coal and biomass) installed capacity trajectories to 2050 (GW)



2A.F Offshore wind Level 4

In the 2050 Pathways Analysis report in July 2010 we set out four levels of deployment for offshore wind; see section J, page 188 of that report. During the Call for Evidence a large number of respondents raised points on offshore wind, with around 35 respondents referring to this technology and some of them including more detailed responses.

Call for Evidence

Most responses focused on the levels of ambition outlined by the Levels 1-4, about which respondents held differing views. A number of respondents considered the levels overly ambitious, noting the significant technical challenges of working far offshore, the development of supply chains and the need for extensive grid interconnection. However, other respondents felt that the upper level of effort indicated by Level 4 in particular was not sufficiently high, referring to the 2010 Offshore Valuation report which suggested a higher level of potential for offshore wind.[55]

It was also noted that the 2050 Calculator was constructed around considerations of technical feasibility, not behavioural decisions about whether to build offshore wind. The user of the Calculator would need to factor in such behavioural considerations when choosing the level.

It was noted that the capacity factor (or load factor) for offshore wind is likely to change over time rather than being fixed at 35% for 40 years, as is the case in the July version of the Calculator. The capacity factor of a turbine is derived from the turbine availability, the wind speed curve in that location and the turbine's technical parameters. Some respondents felt that technological improvements would drive the capacity factor higher, while others noted the significant challenges of maintaining functioning turbines which are located long distances from the shore and with poor weather conditions.

There were a number of comments about the importance of making use of excess electricity generation during periods of high wind through secondary energy sources such as hydrogen – see Section 2A.A 'Hydrogen'. Additionally, the impacts of periods of low wind have been considered in Section 2A.C 'Electricity balancing'.

In response to the Call for Evidence we have modified the Calculator assumptions for the offshore wind sector in two ways: (i) by increasing the Level 4 to reflect the anticipated potential expansion of floating turbine technology; (ii) modifying the capacity factor so that it gradually increases from 35% in 2010 to 45% in 2035, affecting all levels of effort.

55 Offshore Valuation Group (2010) *The Offshore Valuation*

Enablers

Increased ambition for Level 4

In response to the Call for Evidence data and following recent developments in floating wind technology and discussions with stakeholders, it was felt appropriate to increase the build rates in Level 4 to better reflect the upper limits of technical potential.

A review of the offshore wind supply chain was carried out for both fixed and floating offshore wind turbines. As a result, for fixed wind turbines the build rate has been maintained at the same levels as the previous Level 4 until 2020 and then increased up to a maximum of 6 GW/y, reaching a maximum fixed capacity of 120 GW which is maintained, by replacing retired turbines, up to 2050. This capacity results from the consideration of maximum build rates; it is similar to the output of independent scenario runs by The Crown Estate to consider the seabed area potentially available for fixed offshore turbines in UK waters.[56] The fixed offshore turbine capacity also closely correlates with the maximum capacity for fixed offshore turbines stated in the Offshore Valuation report.[57]

In the absence of a current floating turbine industry there is little data available to suggest how this sector will expand in future. For the purposes of the 2050 Calculator we have assumed a low initial build rate from 2020. This draws on evidence from the company Statoil and others, and reflects the need to learn from demonstration projects and establish new supply chains. From 2030 onwards the installation of floating wind is assumed to have an annual growth rate of 30%, peaking at a maximum build rate of 6 GW/y. This reflects the view that it will eventually become preferable to build floating rather than fixed turbines, as the remaining space for fixed turbines is subject to more constraints, and with the increasing challenges of building fixed turbine foundations in deeper waters. The build rates outlined here result in 116 GW of maximum floating wind turbine capacity which is maintained through replacement of retired turbines up to 2050.

The area available in which floating turbines could be installed is not considered to be the primary constraining factor by 2050. This is based on data from The Crown Estate which estimates that the area potentially available for floating turbines in UK waters is so large that it would be unrealistic to fill all of this space with floating turbines by 2050.[58] However the floating turbine build rate is expected to plateau before the maximum potential sea area has been planted with turbines due to the harsh working conditions far out to sea; long distances from shore for installation, interconnection and maintenance; and a shortage of deep water assembly sites for floating wind turbines in UK waters. Some demonstration models of floating turbines are currently assembled in water at least 100m deep and then towed vertically to their mooring site.[59] However, the UK has a shortage of deep-water ports so at such high build rates floating turbines may have to be towed from deep assembly sites in other countries. There are alternative

56 The Crown Estate used the Marine Resource System (MaRS) database and calculated the best 80% of offshore resource available under both technical and non-technical parameters, removing an 8km coastal buffer. This provided a maximum capacity of 123 GW for fixed offshore wind turbines, using a standard 2.5 MW/km^2 turbine density.

57 Offshore Valuation Group (2010) *The Offshore Valuation* notes that the maximum available offshore wind capacity is 116 GW for fixed offshore wind turbines, using a 20% practical constraint level.

58 The Crown Estate used the MaRS database to estimate that using the best 30% of offshore resource available under both technical and non-technical parameters already represented around 255 GW of floating offshore wind turbines.

59 Statoil evidence.

floating turbine models which may not require such deep water. There may also be the possibility of assembling and towing turbines horizontally and flipping them vertically at the mooring site, and this technology may be required under the high build rates for floating wind from 2030 onwards.

Overall, the revised Level 4 aims to present an extremely ambitious but ultimately deliverable scenario which reflects the outer limit of technological ambition for both fixed and floating offshore wind turbines. The total overall capacity of 235 GW for offshore wind looks sufficiently ambitious in the context of reports such as the 2009 BVG Associates report for The Crown Estate which notes that for the whole of the EU "the European Wind Energy Association forecasts 120 GW of offshore wind operating by 2030, which in turn fits well with an eventual capacity of 150 GW, in line with EU energy strategy looking to 2050".[60]

Revised capacity factor affecting all offshore wind Levels 1-4

There was a general consensus from stakeholders that retaining the current 35% load factor fixed to 2050 is too conservative. At a stakeholder workshop it was suggested that the capacity factor could rise based on the high performance of new turbines and expected improvements to current availability. Following further analysis of evidence, the capacity factor has therefore been increased to 45% from 2035 onwards.

The capacity factor depends on the size of the turbine, the wind speed distribution (improving with distance from shore) and the availability of the turbine (worsening with distance). An analysis of expected output in UK offshore sites based on actual wind speed data supports a 45% capacity factor under 90% availability. In the figures modelled here the load factor increase takes place gradually (40% in 2025 and 45% in 2035) as the capacity factor is the average of the total turbine population which will include older turbines until they are replaced after their 20 year life span.

Table F1: Revised capacity factor increasing over time:

2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
28%	35%	35%	37%	40%	43%	45%	45%	45%	45%

The clarity of the Calculator is maintained by applying the revised capacity factor to all levels of effort, rather than having different capacity factors for different levels. This change has minimal effect on Level 1 where the last new build occurs at 2020.

The Levels

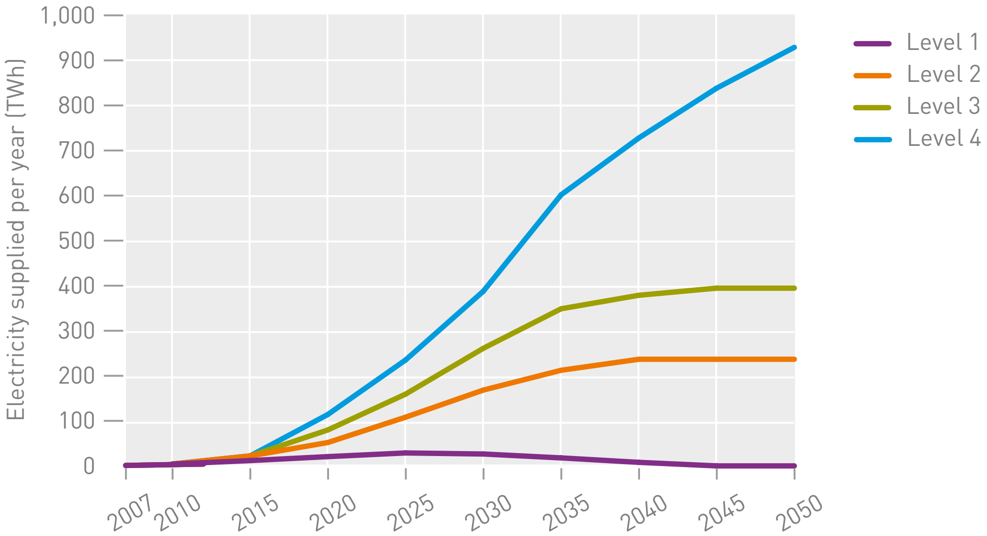
In summary, the revised Level 4 for offshore wind reaches 236 GW installed capacity by 2050, of which 120 GW is comprised of fixed turbines and 116 GW is floating turbines. This generates 929 TWh/yr of electricity at 2050, assuming a 45% load factor; about double the electricity generated under Level 4 in the July 2010 version of the Calculator (430 TWh/yr).

60 BVG Associates (2009) *Towards Round 3: Building the Offshore Wind Supply Chain*

Table F2: The cumulative capacity of the offshore wind levels (GW):

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	0.4	1.3	3.8	6.3	8.2	7.0	4.5	2.0	0.0	0.0
Level 2	0.4	1.3	7.2	16.0	30.8	44.6	53.8	60.0	60.0	60.0
Level 3	0.4	1.3	7.2	24.6	45.4	69.2	88.4	96.0	100.0	100.0
Level 4	0.4	1.3	7.2	35.2	67.0	102.8	152.5	184.5	212.5	235.5

Figure F3: Trajectories for electricity generation from offshore wind



2A.G Tidal range capacity factor

In the 2050 Pathways Analysis report published in July 2010 we set out four levels of deployment for tidal range. See Section K, page 195 of that report.

Call for Evidence

The tidal range sector did not receive many comments, with around 10 respondents commenting on this sector, a few of those in detail. The views submitted were generally supportive of the approach taken and the outputs developed. It was noted that the step changes observed at each level of effort are appropriate to a sector where there is a small number of large projects. Stakeholders also noted that although this renewable energy source is intermittent, it is also highly predictable and therefore can be easier to accommodate into the electricity supply system than other intermittent supply sectors.

A few respondents noted that two-way capture, with generation on both the ebb and flood tides, could provide less total energy output but do so more continuously, which could more closely match the energy demand profile. It was also noted that different combinations of specific named tidal range sites could be considered for the illustrative scenarios.

One respondent (Parsons Brinckerhoff) noted that the capacity factor previously applied to all tidal range sites would only be applicable to the high range west coast sites which would also be expected to be developed first. A lower capacity factor should therefore apply to sites with a lower tidal range, particularly down the east coast.

Enablers

We have reviewed the evidence submitted. We agree that different combinations of named tidal range sites could be considered in the scenarios proposed; however the scenarios offered are only illustrative examples of the sequence in which much of the UK resource could be captured over time. Other scenarios may be imagined which would offer similar generational outputs.

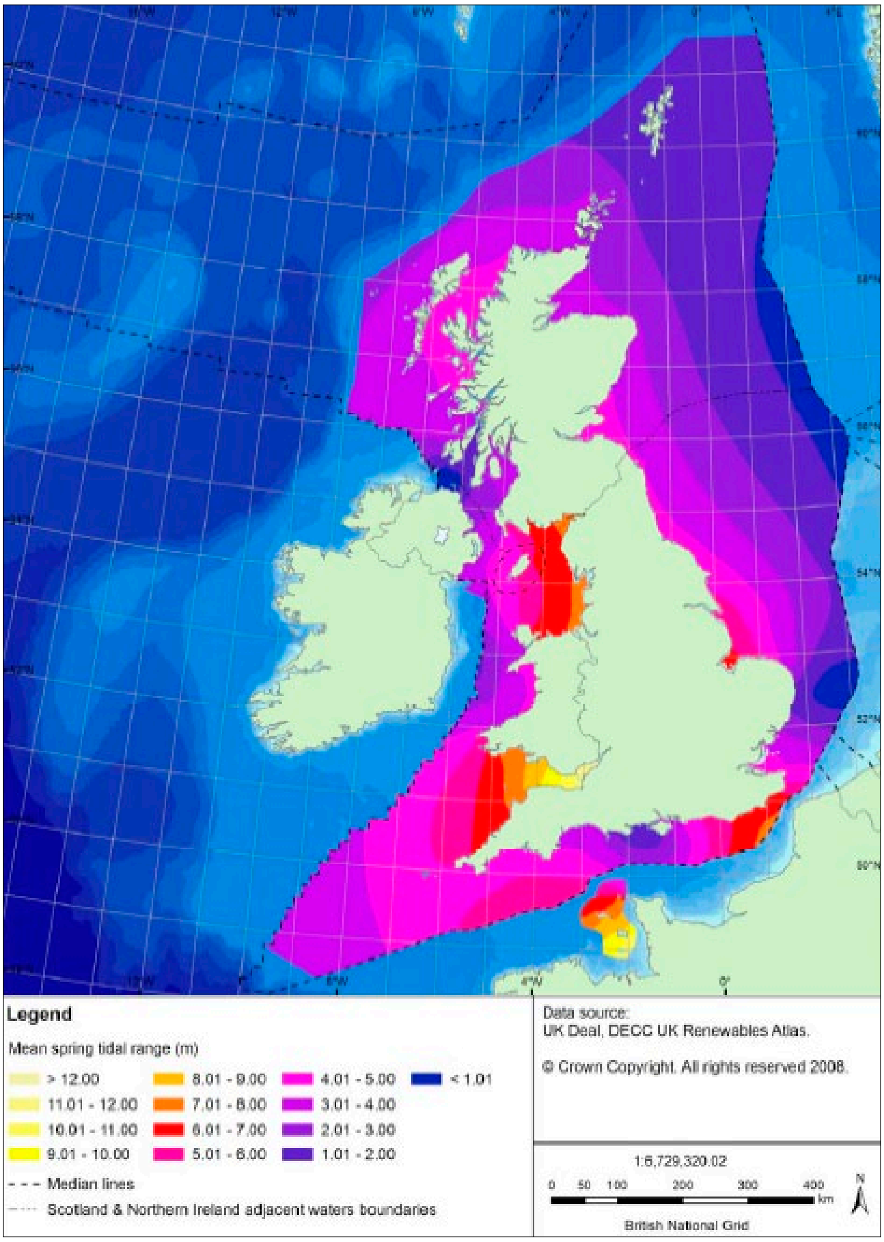
Regarding two-directional tidal range generation, it was felt that this might indeed produce electricity at times when it has more value, i.e. more closely matching the demand profile, but this would need to be balanced by the extra complexity and cost of installing two-way caissons and turbines. Additionally, the 2050 Calculator averages energy demand and supply over a year rather than measuring fluctuations, and so the benefit of more continual generation cannot be modelled. Therefore the Calculator continues to model unidirectional generation but we note the possible balancing role which two-way generation could offer in the future.

We agree with the view that a different capacity factor should be used for different sites, depending on the difference in height between high and low tide. The diagram below illustrates how the mean tidal range can vary at different sites around the UK's coast line. We have responded by separating out the sites with lower tidal ranges (five metres and under) and applying a capacity factor of 20% to those sites, compared to the 24%

applied to higher range sites. This is an estimate based on data supplied by Parsons Brinckerhoff and internal DECC data. The lower range sites, mostly on the east coast, would be expected to be some of the last to be developed and have therefore only been included in our Level 4 illustrative scenario.

This differentiation between high and low range sites has been modelled by assuming that the Thames, Wash and Humber are lower range sites which would have a lower capacity factor applied. This change results in improved accuracy of our tidal range model but only a minor change in electricity output (38.6 TWh/y output in 2050 compared to 40.0 TWh/y in the previous version).

Figure G1: Mean spring tidal range at sites around the UK coast[61]



61 DECC (2008) *Atlas of UK Marine Renewable Energy Resources*

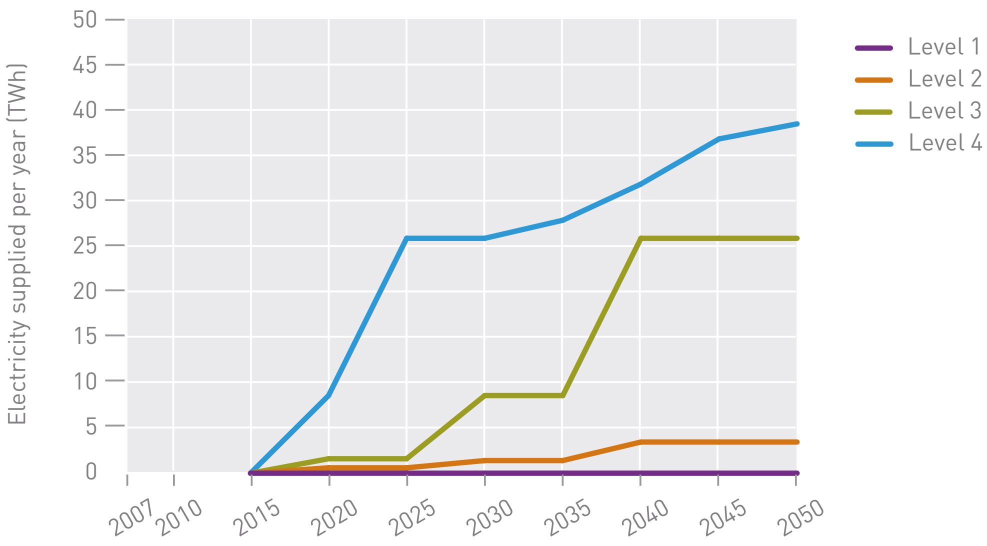
The Levels

Levels 1-3 are identical to the July 2010 analysis for both capacity and electricity produced. Level 4 is identical in terms of installed capacity but has a slightly reduced electricity output (38.6 TWh/y, down from 40.0 TWh/y).

Table G2: Cumulative installed capacity (GW):

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	–	–	–	–	–	–	–	–	–	–
Level 2	–	–	–	0.3	0.3	0.7	0.7	1.7	1.7	1.7
Level 3	–	–	–	0.8	0.8	4.3	4.3	13.0	13.0	13.0
Level 4	–	–	–	4.3	13.0	13.0	14.0	16.0	19.0	20.0

Figure G3: Trajectories for electricity generation from tidal range



2A.H Industry disaggregation into two levers

Context

Industry is one of the more complex sectors in the 2050 Calculator. Its heterogeneity and breadth of influencing factors mean that some degree of simplification in its treatment is inevitable. In the July 2010 report, we split the sector into four broad production groups: minerals, metals, chemicals and wider industry. Minerals, metals and chemicals were considered separately because of the disproportionately high process emissions associated with them. The Calculator offered users the choice of four different scenarios for industry which combined five variables: output growth, energy intensity, process emissions, carbon capture and storage (CCS) deployment and fuel switching. Full details of the scenarios, and in particular the interplay between output and energy intensity, are in Section C, pages 82-83 of the July 2010 report.

The industry sector of the 2050 Calculator incorporated a large amount of detail into a narrow range of choices. The responses received during the Call for Evidence (including from the Food and Drink Federation, the Mineral Products Association and EDF Energy) suggested we disaggregate these variables in order to give users a clearer picture of the choices made.

Trajectories for industry

The Call for Evidence feedback was positive about the assumptions we used in the Calculator, so we have not made any changes to the underlying data. However, we have decided to make a significant change to the presentation of the industry sector. Given that the size and growth rate of industry is linked to the wider role of manufacturing as part of the UK economy, its contribution to GDP and employment, as well as its role in contributing to a low carbon economy, it seems appropriate that this should be a variable chosen separately from the assessments of energy efficiency and the adoption of low carbon technology.

The 2050 Calculator now offers users options for two different trajectories – one where they get to choose a growth rate for the industrial sector, and another where they get to choose a level of emissions intensity. These trajectory sets are based on numbers already in the Calculator, with industry growth rate variables being explicitly separated out from the remaining four energy intensity assumptions (CCS deployment, fuel switching, process emissions and energy demand), which are grouped together. These energy intensity assumptions are grouped along the same three trajectories as previously.

A number of suggestions for disaggregation were received through the Call for Evidence, such as breaking down user choice by industry sector. However, it was decided that given the consensus surrounding intensity and output as being the two key drivers of industrial energy demand and emissions output, it was better not to over-complicate the choices available.

Industry output

As in the previous version of the 2050 Calculator, we have allowed for three different domestic output scenarios: high, medium and low. The growth rates are based on historical trends for each of the specified industry sectors.

It is important to bear in mind that while sacrificing output in the UK may help us achieve our 2050 targets, it does not rule out the possibility of these emissions simply being 'offshored' to another country – a consequence that the Calculator's outputs do not account for.

Scenario A – High output

The high output scenario assumes that the UK's industrial base is renewed by the transition towards a low-carbon economy. Historically strong levels of growth are assumed across all areas. Overall output in terms of gross value added would more than double from a 2007 baseline over the next forty years. All the detailed assumptions are set out on page 85 of the July 2010 Pathways Analysis report.[62]

Scenario B – Medium output

The output figures under the medium output scenario assume the continuation of historical trends (1970 – 2008). Chemicals are treated as an exception to this because an industry stakeholder workshop suggested recent growth rates (c. 2.7% per year) were an anomalous high-water mark. All the detailed assumptions are set out on page 86 of the July Pathways Analysis report.

Scenario C – Low output

The low output assumptions allow the Calculator user to explore a future where the UK restructures the domestic economy by making a distinct shift away from manufacturing.

This scenario implies that unless consumption patterns change dramatically, significant emissions will instead be produced abroad as industries move outside the UK. This would, therefore, leave global emissions broadly unchanged, and even raise the possibility of increased net emissions through the transportation of goods.

For the sake of simplicity, the model assumes a steady decline in output. In reality, such a decline would probably be marked by a series of step changes as individual shifts are made.

All the detailed assumptions are set out on page 86 of the July 2010 Pathways Analysis report.

62 HM Government (2010) *2050 Pathways Analysis*

Energy intensity

As already stated, there are four variables which comprise the three energy intensity scenarios: deployment of CCS, the extent to which industries switch fuels, the level of process emissions, and energy intensity by sector. Like output growth, these are grouped in the Calculator to create three scenarios with high, medium and low possibilities. For CCS and fuel switching, the assumptions used are applied equally to all industry sectors. For process emissions and energy intensity, the model makes specific judgements based on sector. The assumptions lying behind the trajectories are set out in detail in Section C, pages 88-93 of the July report. Table H1 provides a summary.

Table H1: Energy intensity of industrial sector trajectory assumptions

	Scenario A High intensity	Scenario B Medium intensity	Scenario C Low intensity
Carbon capture and storage	No widespread deployment of CCS technology (due to lack of investment / cost ineffectiveness).	CCS begins to roll out after 2025. By 2050, 24% of emissions in the metals, minerals and chemical industries are captured.[63]	CCS begins to roll out quickly after 2025. By 2050, 48% of emissions in the metals, minerals and chemical industries are captured.
Fuel switching	No change in the balance of fuels out to 2050.	Modest shift towards electrification from 2030.	Significant shift towards electrification from 2025, much reduced dependence on gas.
Process emissions	Process emissions from metals, minerals and chemical industries remain static to 2050.[64]	**Chemicals**: 15% lower by 2050 **Metals**: 10% lower by 2050 **Minerals**: 5% lower by 2050	**Chemicals**: 35% lower by 2050 **Metals**: 25% lower by 2050 **Minerals**: 30% lower by 2050
Energy intensity	**Chemicals**: 10% lower by 2050 **Metals**: 10% lower by 2050 **Minerals**: 10% lower by 2050 **Wider industry**:10% lower by 2030	**Chemicals**: 25% lower by 2050 **Metals**: 20% lower by 2050 **Minerals**: 20% lower by 2050 **Wider industry**: 24% lower by 2030	**Chemicals**: 50% lower by 2050 **Metals**: 30% lower by 2050 **Minerals**: 30% lower by 2050 **Wider industry**: 43% lower by 2030

63 Assuming CCS captures 80% of emissions where installed.

64 Process emissions from wider manufacturing are minimal and therefore not considered here.

2A.I Transport

In the July 2010 report we set out choices of trajectories for domestic passenger transport (activity, technology and efficiency), freight transport, international aviation, and international shipping (see Section 2B, page 58 to 75 of the July report).

Call for Evidence

Around 30 respondents to the Call for Evidence commented on the transport sector of the 2050 Pathways Analysis. These represented a broad range of expertise and experience, and the responses covered many areas of transport. The issues raised most often were:

- the treatment of hydrogen in the model;
- the potential for more ambitious changes in passenger transport activity;
- the potential for more ambitious changes in international aviation reflecting reductions in activity levels;
- the potential for three more scenarios to accompany the single scenario for international shipping, and;
- the role of gas, including biogas, in some transport sectors.

In response to the evidence received, we have implemented the following changes to the 2050 Calculator:

- Assumptions on the production of hydrogen have been revised. The separate hydrogen chapter at Section 2A.A of this report sets out the revised assumptions, which impact well-to-wheel emissions of fuel cell vehicles. Within the transport sector, hydrogen fuel cell buses have now been included in the technology assumptions, and are discussed in this chapter.
- Level 4 domestic passenger transport has been revised to reflect the possibility of greater behaviour change. The new Level 4 has fewer miles travelled per person per year by 2050 than envisaged in the previous version of the 2050 Calculator.
- Additional placeholder scenarios B, C and D have been added to international shipping. These are based on the same analysis conducted by the International Maritime Organisation.

In this version of the 2050 Calculator we have not implemented a more ambitious Level 4 for international aviation or a greater role for gas. However, we plan to make both of these changes in a future update to the 2050 Calculator. For more information on these, and on other suggestions which were raised by some respondents but where no change has been implemented in this update, please see Part 2B of this report.

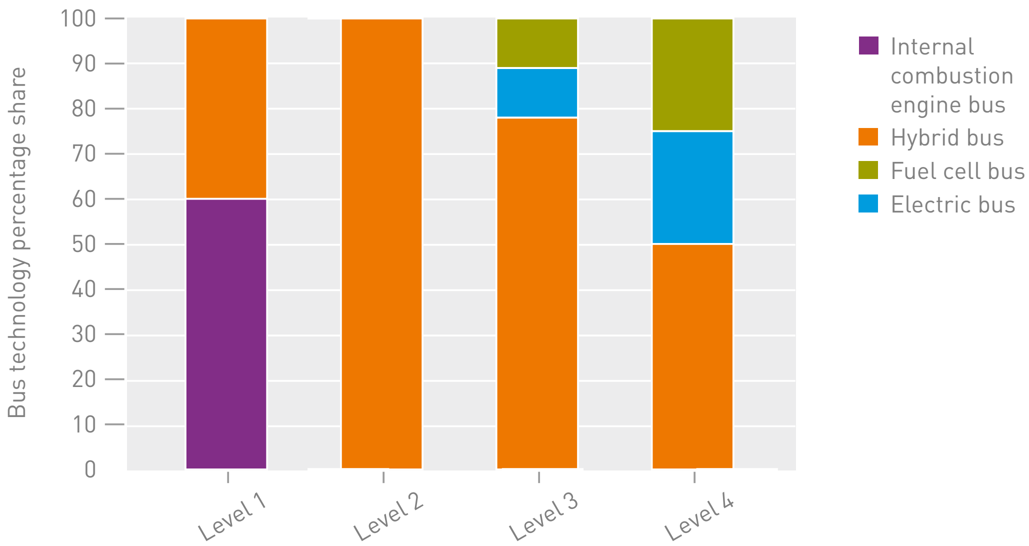
Levels for domestic passenger transport

Bus technology

The July 2010 version of the 2050 Calculator anticipated hydrogen fuel cells in cars and vans, but not in buses or heavy goods vehicles (HGVs). Whilst there would be significant storage challenges and weight penalties for HGVs, buses are likely to be early adopters of hydrogen given that they are captive fleets, and both range and minimum refuelling times are desirable to operators.[65]

In response to the evidence received, we have revised the figures for uptake of electric buses so that within the overall uptake we represent an even share of battery and fuel-cell buses. This approach means that, by 2050, 11% of bus journeys will be undertaken using hydrogen under Level 3 domestic passenger transport, and just under 25% under Level 4.

Figure I1: Bus technology share in 2050 under each level



The Clean Urban Transport for Europe (CUTE) project launched demonstration hydrogen buses in nine major cities globally.[66] The project tested 27 fuel cell buses under normal operating conditions for two years. The CUTE project found that fuel cell buses typically consumed 20-30 kg of hydrogen per 100 km, equating to around 7.87 KWh/km. The CUTE project also identified efficiency improvements that could be made in the near-term of around 35%, and this has been reflected in the Calculator.

From this snapshot of efficiency, the same learning rate applied to fuel cell cars and vans has been applied to fuel cell buses, an efficiency gain of around 2% a year. This means that, by 2050, fuel cell buses would match today's diesel engine buses for energy efficiency, although lag significantly behind battery-powered buses.

65 Clean Urban Transport for Europe (2006) *Final Report*

66 *Ibid*

Figure I2: Bus technology efficiencies

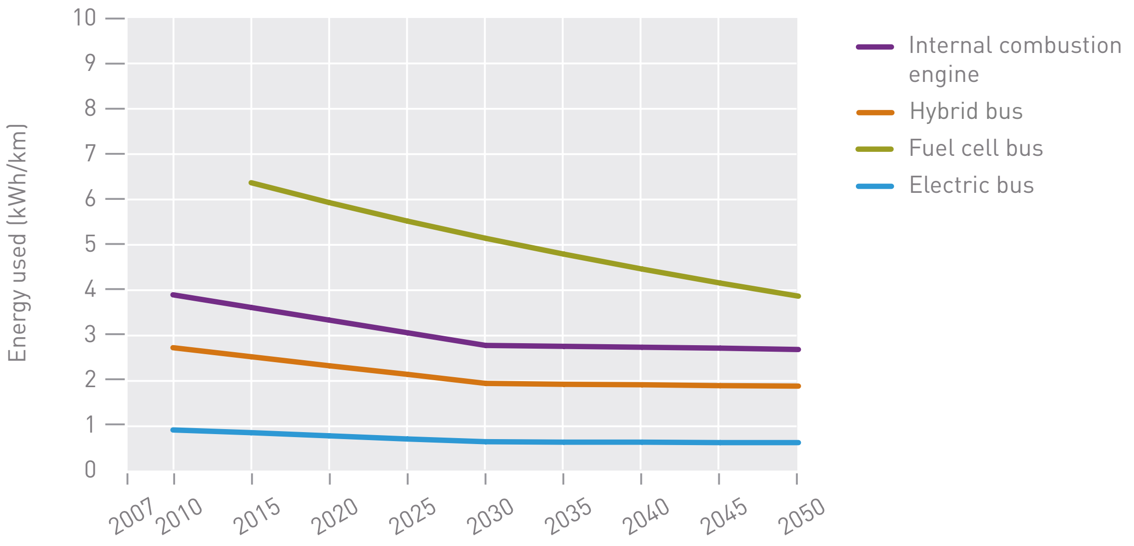


Table I3: Bus technology efficiencies (kWh/km)

kWh/km	2015	2020	2025	2030	2035	2040	2045	2050
Fuel cell bus	6.4	5.96	5.55	5.17	4.82	4.49	4.18	3.89
Electric bus	0.87	0.80	0.73	0.67	0.66	0.66	0.65	0.65
Internal combustion engine bus	3.64	3.36	3.08	2.80	2.78	2.76	2.74	2.71
Hybrid electric bus	2.55	2.35	2.16	1.96	1.94	1.93	1.91	1.90

The successor of the CUTE project, the Clean Hydrogen for European Cities project is now underway. This will give further evidence on the efficiency and commercial viability of hydrogen buses which will be considered in future iterations of the Calculator.

Activity levels

The July 2010 version of the 2050 Calculator reflected a range of futures for passenger transport activity. Under Level 1, travel activity in terms of overall mobility and mode shares is consistent with past trends broadly continuing but with growth in demand slowing over time – whereas Level 4 assumed passenger travel activity of 14,276 km (8,923 miles) per person per year by 2050, compared to 14,104 km (8,815 miles) per person in 2007.

Several respondents questioned whether the range of travel activity (total distance travelled) covered by the domestic passenger transport trajectories fully encapsulated the widest range of potential futures. They argued that under the 'heroic' assumptions of Level 4, a more significant change from past trends should be feasible.

In this revised version of the 2050 Calculator, we have changed the Level 4 assumptions for passenger transport activity (in distance per person per year). In the updated Level 4 we now assume that passenger transport activity in 2050 is no higher in 2050 than in 2010, therefore people would each travel roughly the same distance in the UK in 2050 as they do today, despite the increases in wealth assumed by yearly GDP growth.

Similar to the previous Level 4, the new Level 4 presumes that distance travelled per person per year would continue to increase until the 2030s. But from 2035 onwards, the distance per person would gradually decline back to 2010 levels from its height in 2035 of 14,323 km (8,952 miles) to the 2050 level of 14,076 km (8,798 miles) per person per year.

Figure I4: Levels for domestic passenger transport in km per person per year (previous and new levels)

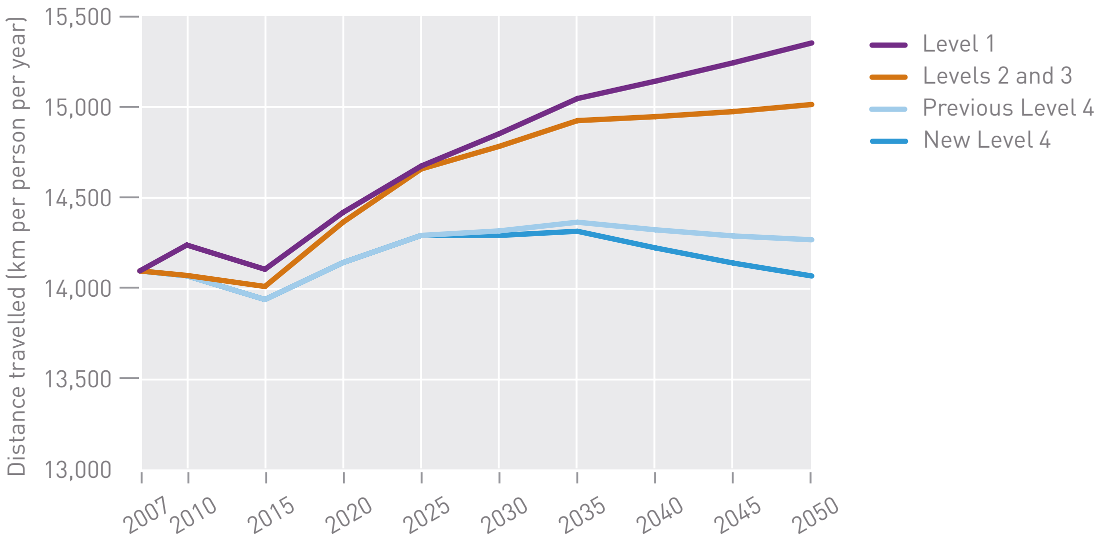


Table I5: Levels for domestic passenger transport in km per person per year (previous and new levels)

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Level 1	14,104	14,247	14,113	14,427	14,683	14,862	15,056	15,152	15,254	15,363
Level 2	14,104	14,079	14,018	14,373	14,667	14,792	14,934	14,956	14,984	15,023
Level 3	14,104	14,079	14,018	14,373	14,667	14,792	14,934	14,956	14,984	15,023
Previous Level 4	14,104	14,077	13,946	14,150	14,300	14,325	14,373	14,331	14,297	14,276
New Level 4	14,104	14,077	13,946	14,150	14,300	14,300	14,323	14,231	14,147	14,076

The new Level 4 entails a steeper reduction in domestic passenger mileage travelled per person per year from 2030 onwards than the previous Level 4. It embraces the possibility that the strong historical correlation between GDP growth and increases in domestic passenger travel activity weakens further from 2030 onwards. This would reverse a strong historical trend of the last decades. For instance, average trip length has increased 50% since 1972 compared to today's levels. These changes to travel patterns would reflect for example:

- Changed approaches to lifestyles and working practices as more employees and business embrace new ways of working, such as teleworking.
- Cycle mileage would be 11-fold higher in 2050 than in 2010; bus passenger mileage would be 3-fold higher in 2050 than in 2010, rail mileage more than double 2010 levels.

Overall domestic transport activity (rather than per person transport activity) would continue to increase in the new Level 4. This is driven by the projected population increase over the period of the analysis.

The evidence we received suggested that there could be a significant impact on distance travelled per person per year in the future due to possible changes in working-from-home patterns, or different spatial planning decisions bringing living areas closer to work places. Some Call for Evidence respondents argued that the adoption of high speed broadband throughout the UK could be expected to have a significant influence on the number of passenger miles with increased home working and greater volume of internet ordered goods. It remains to be seen how factors such as IT developments will interact with changes in wealth, lifestyle choices and planning decisions to have an overall impact on distance travelled per person.

Scenarios for international shipping

The July 2010 version of the 2050 Calculator presented only one illustrative scenario for international shipping (details can be found in Section 2C, p.75 of the July 2010 report).

Respondents to the Call for Evidence questioned whether this was an appropriate approach, given that we had presented a range of possible futures for every other sector in the 2050 Calculator. Feedback emphasised the need to provide more flexibility for this sector, including through the use of alternative International Maritime Organization (IMO) scenarios. To address this, four illustrative scenarios for international shipping emissions have now been developed and included in the Calculator.[67]

International shipping is a large and complicated industry, and there is currently no agreed way of allocating international shipping emissions to countries.[68] International shipping emissions are also not currently included in the UK's 2050 target, primarily because of the complexities around methodologies for inclusion. Further research is needed to understand the UK's share of global international shipping emissions under different approaches. In the meantime, the new scenarios have been included in the Calculator to illustrate potential alternative pathways for emissions from this sector. These scenarios are only placeholders, and the aim is to refine them as more evidence becomes available. Given this, care should be exercised in interpreting them.

67 Due to methodological differences, these illustrative scenarios should not be compared with the international shipping emissions that the UK reports in the national emissions inventory.

68 The UK reports international shipping emissions based on international shipping fuels sold in the UK. However, these emissions do not form part of the UK's national inventory (i.e. those emissions for which the UK is responsible).

Following the method applied to generate the single scenario included in the July version of the Calculator, the new scenarios are based on the IMO's activity-based scenarios of global international shipping emissions.[69] In each scenario, it is assumed that the UK's share of the IMO's global estimates is around 1.2%: the UK's share of global international shipping emissions based on IEA fuel statistics for 2007.[70] In reality, these shares will differ, and the UK's share of international shipping emissions would be expected to change over time.

The IMO scenarios do not show the full potential to reduce emissions from international shipping, but reflect business-as-usual efficiency improvements. All four scenarios include an overall efficiency improvement of 39% between 2007 and 2050. This is assumed to be achieved through a 10% reduction in average fleet speed, the use of larger ships and improvements in ship design, technology and operation. Emissions could be reduced further still if additional efficiency improvements are made or other emissions abatement measures are adopted to reduce ship emissions. In future, governments around the world may also introduce new policies to address international shipping emissions, but the impact of such policies is not reflected in these scenarios.

All four illustrative scenarios demonstrate growth in global shipping levels as the world economy develops, and overall global population grows. The key difference between the scenarios is the different levels of international shipping activity assumed, depending on the size and character of the world economy and rate of population growth. Given this, it should be noted that the differences between these illustrative scenarios do not reflect differences in the extent to which emissions abatement measures are implemented in the international shipping sector or differences in which policies are introduced to address international shipping emissions. It should also be noted that choices made within this sector may be at variance with choices made elsewhere in the Calculator, particularly on industry where high growth rates may contrast with limited growth in shipping. To reflect these limitations, the scenarios available within this sector have been cast as ABCD choices, rather than Levels 1-4.

Trajectory A

This remains based on projections for the IMO's 'A1B' (base) scenario. This assumes a world of fast economic and population growth until 2050, with rapid introduction of new, more efficient technologies. Here economic and cultural convergence is anticipated, substantially reducing regional difference in per capita income, and global shipping activity is assumed to grow, on average, by around 2.7% per year between 2007 and 2050. Some liquified natural gas (LNG) penetration is also assumed. The total energy used by "UK international shipping" in 2050 is estimated to be around 129 TWh.

Trajectory B

This is based on projections for the IMO's 'A2' (base) scenario. It assumes a continuously growing but less convergent world. Here economic growth is more fragmented and more regionally-orientated; global shipping activity is assumed to grow, on average, by around 2.2% per year between 2007 and 2050. Some LNG penetration is also assumed, and 20% of all shipping is assumed to use synthetic diesel

69 IMO (2009) *Second IMO Greenhouse Gas Study*.

70 The UK's share of the IEA global total is based on the emissions from international shipping fuels that are sold in the UK. For the IEA fuel statistics see IEA (2009) *CO_2 Emissions from Fuel Combustion, Highlights*.

by 2050. The total energy used by "UK international shipping" in 2050 is estimated to be around 105 TWh.

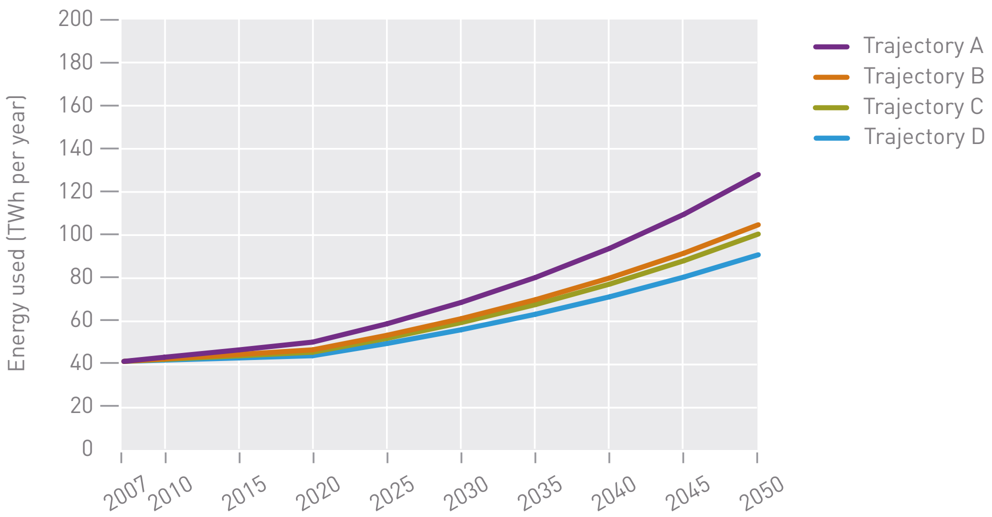
Trajectory C

This is based on projections for the IMO's 'B1' (base) scenario. It assumes a world of growing population and economic convergence (similar to Trajectory A), but undergoing a rapid shift towards a service and information economy, with decreased material intensity and increased deployment of clean and resource-efficient technologies. Global shipping activity is assumed to grow, on average, by around 2.1% per year between 2007 and 2050. It is also assumed that 50% of coastwise shipping and 20% of tanker ships are powered by LNG in 2050. The total energy used by "UK international shipping" in 2050 is estimated to be around 101 TWh.

Trajectory D

This is based on projections for the IMO's 'B2' (base) scenario. It assumes a world with a very pronounced local focus, with a slower growing population and intermediate economic development; global shipping activity is assumed to grow, on average, by around 1.8% per year between 2007 and 2050. 50% of coastwise shipping and 20% of tanker ships are assumed to be powered by LNG in 2050. The total energy used by "UK international shipping" in 2050 is estimated to be around 91 TWh.

Figure I6: The international shipping trajectories



2A.J Space heating – home insulation levels

In the July 2010 version of the 2050 Calculator, home heating was split into three household levers: temperature, insulation and heating technologies. The changes described in this chapter are focused purely on retrofit domestic insulation measures.

The level of loft, window, wall and floor insulation are key determinates of the average heat loss in houses. The greater the amount of insulation measures in the existing housing stock, the lower the energy demand for space heating, with all other things being equal.

Call for Evidence

In our changes to the 2050 Calculator assumptions, the number of households receiving insulation measures has been increased for all levels except Level 4, which already assumed 96% of households received each insulation measure where installation was thought possible. This has been driven by two changes to our assumptions on the uptake of insulation measures:

- Increased ambition for loft, cavity wall and solid wall insulation installations from current policy to 2012, compared to assumptions in the July 2010 report. This has become our new baseline.
- Adding a Business As Usual annual uptake for insulation measures following the end of policy intervention assumptions. For example, in the July 2010 analysis, loft insulation in Level 2 was assumed to have zero annual take up from 2022-2050 following the end of fiscal incentives. This was revised in light of historical evidence, which shows a number of insulation measures are likely to be taken up in the absence of policy.

Drivers and enablers

The number of households receiving insulation measures has been increased in Levels 1-3 due to a revision of the baseline, given greater ambition in short term policy and the addition of business as usual rates after the end of policy interventions. The section below describes the revisions and the effect this has on average heat loss assumptions compared to the July 2010 analysis.

Current UK policy to 2012

A number of policies and initiatives are already in place to encourage the uptake of household domestic energy efficiency measures over the immediate future. The table below summarises the estimated additional insulation in homes from April 2007 to the end of 2012 given current policy:

Table J1: New insulation measures 2007 to 2012 estimated from current policy

Type of insulation	Number of households fitted with new insulation[71]
Cavity wall insulation	3,284,675
Lofts	4,313,176
DIY lofts	1,016,404
Solid wall	17,0267

The new estimates for the number of houses receiving insulation measures to 2012 replace the original Committee on Climate Change baseline for Levels 1-4. We have not included Government policy beyond 2012 within the baseline in order to allow users to compare the four most widely ranging futures for the sector.

Business as usual uptake of insulation measures

As explained above, the assumption of zero insulation installations in the period after modelled policy interventions cease is considered unlikely to happen in practice. The expected annual uptake of insulation measures in the absence of intervention could be driven by a number of factors: the remaining level of technical potential, consumer incentives and the costs of insulation measures and heating. These are likely to vary in each trajectory, however in the absence of evidence a common business as usual (BAU) rate was taken for each level.

Table J2: Business as usual assumptions for the annual installation of different insulation measures

Measure	BAU Annual installation in homes
Solid wall insulation	19,500[72]
Cavity wall insulation	0[73]
Loft insulation from 149mm to 270mm	35,000[74]
Draught proofing	31,416[75]
Floor insulation	n/a
Triple glazing equivalent	n/a

71 DECC estimates based on *A Review of the Energy Efficiency Commitment 2005-2008* Ofgem report August 2008. Available at: http://www.ofgem.gov.uk

72 Based on retrofit estimates from Purple Market Research (2009) *The Solid Wall Insulation Supply Chain Review*

73 Assumed to be zero based on: Inbuilt Ltd & Davis Langdon for DECC (2010) *Study on hard to fill Cavity Walls in domestic dwellings in Great Britain*

74 Half of historical take up rate – from DECC analysis

75 The previous annual uptake from the Level 1, the CCC baseline from 2007-2009, July 2010 analysis was used.

The Levels

The new levels of average heat loss per home have decreased due to an increased baseline scenario based on current policy to 2012 and the addition of an estimate of annual uptake following modelled interventions. This means levels are more ambitious for insulation measures given greater space heating demand reductions. However, Level 4 still does not go beyond 96% of the technical potential estimated. The assumptions described above for estimates of retrofit measures to 2012 and business as usual scenarios are combined with the July 2010 analysis assumptions for take up of technological potential and new building standards. This is summarised in table J3.

Table J3: Summary of policy assumptions used to generate levels of home insulation[76]

	Policy assumptions for existing stock
Level 1	2012 Current Policy baseline, BAU thereafter
Level 2	2012 Current Policy baseline + extend Carbon Emissions Reduction Target (CERT) to 2022, BAU thereafter
Level 3	2012 Current Policy baseline + 100% capital subsidy (+ higher frequency of decision making for some measures). BAU thereafter
Level 4	2012 Current Policy baseline + 100% capital subsidy (+ higher frequency of decision making for some measures)+ mandate those reluctant to insulate. BAU thereafter

The following section sets out the impact of the two changes above on the Levels 1-4 for different insulation measures in households.

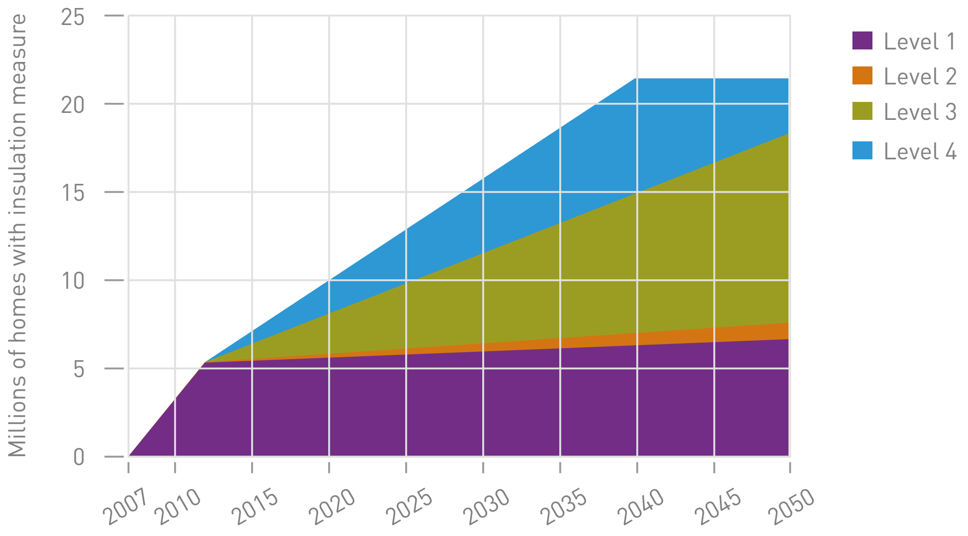
Loft insulation

The larger increase in loft insulation measures to 2012 is common to all scenarios due to the revised baseline. From 2012 the take up rates reflect the previous assumptions of the percentage of take up of technical potential (except for Level 1, which uses the BAU annual take up figure). So, Levels 2 and 3 reach the same final technical potential assumed in the July 2010 report in 2050.[77]

76 Policy assumptions taken from: Element Energy (2009) *The uptake of energy efficiency in buildings, a report to the Committee on Climate Change*. Note: CCC Baseline is replaced by the current policy baseline and some trajectories were adjusted to reflect this.

77 See tables D3-D6 on pages 99-101 of HM Government (2010) *2050 Pathways Analysis*.

Figure J4: Cumulative number of homes with loft insulation, additional to 2007



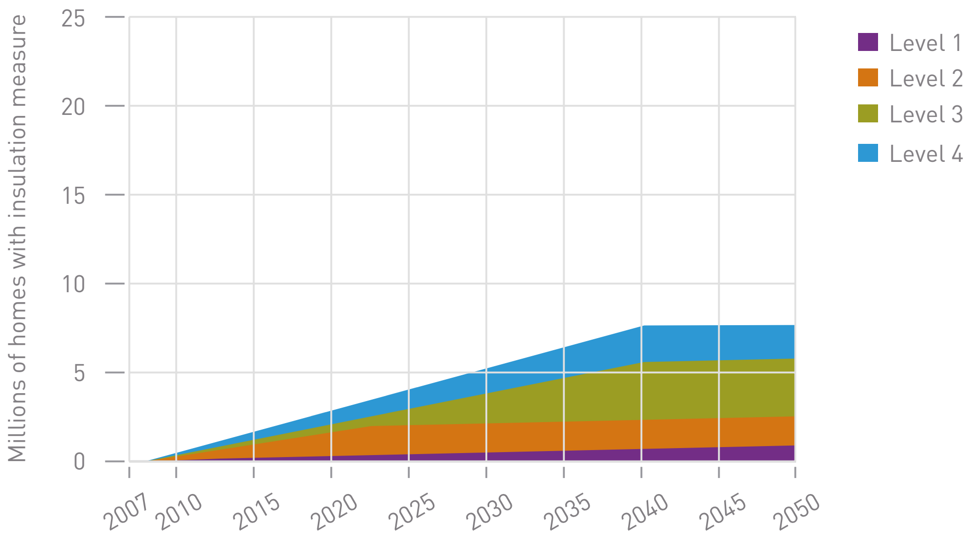
In all insulation trajectories:

- Level 4 take up stops when 96% of the technical potential is realised.
- All insulation numbers are additional to the baseline of 2007.

Solid wall insulation

For solid wall insulation, the previous levels of take up are used until the end of policy intervention, and then a business as usual annual installation rate of 19,500 is applied. The only exception is Level 1 where policy to 2012 figures are used and BAU thereafter. The new Level 1 changes from 400,000 households receiving solid wall insulation from 2007-2011 in the previous analysis to 170,000 from 2007-2012 and 910,000 by 2050.

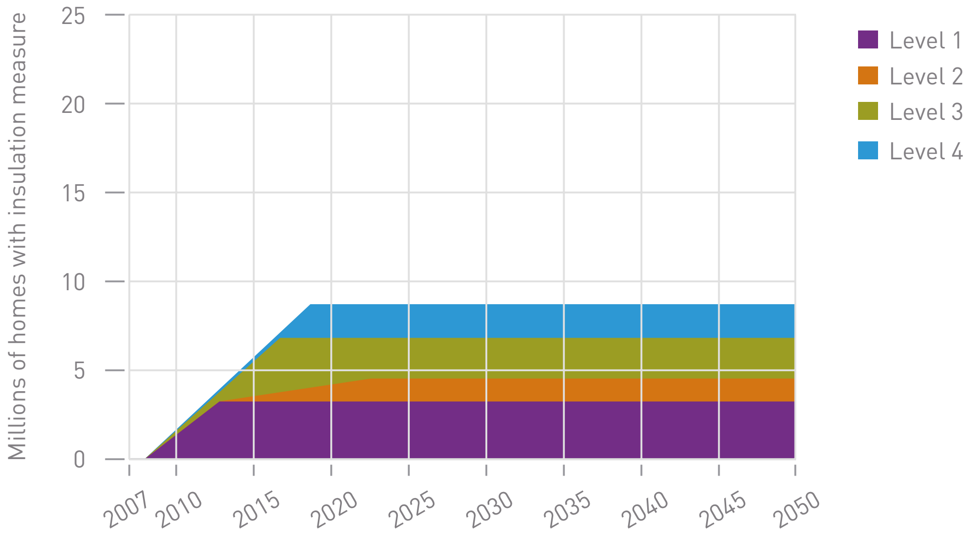
Figure J5: Cumulative number of homes with solid wall insulation, additional to 2007



Cavity wall insulation

In the July 2010 report, cavity wall insulation was assumed to have zero installations per year following interventions. Analysis suggests that after 2012, most remaining cavities will be hard to fill and so the business as usual rate is zero installations per year. Levels 1 and 2 to 2012 have been updated to include updated figures from policy initiatives to 2012. The kink in Level 2 uptake reflects adjusting for increased ambition to 2012 and then slower uptake to 2022, reaching a target level of penetration consistent with the July 2010 analysis.[78]

Figure J6: Cumulative number of homes with cavity wall insulation, additional to 2007



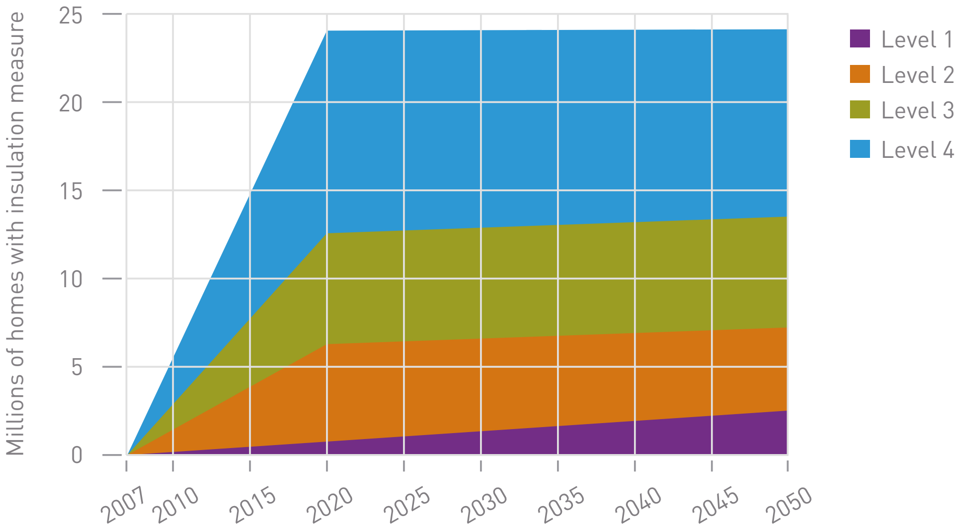
Draught-proofing measures

Level 1 ambition has been raised to achieve 10% of technical potential in draught proofing improvements in homes by 2050, representing 2.5 million homes, from previous levels of 0.25%. This is because business as usual is applied from 2007. The business as usual uptake has been applied to Levels 2-4 following the uptakes assumed from the July 2010 analysis.[79]

78 See table D4 on page 100 of HM Government (2010) *2050 Pathways Analysis*.

79 See tables D3-D6 on pages 99-1-101 *ibid*.

Figure J7: Cumulative number of homes with draught-proofing measures, additional to 2007



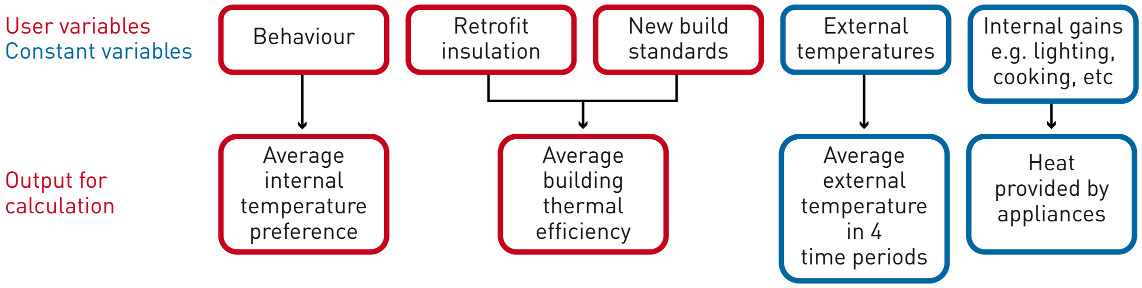
Impact of these changes

The insulation trajectories were then used to derive an average heat loss per household. This improves over time as more homes are insulated and more efficient homes replace old building stock. The results are shown in Table J8.

Table J8: Average heat loss per home (Watts / °C)

Level	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
1	246.8	232.9	223.2	217.2	211.4	205.8	200.4	195.3	190.5	186.1
2	246.8	230.1	213.6	201.0	192.1	185.3	179.8	174.5	169.5	164.7
3	246.8	228.3	203.5	187.8	178.0	168.8	160.3	152.3	147.1	143.0
4	246.8	225.2	194.2	170.5	158.4	147.2	136.8	127.5	122.8	118.5

Level 1 has the largest change in heat loss, reducing from the July 2010 analysis average heat loss per home of 190.6°C in 2050 to 186.1°C . This was mainly due to the increased baseline for loft, cavity wall and solid wall insulation. The figures above combine with assumptions on internal temperature demand, internal gains from heat emitting appliances and mean outside temperatures to give a total household energy demand. The interaction is shown in the following schematic.



These assumptions are combined to calculate annual space heating demand, which can be met by a number of different heating systems.[80]

80 See Chapter D page 94 *ibid*.

2A.K Agriculture disaggregation into two levers

Context

In terms of its scope, the agriculture and land use sector of the 2050 Calculator is one of the broadest. Major issues such as domestic bioenergy crops, forestry, soil management and livestock production are all accounted for as part of the analysis.

The July 2010 report set out four scenarios for the treatment of agriculture and land-use:

- **Scenario A** described a world where current trends and drivers in agriculture and land use remain broadly stable out to 2050.
- **Scenario B** gave a trajectory where there is a specific policy priority to increase food production with a reduced focus on bioenergy crops and forestry cultivation.
- **Scenario C** explored the possibility of securing lower emissions from the agriculture sector through significant investment in technology, alongside an increasing emphasis on bioenergy crop production and woodland creation.
- **Scenario D** imagined a world where there is a more substantial roll-out of bioenergy production, along with a much larger step up in plans to sequester carbon through woodland creation.

Full details on each of the scenarios and the assumptions supporting them can be found in Section E, pages 131 – 146 of the July report.

Call for Evidence

We received some useful and positive feedback during the Call for Evidence. A number of respondents, including E.On and the Energy Technologies Institute, expressed satisfaction with our approach. In terms of improvements, two key suggestions were made.

First, the Campaign to Protect Rural England recommended that we attempt to show the land use consequences of energy system choices, such as how much space deploying different levels of wind turbines would take up. We agree that showing this pictorially could be a very useful way of demonstrating the real-life impact these long-term choices could have on our landscape, and the updated 2050 Web tool includes information showing some of the physical impacts choices could have on UK land use.

A second presentation point made by respondents was that the large group of trajectory variables in this sector makes the user's choice rather opaque. At present, when a user chooses a land use scenario, they by extension make a choice on:

- Land use assignment by area
- Livestock number growth rates
- Yield growth for food, bioenergy crops and agricultural waste products

- Emissions intensity growth of enteric fermentation and manure
- Total emissions growth from soil management
- Forestry emissions
- Levels of straw collection
- Levels of manure collection
- Forestry arisings collection, old forests
- Total forestry arisings, new forests.

Some respondents expressed concern that the 2050 Calculator was not providing enough information on the distinct implications of a user's choice, and that the grouping of variables risked conflating factors which were more sensibly considered separately.

The new version of the 2050 Calculator has been revised to disaggregate the trajectory variables to allow for two separate user choices on 'land use management' and 'livestock management'. The assumptions are broken out as follows:

Land Use Management	Livestock Management
Land use by area	Livestock numbers growth rates
Emissions intensity growth, enteric fermentation and manure	Yield growth (manure)
Total emissions growth, soil management	
Forestry emissions	
Straw collection rates	
Manure collection rates	
Forestry arisings (old forest) collection rates	
Total forestry arisings, new forests	
Yield growth (food and bioenergy crops)	

Land use management covers a wide range of assumptions about how we assign tasks to areas of land, as well as how we manage these areas. This is important not just for the emissions associated with the land, but also for our treatment of the energy sources arising from forests and waste. Straw, manure and wood chips all have an important role to play in the energy mix as a potential source of bioenergy.

Livestock management groups the assumptions explicitly related to animals – the speed at which their numbers grow or decline, and the amount of waste which they yield. These two factors have implications for both emissions, as numbers directly correlate with associated enteric fermentation; and energy, as yields directly correlate with the amount of waste available for use as bioenergy.

One final presentational change that has been made is to swap scenarios A and B around, so food production is prioritised in A, and the continuation of current trends is given in B. This has been done in order to show more logically the increased prioritisation of bioenergy through scenarios A to D. This applies to both the land use and livestock management trajectories.

In terms of the assumptions themselves, we have left the numbers largely unchanged from the July 2010 report, as respondents were happy with the treatment. The one small change we have made relates to the yield growth potential of 2nd generation biocrops, where we have allowed for more cautious rates of improvement out to 2050 in some of our land use management scenarios. This is explained in more detail below.

Drivers and enablers

The July 2010 Calculator treated this sector in such a way as to imply a trade-off between bioenergy crops and livestock production.

In the earlier version, choosing either Scenario C or D increased bioenergy production. In the Calculator, this is largely created by switching grassland pasture for livestock, to space used for growing 2nd generation biocrops, such as short rotation coppice (SRC). The problem with this treatment is that it presumes a correlation between these two factors (livestock numbers and crop production) which although plausible, does not necessarily exist. The land suitable for livestock production is not necessarily going to be suitable for growing crops in all cases. Furthermore, it is possible to imagine scenarios where we make a decision to either increase or decrease our livestock production entirely independently of changing our bioenergy priorities. Domestic food security, dietary changes and animal welfare concerns could all affect our farming choices separately to the sector's role in energy production.

By breaking the sector into two separate trajectory groupings we reduce the risk of these two issues being conflated. Although this remains a highly complex area, we hope the increased flexibility and transparency of the tool will put users in a stronger position to consider the major land use questions the country faces out to 2050. For example, by allowing users to specifically make choices on our management of livestock it is now possible to see more clearly what impact a change in our national dietary habits may have on total emissions.

The Trajectories

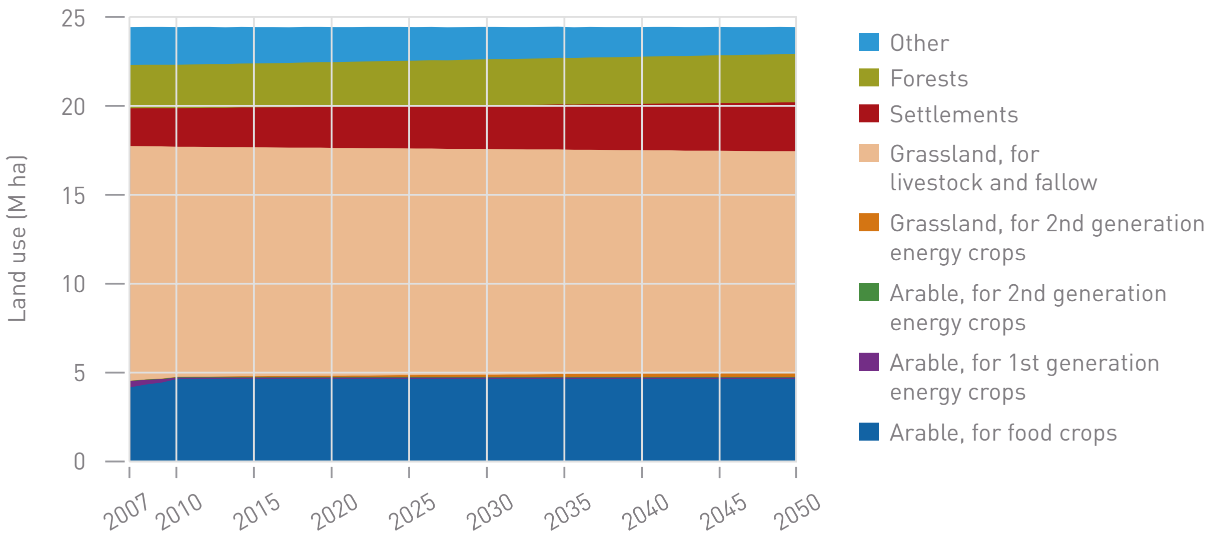
As already stated, we have made only small changes to the basic numeric assumptions in the Calculator. The key differences are in our presentation. Full details on the numbers can be found in the Excel version of the 2050 Calculator, and are explained in Section E of the July report.

Land use management

Scenario A – Food production

Scenario A describes a situation where food production is prioritised over bioenergy in land management decisions out to 2050. Along with bioenergy crop production, forestry cultivation is also given a lower priority. This scenario represents a case where UK food production could potentially outpace population growth (though this outcome would also depend on decisions related to livestock numbers made through the livestock management trajectory choices), ensuring a good level of domestic food security.

Figure K1: Scenario A land use change



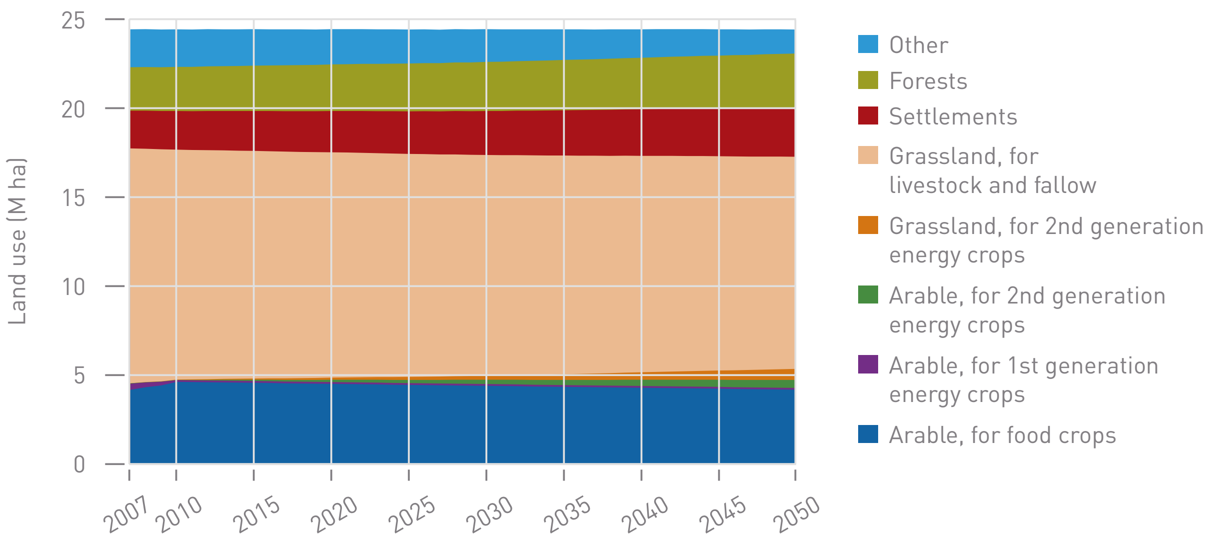
The following specific assumptions are made:

- Land use change over time is minimal. Area used for food crops and cropland remains constant, with minimal increases in space for forestry and 2nd generation bioenergy crops.
- Proportions of collected straw and woodland residues remain very low (5%).
- The amount of land given over to forestry increases by around 300 kha by 2050, following current trends.
- Soil N_2O emissions decline by 8% to 2020, but remain flat thereafter.
- Crop production efficiency increases through technological improvements in crop breeding and pest control. Food crop yields improve faster than in Scenario B.

Scenario B – Current trends

Scenario B presents a scenario where current trends and drivers in land use management continue out to 2050. Even though this is effectively a 'steady state' scenario, it means domestic production of bioenergy crops would still be dramatically higher than today – roughly a five-fold increase over the next forty years.

Figure K2: Scenario B land use change



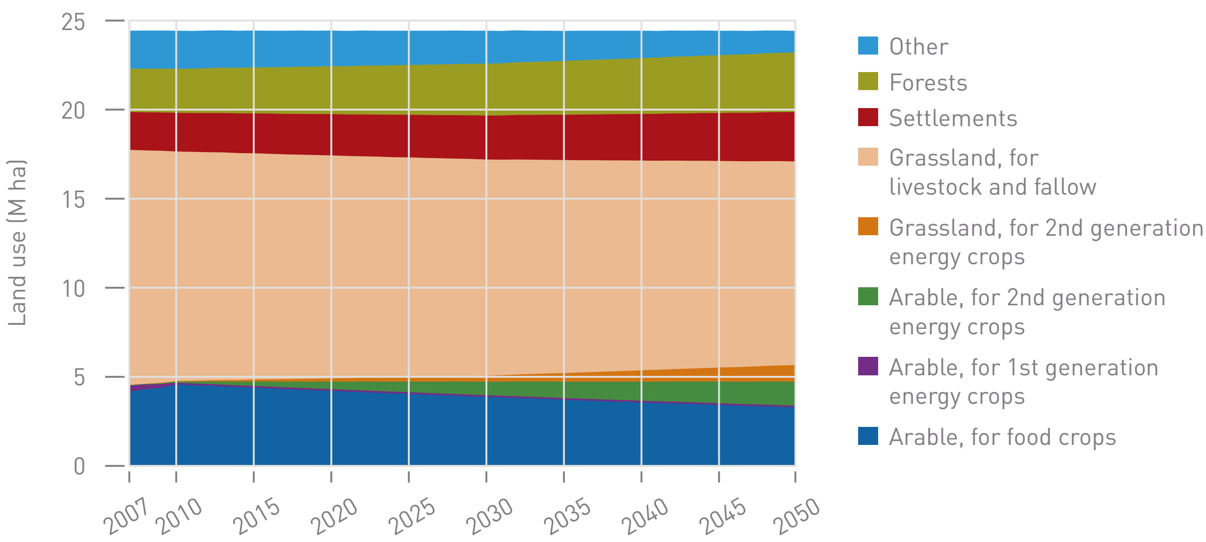
The following specific assumptions are made:

- As the area used for temporary grassland and growing food crops declines up to 2050, this land (around 1.2 million hectares) is instead used to grow bioenergy crops.
- Proportions of manure, straw and woodland residues collected rise to 15-24%.
- The amount of land given over to forestry increases by around 600 kha (15 kha per year).
- Soil N_2O emissions decline by 10% to 2050, through continued improvement of nutrient management processes.
- Crop production efficiency increases through technological improvements in crop breeding and pest control.

Scenario C – Bioenergy begins to breakthrough

Scenario C explores a scenario where bioenergy begins to break through as a significant part of domestic agricultural output. It is assumed that there will be an appreciable improvement in soil and crop management technologies, with some land used for food crops being reassigned to bioenergy production. A large amount of grassland currently used for livestock is converted to bioenergy crops production and forestry.

Figure K3: Scenario C land use change



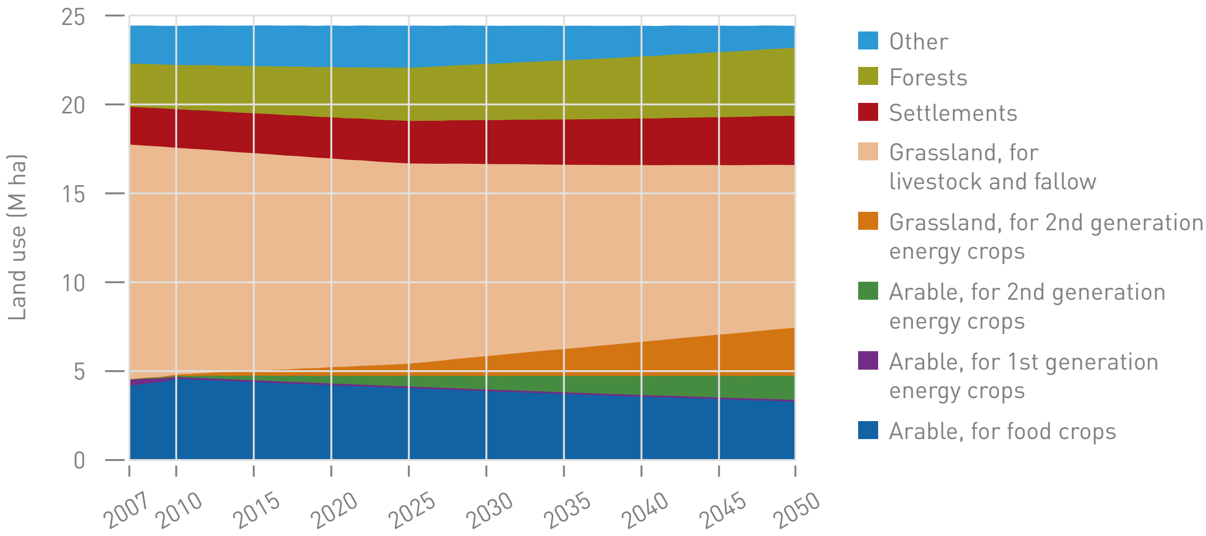
The following specific assumptions are made:

- 1.2 mha of cropland and 1.7 mha of grassland switches to bioenergy production.
- Manure, straw and forestry arisings collections increase significantly to 2050.
- Soil N_2O emissions decline by 15% to 2050, through continued improvement of nutrient management processes.
- Land given over to forests increases by 1 million ha by 2050 (23 kha per year).
- Crop production efficiency increases with technological improvements keeping up with climate change.

Scenario D – Biomass culture shift

Scenario D imagines a future with a strong UK bioenergy production focus, with both land allocation and technological improvements focused towards this area of development. Extensive carbon sequestration through forestry and the effective management and collection of waste materials for bioenergy use are also key themes. This scenario represents a highly ambitious ambitious shift in the UK's land use patterns.

Figure K4: Scenario D land use change



The following specific assumptions are made:

- Significant shift towards bioenergy production. Almost 4.2 million hectares is used – 20% of UK land. The vast majority of this is 2nd generation bioenergy crops, such as short-rotation coppice (SRC) or miscanthus grasses, being cultivated on grasslands.
- Manure, straw and forestry arisings collection increases significantly out to 2050, as in scenario C.
- Soil N_2O emissions decline by 10% to 2050. This is less than given in scenario C as bioenergy crop deployment is assumed to limit the potential gains.
- Land given over to forests increases by 1.4 mha by 2050 (34 kha per year).
- Crop production efficiency increases with technological improvements keeping up with climate change.

Crop yields

One area where we have made small adjustments to the model input assumptions is in terms of crop yields. Previously the range of possible yields for 2nd generation bioenergy crops was relatively small, with potential increases (gained through improved technologies such genetically modified crops rather than more intense farming) ranging from 1% to 1.5% per year.

On the basis of recent studies which suggest a wider range is possible given the destabilising affects of climate change[81], we have now allowed for more cautious yield gains under the less dramatic scenarios, while still maintaining a best possible yield improvement of 1.5% per year in Scenario D. This will give users greater flexibility in the breadth of possible technology improvements they can choose. The new yields for 2nd generation crops are as follows:

Trajectory	Description
A	0.25% improvement per year to 2050 (total increase in yield from 2010-2050
B	0.25% improvement per year to 2050 (total increase in yield from 2010-2050
C	1.0% improvement per year to 2050 (total increase in yield from 2010-2050
D	1.5% improvement per year to 2050 (total increase in yield from 2010-2050

Livestock management

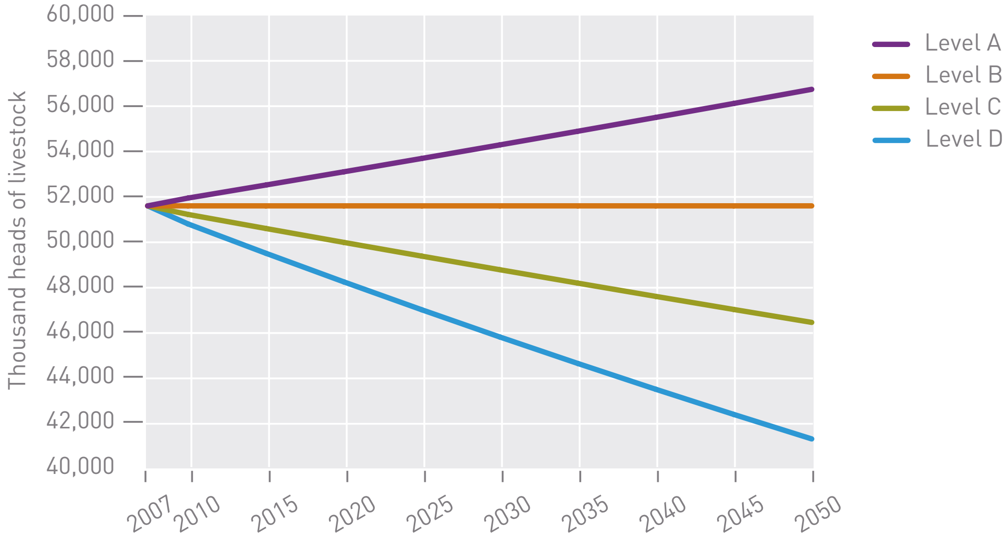
Through disaggregation, users now have more flexibility than in the previous version of the Calculator, and can select livestock numbers and manure yield changes independently of the land use management option.

The trajectories offered in the Calculator show scenarios ranging from a 10% increase in livestock numbers[82] to a 25% decrease by 2050.

81 Centre for Ecology and Hydrology, (2009) *Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO2 and drought on water use and the implications for yield.*

82 In all cases 'livestock numbers' excludes poultry – their numbers remain constant in all scenarios.

Figure K5: Number of livestock produced in the UK



Trajectory	Description
A	Food production is prioritised, with numbers increasing by 0.2% pa.
B	Current trends and drivers – numbers remain static through to 2050.
C	Numbers are reduced by 0.2% pa.
D	Significant shift away, potentially caused by major movements in dietary preferences or a heightened focus on bioenergy. Numbers decline by 0.5% pa.

Livestock management also considers the issue of manure yields. Yields are relevant for manure collection and therefore the total amount of bioenergy produced from the agriculture sector.

In all trajectories except for Scenario A, yields of manure from livestock are expected to increase at a rate of 0.2% per year, given livestock yield improvements as animals get larger. The one exception, Scenario B, holds yields growing at 0.5% per year out to 2050. This higher figure is explained by the focus on food production in this scenario, as we assume commensurately greater improvements in technologies supporting animal growth.

We recognise that by offering this additional flexibility in the Calculator, scenarios which stretch the boundaries of possibility can be created. For example, it is now possible to select Scenario D in land use management, thereby dramatically reducing the amount of land available for livestock production, whilst at the same time increasing the number of animals occupying that land by up to 10% by selecting Scenario A in the livestock management. We have looked closely at the implications of such a scenario, and while we believe it is unlikely to happen in reality, it is still one that is technically feasible. It would, however, have major implications for farming intensity and animal welfare which should be noted by users of the Calculator.

Part 2B: Where existing analysis is robust and changes have not been made

We have carefully weighed all the evidence received during the Call for Evidence. As the previous section of this report sets out, we have made a series of changes to the Calculator in response.

However, there were some suggestions that we received which we have not reflected in the updated Calculator. The original 2050 Calculator was put together using a large amount of evidence and analysis, as well as detailed engagement with over 100 expert stakeholders from academia, industry, and the third sector. For much of the evidence in the Calculator, we remain confident in the analysis presented in July 2010.

In this section we set out our response to come of the major themes received in the evidence. We summarise the proposed changes and explain why we have either not felt it appropriate to revise the Calculator to accommodate them, or not yet been able to revise the Calculator to accommodate them.

Cross-cutting issues

Interim levels

The 2050 Calculator sets out four levels of effort for most levers – and in some cases this is described as four scenarios rather than levels, as the choice reflects some kind of switch rather than increased effort. The four levels were broadly defined as:

- Level 1: assumes little or no attempt to decarbonise or change or only short run efforts; and that unproven low carbon technologies are not developed or deployed.
- Level 2: describes what might be achieved by applying a level of effort that is likely to be viewed as ambitious but reasonable by most or all experts. For some sectors this would be similar to the build rate expected with the successful implementation of the programmes or projects currently in progress.
- Level 3: describes what might be achieved by applying a very ambitious level of effort that is unlikely to happen without significant change from the current system; it assumes significant technological breakthroughs.
- Level 4: describes a level of change that could be achieved with effort at the extreme upper end of what is thought to be physically plausible by the most optimistic observer. This level pushes towards the physical or technical limits of what can be achieved.[83]

Some respondents to the Call for Evidence highlighted that these trajectories require crude intervals between levels; and some respondents called for interim steps (e.g. level 1.5, level 2.5 etc). We acknowledge that the model deliberately indicates broad brush changes, with big steps between the levels.

83 HM Government (2010) *2050 Pathways Analysis*, page 10.

The approach was kept as simple as possible to make the assumptions and choices transparent, and to allow the 2050 Calculator to be as flexible as possible. One of the Calculator's roles is as an engagement tool: it enables the public to explore the choices and trade-offs involved in ensuring secure, low carbon energy supplies. The simplicity of four trajectories per sector seemed fit for this purpose.

Even with just four trajectories per sector, the 2050 Calculator offers insights about messages common to pathways to 2050 (see section 1A on Pathways to 2050). But for the purpose of policy development, other more sophisticated tools would be used alongside the 2050 Calculator. For example, the 2050 Pathways Analysis will be just one source of evidence used by the Government in determining the UK's fourth carbon budget, for the period 2023-2027.

Underpinning assumptions

Population and GDP change

The 2050 Calculator has a fixed rate of population growth as a central assumption running throughout the calculator (see page 10 of July report). This is in line with the Office of National Statistics' central projections for population and equates to 0.5% growth per year. Some respondents suggested that the assumption on population should be a lever that users of the Calculator can vary.

Similarly the 2050 Calculator is underpinned by a central assumption that the UK's GDP grows by 2.5% per year (see page 10 of July report). This reflected HM Treasury's assumption about long-term growth at the time the Calculator was constructed. Some respondents suggested that the Calculator should allow the user to explore the impacts of different assumptions about long-term GDP growth.

In both cases, whilst we agree that it would be interesting to see the impact of such changes, we have decided not to add these underpinning assumptions as user-variables in the 2050 Calculator. The individual sector trajectories are designed broadly to reflect the central projection of population change and the GDP assumption. But in neither case are the assumptions 'hard-wired' into the model in the sense that the user could make a change to this GDP or population assumption and automatically see that change reflected across all the other sector trajectories. It has therefore not been possible to reflect this suggestion in the updated 2050 Calculator.

Scope of the model

Embedded emissions

It has been pointed out that the Calculator fails to account for the embedded emissions of imported goods. This is true. Similarly the Calculator does not deduct the emissions of manufacturing goods that are exported. This is because the Calculator looks at greenhouse gas emissions at the point of production, rather than consumption. We chose this method as it follows current international conventions on the measurement of emissions, and is how we currently assess the UK performance against the 2050 target. Calculating embedded emissions is also notoriously difficult to do. However, we acknowledge that carbon leakage would be a risk for certain trajectories.

Lifecycle emissions analysis

Several respondents recommended that the Calculator model full lifecycle emissions. This included emissions for the construction of new infrastructure, especially those requiring substantial quantities of concrete, and emissions for the manufacturing and import of materials where manufacturing took place abroad. No change has been undertaken here.

It is true that, with some exceptions, the Calculator does not try to model the impact of changes in one sector on other sectors. This was an explicit design choice to keep the model to manageable complexity and to ensure that the Calculator was as transparent as possible to the user. For example, a change in the rate of growth of wind generation does not automatically produce an increase in the output of the industrial sector.[84]

However, when constructing pathways to 2050, the user can choose a higher growth trajectory in the industry sector, in part to try to account for this potential inconsistency. Likewise, it is possible to set the growth rates in, for example, domestic transport or international shipping to reflect one's belief of the impact on these sectors of an increase in manufacturing activity.

This is an imperfect answer, but it does go some way to reflect the lifecycle emissions of new infrastructure build.

Accurately modelling the full lifecycle emissions for infrastructure manufacture and imports across several territories would not be feasible: it would require substantial assumptions about market conditions and emissions levels in other countries. Therefore, as explained above, and in line with the 2050 target, the Calculator is focussed on UK greenhouse gas emissions at the point of production.

Spatial factors

Several respondents had views on the degree to which the 2050 Calculator could be relevant to local decision-making, suggesting that the inclusion of further detail at the local level could make this a useful tool for Local Authorities. However other respondents felt that adding further detail on local energy supply and demand was unnecessary, suggesting that in the context of the UK's national emissions targets and national energy infrastructure, it was appropriate to focus on the national picture.

We have kept the current national model of the 2050 Calculator. But we have made a number of changes that will improve the user's understanding of the potential impact on the local environment. For example, the 2050 Web tool now includes the facility to see the land use impact of different choices on the supply and demand side. We have also made some changes to the Calculator which will help to clarify the impact of choices in these sectors: we have disaggregated the 'agriculture and land use' lever into two separate sectors ('land use management' and 'livestock management'); and we have updated the assumptions around bioenergy grown in the UK.

A number of stakeholders pointed out that the 2050 Calculator was an invaluable tool for engaging the public, as well as for experts and decision-makers, suggesting that dissemination of the Calculator would ensure that wide and meaningful discussions

84 The Calculator does model interactions within some sectors: the bioenergy sector, for example, does calculate the land use, land use change and forestry emissions for domestically-grown biocrops.

could take place. We actively agree, and are keen to engage the public in an energy-literate debate about the scale of the energy and climate change challenge, and the choices and trade-offs facing the UK as we transition to a secure, low carbon energy system.

We are therefore presenting a series of materials on the DECC website, which we will add to and improve over time, to support those who would like to use 2050 tools and analysis to facilitate such dialogues at local level. We are also keen to hear back from stakeholders and the public and Section 1B of this report sets out ways in which to feed back to Government.

Energy demand

Overall effort on reducing energy demand

Several respondents suggested that the model was insufficiently ambitious in terms of reflecting reductions in energy demand that might be expected over a 40-year period.

It remains our view that for the most part, the 'Level 4s' in the 2050 Calculator – the most ambitious trajectories – are considered to represent the full range of options that are physically and technically possible in each demand side sector. We believe that the 2050 Calculator does therefore allow people to make pathway choices which are extremely bold on energy demand.

As an example, under the most ambitious trajectory within the home insulation sector, we see a picture of the UK in which:

- People lower their thermostats to 16 degrees Centigrade – the lowest considered safe for vulnerable people, and a significant decrease of 1.5 degrees on the 2007 winter average.
- All possible efficiency improvements to existing homes are made, including solid wall insulation, cavity wall insulation, floor insulation, super-glazing (equivalent to triple glazing), loft insulation and draught-proofing. These measures address 96% rather than 100% of 1997 potential, based on the CCC analysis of maximum technical potential.[85]
- The demolition rate for existing stock (of 0.1% per annum) equates to the demolition of 25,000 dwellings per year, which is about twice the current rate.
- New build standards are assumed to be equivalent to PassivHaus, which is a domestic thermal efficiency standard developed in Europe and representing close to the limit of what is physically possible in terms of energy demand reduction for heating.
- There is a 50% decrease in hot water consumption per household. This is thought to be the limit that could be achieved with greater consumer awareness of hot water efficiency, and more water efficient fittings.
- It is assumed that no additional domestic air conditioning is used relative to today, despite the warming impacts of climate change.

85 Element Energy (2009) *The uptake of energy efficiency in buildings*, a report to the Committee on Climate Change.

We believe this represents a level of ambition which matches the maximum physically possible. Therefore for much of the demand side, we believe that this critique may conflate the ambition of the 'sector trajectories' in the Calculator and the 'illustrative pathways' set out in the July report.

The 'illustrative pathways' combine sector trajectory decisions across the whole energy and emissions system. The six pathways presented in Part 1 of the July 2010 report (Pathway Alpha through to Pathway Zeta) were purely illustrative and intended simply to indicate different directions of travel. It is true that none of the pathways included maximum ambition across demand side sectors, but in Part 1A of this report, Pathway 2 shows a picture of maximum demand reduction across all sectors. The purpose of the 2050 Calculator is to allow stakeholders and the public to develop a wide variety of pathways and to explore the full range of options available to us as we transition to a secure, low carbon economy.

Industry

Carbon Capture and Storage in Industry

A possible inconsistency in the Calculator's treatment of Carbon Capture and Storage (CCS) was raised by one respondent. It is currently possible in the Calculator to set the energy supply through CCS to Level 1 (i.e. where there are no functioning large scale plants) but still deploy CCS widely on an industrial scale. It was suggested that if CCS supply is set to Level 1 in the model, it should not be possible to use any CCS in industry.

However, on the basis of our analysis, we believe the current modelling does not represent an inconsistent position:

- CCS is potentially more likely to be successfully applied at industrial installations than at power stations as the concentration of CO_2 tends to be much higher and therefore easier to separate.
- If CCS fails on power generation for economic reasons, (i.e. by significantly reducing the cost-effectiveness of coal or gas powered generation), this should not preclude CCS usage on industrial processes (e.g. top-gas recycling in blast furnaces in the production of steel).

CCS deployment on an industrial scale is already being tested by a number of companies.[86] We do not agree therefore, that widespread deployment of CCS in industry in 2050 should necessarily be precluded by the failure of large-scale power generation CCS projects, and have left the model unchanged in this respect.

Transport

International aviation

Some Call for Evidence respondents questioned the range of possible futures offered by the three international aviation levels of the 2050 Calculator. In particular, they pointed to the potential for greater reductions in activity levels than presented by the current Level 3.

86 ACCAT (2009), *Accelerating the deployment of Carbon Abatement Technologies – with special focus on Carbon Capture and Storage.*

The international aviation levels have been taken from the Committee on Climate Change advice to Government in December 2009.[87] The Levels 1 to 3 reflect the CCC's three scenarios presented in this report – Level 1 based on the CCC's 'likely scenario', Level 2 based on the CCC's 'optimistic scenario' and Level 3 based on the CCC's 'speculative scenario'. As well as fuel efficiency improvements and the uptake of biofuels, this analysis also includes assumptions about behaviour change. For example, under Level 3, a new high-speed rail line in the UK and a fully integrated European high-speed rail network results in an 8% demand reduction by 2050. The CCC states that this is consistent with the high end of the range from the academic literature and current best practice. The result of these assumptions is that the increase in passenger demand above 2050 levels reduces from over 200% (with unconstrained airport expansion and without the impact of aviation joining the EU Emissions Trading System from 2012) to about 90% by 2050.

However, for consistency with other sectors, we would like to include four levels for international aviation emissions in a future update of the 2050 Calculator, and are grateful for the evidence presented on which we might base the assumptions. The Department for Transport expects to publish updated aviation demand and emissions forecasts later this year. These will form the basis for developing four scenarios with a view to including four scenarios in a future update of the 2050 Calculator.

Vehicle efficiency

The efficiency assumption of passenger cars in the July version of the 2050 Calculator, whilst varying over time and for the different technology types (i.e. different efficiency improvements for battery vehicles and combustion engines) is not a variable which the user of the model can change. Some respondents pointed to the advantages of having greater flexibility in the model for the user to be able to vary these efficiency improvements.

We agree that this would be a helpful addition. However, the transport worksheet of the Calculator already has a large number of variables:

- Miles travelled per person
- Mode of transport
- Mix of vehicle technology types
- Efficiency of the vehicle and type of fuel used
- Occupancy of the vehicle

To switch the efficiency factor from a fixed variable to one which users can alter would push the limits of the feasibility of the Excel model, and so this change has not been made.

Households

Lighting

Around eight respondents in the Call for Evidence commented on the Lighting and Appliances sector of the July analysis (Section A; pages 48 – 57). Some of the respondents challenged the assumptions about the energy savings which might be

87 Committee on Climate Change (December 2009), *Meeting the UK Aviation target – options for reducing emissions to 2050*. http://www.theccc.org.uk

possible in this sector. Most of these respondents argued that greater savings are possible under specific product assumptions.

The lighting and appliances sector covers diverse areas such as cooking, consumer electronics and home computing, cold and wet appliances, and lighting. Product innovation, as well as turn-around, is particularly high in this sector. This makes it more difficult to predict. The 2050 Pathways Analysis is informed by historical trends of the sector as well as driven by underlying economic and population growth assumptions. Although we recognise that innovation can occur and be implemented very quickly in this sector, we believe there is not enough evidence yet for us to change the four levels set out in July for lighting and appliances. The range of possible futures for this sector is already satisfactorily wide between Level 1 and Level 4.

Some respondents raised an interesting question. They enquired whether the impact on heating requirements had been considered if there is a 100% switch to LED lighting? Indeed, the heat replacement effect was considered in the heat section of the July 2010 report. DECC and Defra routinely take the heat replacement effect into account when assessing the effects of new lighting or appliances, such as the *Efficient Product* publication[88] or the *Heat Replacement Effect Factors in Lighting – A Review of New Evidence*, Defra (2007).

Heating supply packages

Heating supply technologies
Around 40 Call for Evidence respondents commented on the 'Space heating, hot water and cooling' section of the July report (pages 94 to 124). Several respondents commented on insulation levels and these are dealt with in Section 2A.J of this report. Some Call for Evidence respondents appeared to be confused by the way heating supply technologies are presented in the 2050 Pathways Analysis. This led to some respondents believing that pivotal heat supply technologies, such as micro CHP or heat pumps were omitted by the 2050 analysis.

We agree that the standard approach of Levels 1 to 4 has not been followed in this section, which makes the section less intuitive than others. Thus, a more user-friendly description of our approach to heating technologies for the UK leading to 2050 is put forward in this section. Overall, the actual analysis remains unchanged.

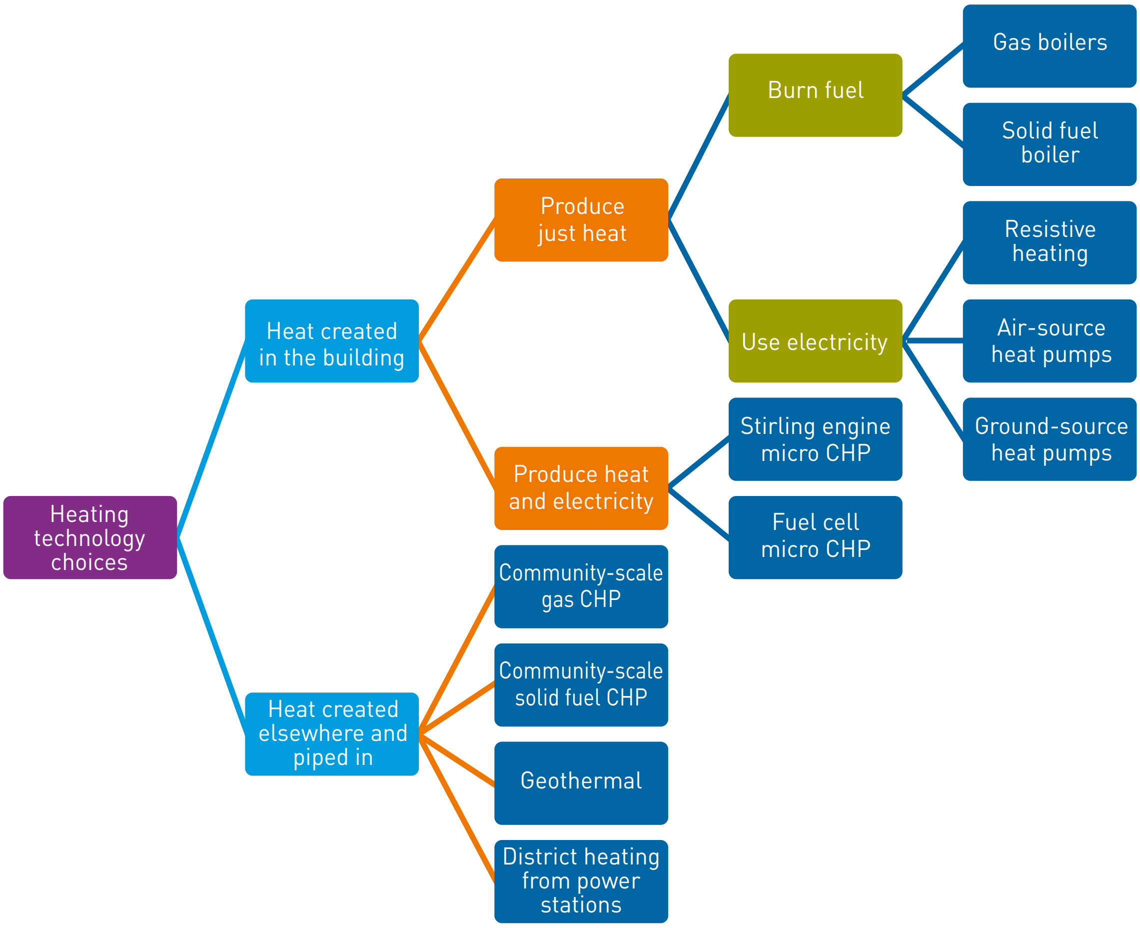
User-friendly description of heating supply technology 2050 packages
Eleven ways of heating homes have been modelled. Combinations of these can be chosen through two choices: one that mainly influences the level of electric heating and the other that influences the choice for the remainder of the heating supply. The matrix below gives a sense of what the choices trigger.

88 http://efficient-products.defra.gov.uk/cms/library-publications/

Electrification choice	Other choice	Gas boiler	Solid-fuel boiler	Resisitive heating	Air-source heat pump	Ground-source heat pump	Stirling engine micro CHP	Fuel cell micro CHP	Community scale gas CHP	Community scale solid-fuel CHP	Geothermal	District heating from power stations
A	A	90%		10%								
	B		24%				5%			63%	1%	7%
	C		19%				10%		24%	35%	1%	11%
	D		19%				10%		30%	33%	1%	7%
B	A			10%				90%				
	B		10%			20%				70%		
	C				14%	20%	15%		15%	25%		11%
	D					25%	5%	16%	23%	23%	1%	7%
C	A		10%			30%		20%	33%			7%
	B				18%	30%				45%		7%
	C				58%	30%					1%	11%
	D				25%	25%	10%		13%	20%		7%
D	A				55%	30%			15%			
	B				50%	30%				20%		
	C			7%	60%	30%						3%
	D			10%	60%	30%						

This approach allows the Calculator user to see the impact of 16 different heating technology packages for the UK in 2050. As the heating technologies available over the coming four decades are very variable and all could be significantly scaled up within the timeframe, this approach rather than the Level 1 to 4 approach is preferred. The Calculator user can see how 16 different mixes of heating technologies for the domestic as well as commercial sector impact UK energy demand, supply and emissions.

The diagram and bullets below describe how to select the main technology groups:



- **Gas boiler:** To maximise the use of gas boilers, choose AA. This will result in 90% of heating being delivered by gas boilers, up from 82% in 2007. The boilers are all assumed to be 91% efficient at turning gas into space heating or hot water, compared with a 76% average efficiency in 2007. The boilers are assumed to be capable of using biogass or any biogass/natural gas mix.
- **Solid fuel boiler:** To maximise the use of solid fuel boilers, choose A for electrification and B for other. This will result in 24% of heating being delivered by a solid fuel boiler, up from 4% in 2007. The solid fuel boiler is assumed to be 87% efficient at turning solid fuels into space heating or hot water. The solid fuel boilers are assumed to be capable of using coal or biomass.
- **Resistive heating:** To maximise the use of resistive heating choose AA, BA or DD. This will result in 10% of heating being delivered by resistive heating, the same as in 2007. Resistive heating can include wall-electric heaters, night storage heaters, portable fan heaters and portable radiactive heaters. All are assumed to be 100% efficient in turning electricity into space heating and into hot water, although depending on choices around electricity generation, the efficiency of electricity production will be less than 100%.
- **Air-source heat pumps:** To maximise the use of air-source heat pumps choose DC or DD. This will result in 60% of heating being delivered by heat pumps that draw heat from the outside air, compared with almost none in 2007. The heat pumps are assumed to be able to pump three units of heat for one unit of electricity when heating the air, or two units of heat for one unit of electricity when heating hot water (i.e., they are 300% efficient at space heating).

- **Ground-source heat pumps:** To maximise the use of ground-source heat pumps choose DC or DD. This will result in 30% of heating being delivered by heat pumps that draw heat from the ground, compared with almost none in 2007. The heat pumps are assumed to be able to pump four units of heat for one unit of electricity when heating the air, or three units of heat for one unit of electricity when heating hot water i.e. they are 400% efficient at space heating).
- **Stirling engine micro CHP:** To maximise the use of stirling engine combined heat and power units, choose BC. This will result in 15% of heating being delivered by this type of heating, compared with almost none in 2007. The stirling engines are assumed to be able to 63% efficient at turning gas into space heating or hot water and 23% efficient at turning gas into electricity, making them 85% efficient overall. The stirling engines are assumed to be capable of using biogass or any biogass/natural gas mix. The choices to increase biogas use in heating are described lower.
- **Fuel cell micro CHP:** To maximise the use of fuel cell combined heat and power units, choose BA. This will result in 90% of heating being delivered by this type of heating, compared with none in 2007. The fuel cell units are assumed to be able to 45% efficient at turning gas into space heating or hot water and 45% efficient at turning gas into electricity, making them 90% efficient overall. The fuel cells are assumed to be capable of using biogas or any biogas/natural gas mix. The choices to increase biogas use in heating are described lower.
- **Community scale gas combined heat and power:** To maximise the use of community scale gas combined heat and power, choose CA. This will result in 33% of heating being delivered by this type of unit, up from less than 1% in 2007. The units are assumed to be 38% efficient in turning gas into space heating and hot water, once the losses in piping to homes have been taken into account and 38% efficient at turning gas into electricity, giving a total efficiency of 76%. The units are assumed to be capable of using biogas or any biogas/natural gas mix. The choices to increase biogas use in heating are described lower.
- **Community scale solid fuel combined heat and power:** To maximise the use of community scale sold combined heat and power, choose BB. This will result in 70% of heating being delivered by this type of unit, up less than 1% 2007. The units are assumed to be 57% efficient in turning solid fuels into space heating and hot water, once the losses in piping to homes have been taken into account and 17% efficient at turning solid fuels into electricity, giving a total efficiency of 74%. The units are assumed to be capable of using coal or biomass. The choices to increase biomass use in heating are described lower.
- **Geothermal:** To maximise the use of geothermal heat, choose AB, AC, AD, BD or CC. This will result in 1% of heating being delivered from geothermal heat sources. These are assumed to loose 15% of the geothermal heat on the way to the building. Note that geothermal heat can also be used to generate electricity by altering the supply choice on geothermal electricity.
- **District heating from power stations:** To maximise the use of district heating from power stations, choose AC, BC or CC. This will result in 11% of heating being delivered by pipes from large power stations whose principal purpose is generating electricity (e.g., a big gas, coal or biomass power station). 10% of the heat is assumed to be lost en-route from the power station to the home. The power station is assumed to reduce its electrical output by one unit for every seven units of heat taken.

Use of bioenergy: If a heating system is able to use a solid, liquid or gaseous fuel then it is assumed to default to coal, oil and natural gas but be capable of using a bioenergy alternative if available.

Energy supply

Cross-cutting supply issues

Variation of capacity factors for supply sectors

We received information from several respondents who felt that capacity factors (often referred to as load factors) should be varied over time in order to improve the accuracy of the 2050 Calculator. Some respondents also felt that the capacity factor could vary between the different levels of effort within each sector.

We agree that some of the sectors make simplistic assumptions in applying the same capacity factor to all levels and all time periods to 2050. There is evidence to suggest that higher levels of effort or later time periods would benefit from technological improvements to the availability and efficiency of equipment, increasing the quantity of energy captured, in ways which would not be possible at lower levels of effort or nearer time periods. It is also anticipated that under more ambitious levels of effort it might be possible to capture more energy from locations further offshore where there are stronger wind speeds or greater wave energy. By contrast the availability and efficiency of equipment such as power plants can be expected to decline as they age. And, under more ambitious levels of effort, equipment such as wave machines and offshore wind turbines may also be constructed in more remote areas where operations and maintenance are harder to perform.

We are confident that the capacity factors currently used in the 2050 Calculator represent reasonable working assumptions about each technology. Where there is sufficient evidence on which to base assumptions of flexible capacity factors, we have done so (for example in the offshore wind sector). We are keen to keep the accuracy of all these assumptions under review, in particular by better taking into account the factors listed above.

Availability of fossil fuels

A number of respondents noted that peak oil was not considered to be a constraining factor in the 2050 Calculator. The term 'peak oil' refers to maximum global oil production, where the main areas under discussion are the timing and level of a peak in production, the shape of the production profile and the drivers of oil production.

We have looked at a variety of sources that assess oil demand and oil depletion including the International Energy Agency (IEA), industry and other research organisations. These broadly follow the conclusions of the IEA's analysis, namely that conventional oil production is unlikely to grow in the future as it has in the past, and that a supply 'crunch' (a tightness in the oil market), if not a peak in oil production, is very likely before 2020. There is no consensus on the level and nature of the peak, with some experts believing that total oil production could then plateau for up to 20 years, while other experts anticipate that a peak could be followed by a slow, undulating decline, or that production will fall off as quickly as volume increased. These situations could have a significant impact on the UK economy, leading to oil price rises and volatility.

However in the context of the 2050 Calculator there is no suggestion that oil will run out completely before 2050 and therefore no physical constraint – aside from the overall constraint of meeting the 80% emissions target – has been placed upon the use of oil (or other fossil fuels) in the 2050 Calculator. The Calculator currently does not cost-optimise the pathways created and therefore cost is not yet a limiting factor; it is assumed that oil is available to the Calculator user should they design a pathway which requires it.

Interconnection

Some Call for Evidence respondents questioned whether the levels of interconnection with the European mainland are sufficient to cater for high levels of UK electricity production which could be utilised for exports. They argue that if the UK should succeed in becoming a net exporter or electricity, or energy, the development of offshore renewables will be essential and this will require high levels of interconnection to service the export of UK generation.

The Government acknowledges that very high levels of wind as well as other renewables could generate an excess of supply under many pathway combinations. Since the 2050 Calculator is focussed on the UK domestic supply, demand and emissions system, it does not attempt to model any possible exports to the European mainland. We acknowledge that electricity exports might become a reality in the coming decades and if so, higher interconnection levels than those that exist currently may be necessary.

In the July version of the Calculator, it was not specified what the UK would do with potential excess electricity generation. The revised version of the Calculator implements several changes to the electricity balancing test (see Section 2A.C Electricity balancing), such that during periods of adverse weather conditions any excess capacity would be utilised to balance the UK system. Exports of electricity to European neighbours might be assumed to be feasible over periods when the domestic electricity system is balanced and excess capacity achieved but this is not explicitly modelled.

The Calculator models interconnection for the purposes of electricity balancing and imports. The maximum level of interconnection assumed in Level 4 of the storage, demand shifting backup section is 30 GW in 2050. This figure is in line with other analyses of the potential for a highly interconnected European grid and is, for example, higher than the maximum 21 GW suggested in the 2050 roadmap by the European Climate Foundation.[89] The maximum level of interconnection assumed in Level 4 electricity imports is 20 GW dedicated to imports of 140 TWh in 2050.

Thermal plant

Unabated gas

A number of companies suggested including a lever in the Calculator to allow users to switch between coal and unabated gas for thermal electricity generation in the short-run. This change was not implemented. The retirement rate for coal plant used in the Calculator is based on that required by the Industrial Emissions Directive, meaning that all existing unabated coal plants (including those co-firing with biomass) are retired by 2035. However, by choosing to supply no solid biomass and selecting to increase installed capacity of coal/biomass plants you can choose to generate electricity from unabated coal.

89 www.roadmap2050.eu

It is considered highly unlikely that coal plants will be replaced by unabated gas plants at a speed faster than the existing retirement rate, without significant policy intervention. Therefore, gas plants are assumed to be the only available unabated fossil fuel generation after 2030.

Treatment of unabated fossil fuel power generation in the Calculator

As set out above, unabated coal generation has a fixed assumption of retirement before 2050, and the same is true for unabated oil electricity generation. In 2007, oil electricity generation had an installed capacity of 4.1 GW and produced 2.6 TWh. The Calculator assumes that there will be no further electricity generation from oil plants after 2015.

In the Calculator, if there is a shortfall between the amount of electricity demanded by your demand side choices and the amount of electricity supplied by your supply side choices, this shortfall is assumed to be met through unabated gas generation. Combined Cycle Gas Turbines (CCGTs) meet such a shortfall, with a 50% thermal efficiency and an own use requirement of 2%.

Substitution of fossil fuels with biomass

The Calculator treats biomass as a substitute for fossil fuels, where:

- Solid biomass substitutes for coal
- Liquid biomass substitutes for oil, petrol, aviation fuel and diesel
- Gaseous biomass substitutes for natural gas.

These are substitutes given the same energy content: 1 kg of coal is not considered equivalent to 1 kg of biomass but 1 TWh of coal is considered equivalent to 1 TWh of biomass. The original biomass extracted also faces conversion losses before it is used as a direct substitute.

The Calculator does not make assumptions about where the biomass will be used i.e. which sectors will use the energy. Instead it assumes that the demand for hydrocarbons will first be met by biomass and then any remaining demand for hydrocarbons will be met through fossil fuels.

Nuclear build rates

We are glad to see that the majority of respondents have endorsed the technical feasibility of the different build scenarios for nuclear. Some respondents noted the challenge posed by the fast build rate and/or the high level of ambition displayed in the nuclear Level 4, while others noted that Level 4 assumptions looked reasonable, particularly if linked to improvements in reactor design such as fast breeder reactors or using coolants other than water which offer technological options for the future.

We explored the evidence and welcome the points raised but are happy that our original inputs were valid. In terms of the deliverability of high build rates, there was little evidence presented to suggest these build rates are not technically feasible but rather statements of opinion that the build rates under Level 4 would be challenging. The challenging nature of Level 4 is recognised in the definition used in the 2050 Pathways Analysis as a "level of change that could be achieved with effort at the extreme upper end of what is thought to be physically plausible by the most optimistic observer".

In terms of the timing of new nuclear build rates, one respondent suggested to shift the timescale to the right by three years. However the 2050 Calculator scenarios are split in five year intervals across all technologies for simplicity. To shift by three years would in effect mean shifting by five years or not shifting at all. If we shift by five years none of the scenarios would show any nuclear on the grid by 2020 which does not seem in line with current market information, e.g. the plans by EDF to have the first nuclear power plant connected to the grid by 2018.

Where respondents highlighted the difficulties with higher levels of nuclear it tended to be in the context of enablers such as the transmission system and the pricing of electricity which will have to be considered in the round for all generation technologies. These issues are cross-cutting, and cost is currently not considered to be a limiting factor within the technological parameters of the 2050 Calculator.

The availability of new nuclear sites and the need to consider the route for nuclear waste were covered to some extent by the original nuclear analysis. If a higher build scenario for nuclear were to be pursued by the UK then such issues would need to be given the appropriate focus. We will keep this sector under review for future versions of the 2050 Pathways Analysis.

Carbon Capture and Storage build rates

Three respondents felt that the build rates for the CCS Level 1 commenced very soon, in 2015. However Level 1 models the build rate of the four CCS demonstration plants, as announced by the UK Government, and reflects the timing envisaged in that competition.

The build rates and timing of these demonstration plants have been updated to reflect the announcement in November 2010 that the CCS demonstration programme will be open to projects on gas-fired power plants as well as coal-fired power plants. The Office of Carbon Capture and Storage (OCCS) in DECC is currently developing detailed proposals for a process to select and fund demonstration projects 2 to 4. The updated rate of deployment in Level 1 of the 2050 Calculator is therefore a revised estimate of the mix of projects that will form the CCS demonstration programme; this does not represent the Government's desired project mix:

- Two post-combustion coal CCS plants: 0.4 GW (one in 2014, one in 2018)
- One pre-combustion coal CCS plant: 0.45 GW (in 2018)
- One gas combustion CCS plant: 0.45 GW (in 2015)

Please note that all capacity figures used in the Calculator are gross capacity, e.g. the net capacity plus the 'parasitic' own energy use of both the plant and the CCS equipment.

The Government is committed to continuing public sector investment in all four CCS projects. In the Spending Review, the Government announced up to £1bn to support the capital costs of the first demonstration project which is planned to be operational in 2014-15. If evidence changes, we will keep this under review for future iterations.

Nuclear fusion

One respondent noted that nuclear fusion was not included within the 2050 Pathways Calculator and suggested that this could be included as a supply side sector in future revisions.

The decision to exclude fusion power was made because there was no evidence submitted during the 2050 Pathways Call for Evidence to suggest that any of the different forms of fusion technology which are currently being investigated was capable of being commercially deployed at scale before 2050. However, the Government is committed to supporting ongoing research both at the Joint European Torus at the Culham Science Centre and also the ITER fusion reactor, currently under construction in France. The most ambitious vision for fusion predicts that, if developed successfully to commercial scale, it could be capable of supplying high levels of low carbon electricity, providing a major contribution to energy needs. We will keep this sector under review for future updates of the 2050 Calculator,

Renewables

Intermediate levels of offshore wind

A few respondents proposed that higher levels of effort could be achieved for Levels 2 and 3 of offshore wind, as well as an increase to Level 4. Other respondents felt that Levels 2 and above were already optimistic, and cited the challenges of replacing retired turbines, interconnection and the planning process.

Having reviewed all of the responses we did not consider that there was sufficient new or compelling evidence to warrant a revision of the Levels 2 and 3 for offshore wind (Level 1 assumes that no further offshore wind is built after 2020 and therefore there is no generation at 2050). Level 2 is intended to represent annual deployment "similar to the build rate expected with the successful implementation of the programmes or projects currently in progress". It is therefore appropriate that our existing Level 2 meets our 2020 Renewable Energy Systems (RES) lead scenario.

Floating wind turbines were not explicitly considered separately in the offshore wind Levels 2 or 3, as they were in the revised Level 4 but, as stated in the July 2010 Analysis, it is considered that 'if significant offshore wind capacity is required beyond the current industry ambitions, then wind farms in zones with water depth greater than 60m may need to be developed using a range of technology types including floating turbines.'

We therefore remain satisfied that the current Levels 2 and 3 for offshore wind are suitably ambitious and appropriate to the definitions of those levels.

Bioenergy availability

We received evidence from a variety of respondents requesting that we examine some of our assumptions on bioenergy availability, and specifically, whether our Level 4 trajectories properly accounted for questions of sustainability and practicality. To address these responses, we looked again at our positions on marine algae, bioenergy imports and non-agricultural waste.

Some respondents misunderstood our report when it stated the Level 4 assumption in macro-algae production as being the development of an area 'three times the size of the existing natural reserve in Scotland'. This was interpreted as meaning that cultivation would be focused entirely on Scottish waters. We recognise that there are other potentially suitable sites in the UK, and used the Scottish development size purely as an area comparative.

On microalgae, it is worth noting that we did consider this in the original model, but only within imports of bioenergy. We still consider it unrealistic to expect that the UK would be able to produce microalgae at a competitive rate in a global market.

There were three respondents who raised concerns that our assumptions on bioenergy imports may be over-ambitious, given proper consideration of sustainability concerns. We believe that our estimates are broadly in line with the most recently published estimates of an UK share of global supply and, if anything, may be slightly cautious. As with any global and long-term questions, it is inevitable a high degree of uncertainty is associated with these projections. We have opted not to change the Calculator data.

Finally, one respondent questioned whether the amounts of waste arising were too high in light of findings from other studies. We agree that this is an area that should be looked at closely in the future, and plan to integrate findings from the Government's Waste Review into the Calculator on its conclusion later this year.

As with all sectors in the Calculator, technological developments are moving forward rapidly in bioenergy and we will continue to monitor developments closely, updating the Calculator in light of new evidence as necessary.

Solar PV

The solar PV levels in the Calculator demonstrated a wide range in the potential deployment of the technology. This reflected the fact that solar PV could make a significant contribution to UK generation if deployed at scale, but that commercial viability would determine deployment rates in the long term – with government support helping drive initial uptake.

The sector received thirteen responses in the Call for Evidence, with comments made on roof space and efficiency expectations, the scale of ambition, and on the spacing between levels.

The historic trend for photovoltaic panels shows a sharp decrease in costs, and the International Energy Agency (IEA) expects solar PV to become commercially competitive from 2020.[90] In addition, the UK build-rate has grown substantially in recent years, and build rates in Germany and Japan demonstrate that higher rates are possible, and far higher installation levels can be sustained.

The Level 4 ambition builds on this, and is on the very edge of what is thought theoretically possible by the UK solar PV industry.[91] Here the UK would match today's deployment-levels in Germany by 2016, and reach a total 2050 capacity of around 12 times the current global total. This level of deployment is unprecedented, necessitating the addition of ground-based installations and assuming a marked lack of deployment obstacles.

In contrast, Level 1 reflects that, in the absence of government support and longer-term commercial competitiveness, PV may not be a feature of the UK's future electricity mix. This enables users to explore generation mixes that do not include solar PV.

90 International Energy Agency (2010) *Technology Roadmap, Solar Photovoltaic Energy.*

91 UK-PV (2009) *2020 A vision for UK PV.*

Maintaining this range of ambition means accepting large ranges between available levels. To mitigate this, we have based Levels 2 and 3 on available literature, giving trajectories that are considered credible rather than picking arbitrary midpoints:

- the Level 3 trajectory is based on projections by the UK Energy Research Centre. It is also equivalent to continuing the European Photovoltaic Industry Association and Greenpeace's projected 8% growth rate for 2020-2030 for the period 2030-2050.[92]
- Level 2 is based on an estimated potential for solar PV by Element Energy and PÖYRY, and represents an annual growth rate of 22.6%. This is also broadly comparable to the 20% illustrative growth rate suggested by the Centre for Solar Energy Research.[93]

The full range of literature and the implication of each trajectory are detailed in the July report.

It is important to note that Levels 3 and 4, in particular, represent highly-ambitious trajectories, and that this scale of deployment would preclude also deploying significant levels of solar thermal within the available UK roof space. Here, the Calculator's assumption for total available roof space has not been updated, and continues to be based on UK-PV estimates of total UK roof space and facades.[94]

The assumed efficiency of solar PV cells has also not been revised. Whilst 20% efficiency is high for current cells and may under-represent average efficiencies longer term, 20% is considered a sensible proxy for this period. In part, this reflects that cell efficiencies are not expected to increase dramatically. For example, the IEA expects the efficiency of single-crystalline modules to increase from 14-20% today, to around 25% by 2050. It also reflects that less-mature technologies are expected to have an increased market share. In the case of emerging thin-film technologies, efficiency is lower (the IEA has an 18% target by 2030), but cells are expected to compete on cost, practicality and appearance.

92 European Photovoltaic Industry Association and Greenpeace (2008) *Solar Generation V*. See also: Centre for Solar Energy Research and Photonics (2009) *UK Photovoltaic Solar Energy Road Map*

93 Element Energy, PÖYRY (2009) *Design of Feed-in Tariffs for Sub-5MW Electricity in Great Britain*. Final Report.

94 UK-PV estimates that 4,000 km^2 of roof and facade space is available in the UK: UK-PV (2009) *2020 A vision for UK PV*.

Geothermal

One respondent queried whether we had been too cautious in our assumptions about the capacity for geothermal electricity and heat generation in the Calculator.

In terms of power generation we are confident that given the risks and uncertainties associated with geothermal technology, and the available resource we have in the UK, the Level 4 boundary of 35 TWh/y represents a sensible upper bound on the resource. It is important to remember that like many low-carbon technologies, geothermal power generation is relatively immature and there remains a good degree of uncertainty over its successful deployment. With this in mind, mitigating our assessment of the technical limits of possibility seems prudent.

For heat, geothermal is currently considered as part of some technology packages in the heating sector of the Calculator, providing up to 1% of energy for total UK heat demand (domestic and non-domestic). How useful the available resource is rests on the location of low enthalpy hot rocks, and whether they are sufficiently near urban centres. The technology also relies on heat pumps to 'step up' the heat energy in the rocks, much like a transformer. An indicative mapping exercise carried out within DECC suggested that while there was a level of heat generating potential that should be considered (approximately 10 TWh/y on rough calculations), there was not sufficiently compelling evidence that we should increase the potential role of geothermal beyond what is already considered in the Calculator. We will keep the evidence under review for future iterations.

Anaerobic digestion and biomethane

One respondent submitted evidence suggesting that the Calculator had failed to account for anaerobic digestion. However, anaerobic digestion is considered as part of the technology packages for heating, improved manure management processes in land use management and as part of the energy from waste generation process.

A small number of respondents suggested that biomethane and other forms of biogas are under-represented in the model. The Calculator does allow for the possibility of biogas in the model (indeed, it is possible to focus biomass conversion on to gas), but the treatment of it is slightly unclear. Once biomass has been converted to a usable form of energy in the Calculator, whether solid, liquid or gas, it is considered to be directly substitutable for fossil fuel hydrocarbons. Therefore biomethane is considered within 'gaseous hydrocarbons' and is transported to its end use as such. This is why it does not appear explicitly in the Calculator, even though it may form an important part of various 2050 pathways.

Ultimately, the amount of biogas available in 2050 is constrained by the amount of biomass produced domestically, given the difficulties associated with importing biogas. As we believe our assumptions on this sector are robust in light of current evidence, we think the amount of available biogas is also realistic.

Annexes:

Annex A: The Call for Evidence Questions in July 2010 Pathways Analysis Report

1. Scope of model:

(a) Are there any low carbon technologies or processes or major demand-side options which are not currently included within the scope of the model but that you consider should be in future?

2. Scope of sectors:

(a) Does the range of alternative levels of ambition presented for each sector cover the full range of credible futures? If not, what evidence suggests that the range of scenarios should be broader than those presented?

(b) Do the intermediate levels of ambition (Levels 2 and 3) provided for each sector illustrate a useful set of choices, or should they be moved up or down?

(c) The 2050 Pathways Calculator currently describes alternative directions of travel rather than different levels for some sectors where changes reflect a choice rather than a scale. Is this a suitable approach and clear to users?

3. Input assumptions and methodologies:

(a) For each sector, are the input assumptions and the methodologies applied to those input assumptions reasonable?

As regards specific sectors:

(b) Are the bioenergy conversion routes used in the model accurate, or are there more efficient routes for converting raw biomass into fuels?

(c) Can the model's assumptions on wave resource be improved, for example regarding the length of wave farms, their distance from shore, the efficiency of devices, constraints from other ocean users, and other assumptions?

(d) Can the model's assumptions on tidal stream resource be improved, for example regarding the method for assessing the resource at specific locations, and the scaling up of individual devices into an array?

(e) Is there any evidence that would help build an understanding of the potential impact of long term spatial development on transport demand, and how could this be accounted for in the model?

(f) Due to uncertainties in the evidence base on energy demand and associated emissions, the model currently sets out only one level of ambition for the future UK share of international shipping. Is there any evidence you could contribute to help build a greater understanding of the potential shipping trajectories?

(g) Could the relative roles of coal and gas out to 2050 vary from the assumptions shown in this work, and if so, how?

4. Common implications and uncertainties:

(a) The introduction to the report sets out some of the implications and uncertainties common to the illustrative pathways. Does this list cover the key commonalities? If not, please identify other common implications and uncertainties and provide evidence as to why these are key conclusions from the analysis.

5. Impact of pathways:

(a) What criteria should be taken into account in understanding the impact and relative attractiveness of pathways?

6. Cost analysis:

(a) Can you suggest a methodology by which the wider cost implications of choosing one pathway over another could be accurately reflected, and any relevant findings from such an approach?

7. Future improvements to model:

(a) Do you have any further suggestions for refining the 2050 Pathways Calculator?

(b) Could the 2050 Pathways Calculator be improved to reflect the fact that the level of ambition for some sectors will depend on local preferences? Could the Pathways Calculator be improved such that the inherent degree of individual and local choice in a chosen pathway were clear?

Annex B: List of organisations which responded to the Call for Evidence July–October 2010

A C Architects Cambridge Ltd

AeroSynergy Ltd

Air Fuel Synthesis Ltd

Aquamarine Chemicals

Association of Electricty Producers

Atkins

Aviation Environment Federation

Bellona Foundation

Biofuelwatch

BP

British Hydropower Association

Bryte Energy Ltd

Campaign for Better Transport

Campaign to Protect Rural England

Center for the Advancement of the Steady State Economy

Centre for Alternative Technology

Centrica plc

Ceravision

Combined Heat and Power Association

Drax Power Limited

E.ON UK

E4Tech (UK) Ltd

EDF Energy

Energy Networks Association

ESR Technology (engineering, safety and risk consultancy)

Estover Energy Ltd

Ethical Markets Media

Exxon Mobil

Food and Drink Federation

FSK Technology Research

Furness Enterprise Ltd

GL Noble Denton

Greenpeace UK

Grosvenor Britain & Ireland

HgCapital

Health and Safety Executive

IHS

Institution of Mechanical Engineers

InterGen

International Power

Isentropic Limited

Imperial College

Johnson Matthey plc

London Analytics

John Muir Award

Loughborough University and Bryte Energy Ltd

Loughborough University – London-Loughborough Centre for Doctoral Research in Energy Demand

Mainstream Renewable Power

Manchester: Knowledge Capital Ltd.

Mineral Products Association

Mitsubishi Electric

MVA Consultancy

Micropower Council

National Grid

National Nuclear Laboratory

National Farmers' Union

NIBE Energy Systems Ltd

Natural England

Norfolk County Council

Orchard Partners London Ltd

Oil and Gas UK

Parsons Brinckerhoff,
a Balfour Beatty company

Oxford City Council

powerPerfector

Progressive Energy

Public Affairs Advisers to Calor Gas Ltd

Public Interest Research Centre

Renewable Energy Association

RenewableUK

Rolls Royce

RSPB

RWE nPower

Scottish and Southern Energy

ScottishPower

Shell

Statoil

Tyndall Centre

Sustainable Aviation

The Anaerobic Digestion and Biogas Association

The Association for the Conservation of Energy

The Carbon Footprint Insulation Company Limited

The Energy Technologies Institute

The Sustainable Energy Partnership

Transition Wales

UK COAL Mining Limited

University of St Andrews, Dept of Earth Sciences

UK Energy Research Centre

University of Cambridge

University of Oxford – Transport Studies Unit; Halcrow Group, Transport Research

Verdanarch

WWF UK

Waterwise

Welsh Assembly Government

Annex C: Implications of Pathways for energy imports

The charts illustrate the implications of different illustrative pathways for energy imports. These highlight a number of important messages:

- In all the illustrative pathways shown in this document, the UK's oil imports will be higher in 2050 than today. This is largely because the rate of decline in North Sea oil production is faster than the decline in our oil use. The rate of increase in oil imports slows after 2020 reflecting choices to constrain overall oil consumption, but only under the most ambitious scenarios are oil import levels in 2050 below those in 2020.
- Gas imports increase in the near term under all the pathways shown. Their longer term role varies significantly between different pathways, but under most they have an important role to play even in 2050. Indeed under some pathways gas imports in 2050 are considerably larger than they are today. However these larger gas import scenarios are associated with CCS being applied to gas-fired generation.
- In all the illustrative pathways shown coal imports fall over the medium term as coal power plants retire. The diagram shows the UK has an over-supply of coal in a number of scenarios from 2050.
- Under almost all the illustrative pathways shown there is a very significant increase in our bioenergy imports between now and 2050, although there is a broad range of possible outcomes within this. The average of the results sees 2050 bioenergy imports at a level broadly similar to those of oil today.
- In none of the illustrative pathways do we expect to be net importers of electricity (although imported electricity may at times be important to balance intermittency in UK generation), and in some cases we may be significant net exporters of electricity.

Please note: When reading the graphs below, positive figures are imports and negative figures are exports.

Figure AC1: Gas imports under different illustrative pathways

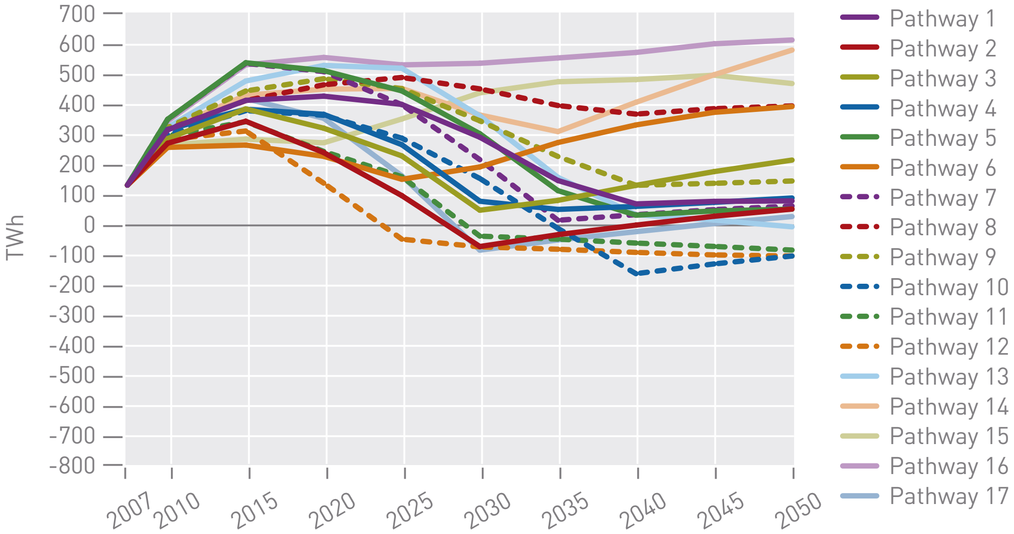


Figure AC2: Oil imports under different illustrative pathways

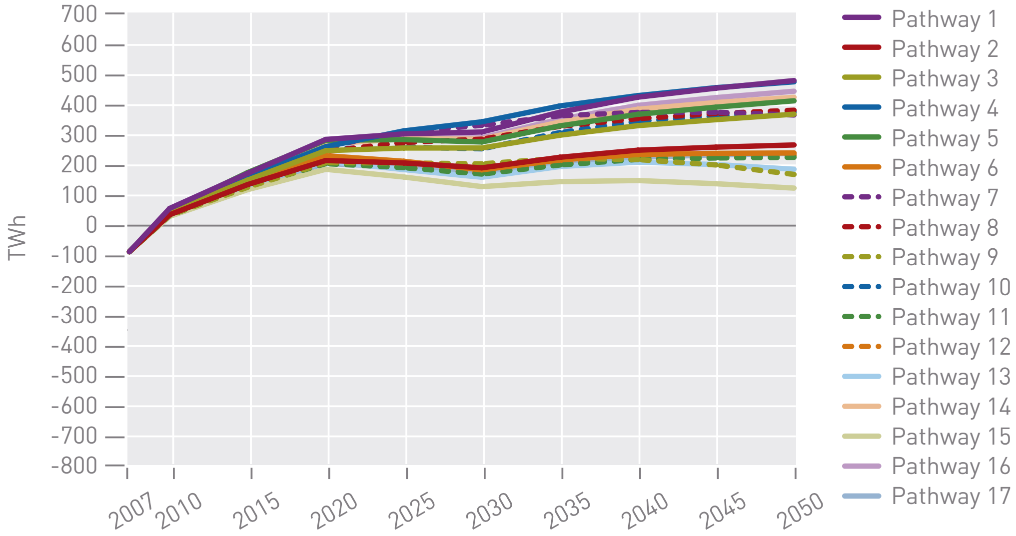


Figure AC3 Coal imports under different illustrative pathways

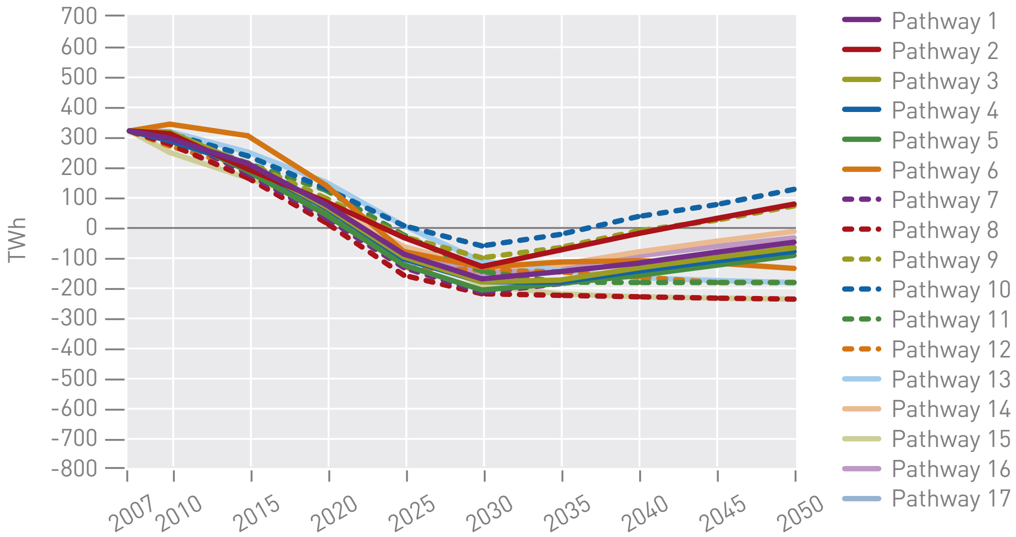


Figure AC4: Bioenergy imports under different illustrative pathways

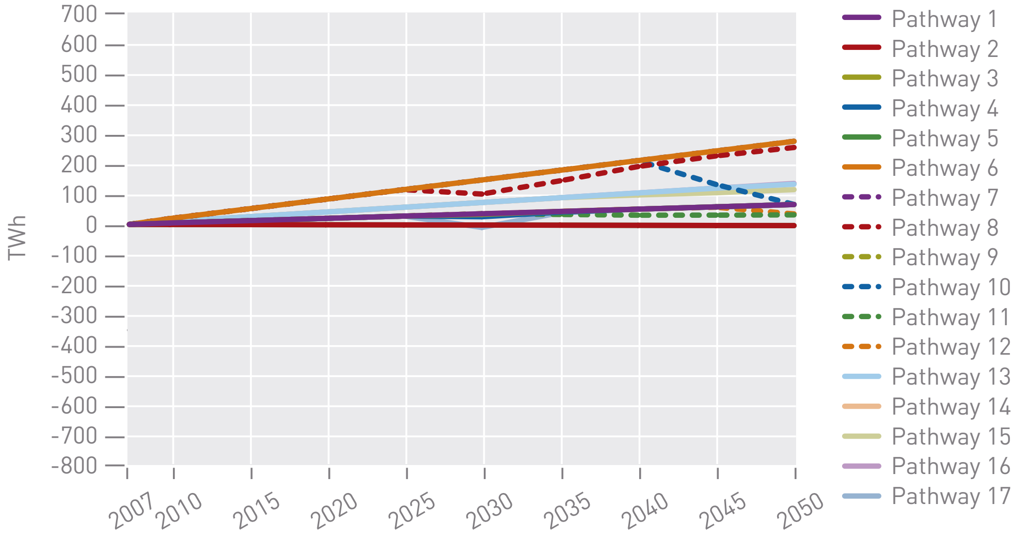
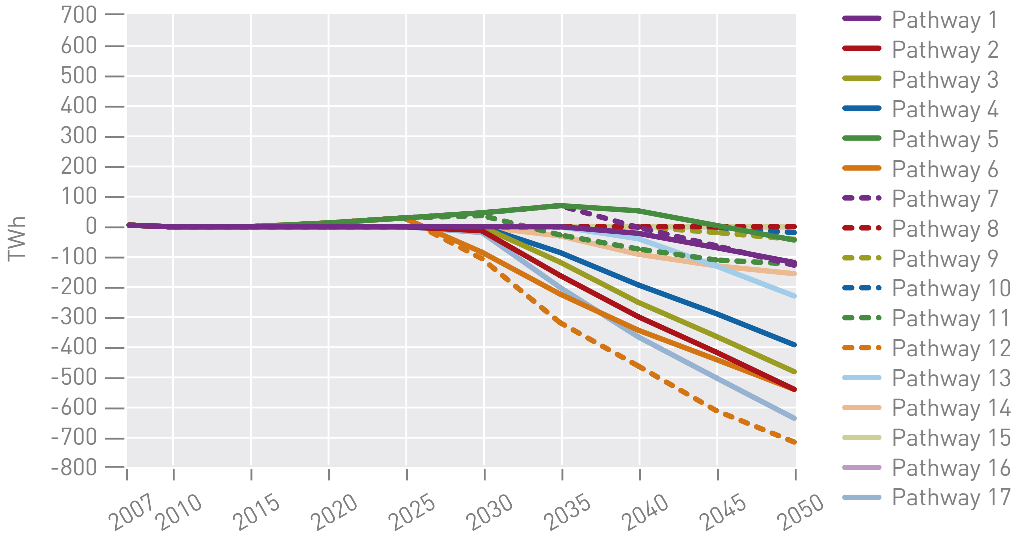


Figure AC5: Electricity imports/exports under different illustrative pathways



Annex D: Key to the Pathways charts

Demand

Lights and appliances
Heating
Industry
Transport

Supply

Pumped heat
Bioenergy
Electricity imports
Hydro
Geothermal
Wave
Tidal
Wind
Solar
Nuclear
Coal
Oil
Natural gas

Emissions

Other
International Air and Sea
Waste
LULUCF*
Agriculture
Solvents
Processes
Fuel combustion
Bioenergy credit
CCS
Total net emissions

* Land use, land use change, and forestry

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First published March 2011.

URN 11D/0024