Contents

Part 2 – Detailed sectoral trajectories
Energy supply-side sectors

Section E: Agriculture and land use

Context

This section explores the emissions and energy produced by agriculture and land use in the UK. In 2007, agriculture and changes in land use were responsible for around 7% of UK greenhouse gas (GHG) emissions.[186] This section uses four different scenarios or trajectories that describe possible changes in agriculture and land use in response to different policy directions. It considers the possible impacts of such changes on food and bioenergy production, as well as other environmental impacts.

Within this sector, it is important to consider the global impacts of agricultural and land use change in the UK. In a scenario where less food is produced domestically, there would be an inevitable increase in UK reliance on food imports, which would mean that products, and their associated emissions, are produced elsewhere and could increase the overall carbon impact of UK consumption. Increased global demand for food and bioenergy can also lead to deforestation and other serious land use impacts abroad. Exporting emissions in these ways would not help to tackle climate change.

Over the past 50 years, land use has remained relatively constant but has become more intense. In England over the last 20 years, an average of 0.05% of agricultural land has changed use each year.[187] Land use change may occur as a result of a complex interaction of drivers. Climate change is likely to influence the frequency and severity of flooding and drought episodes, which will affect how agriculture adapts at the regional level, resulting in the adoption of new practices or changing the crops grown. Farmers will exploit opportunities offered by climate change as well as managing risks to their businesses. The availability and uptake of new technology will influence the ability of farmers and land managers to adapt to climate change, which will influence the rate of land use change.

Over the next 40 years, pressure on land is likely to increase because of the effects of climate change,[188] rising global population and food demand, demand for renewable energy (including bioenergy and wind) and carbon sequestration and increasing demand for housing and leisure space. With limited available land in the UK for crops and livestock, it is important that the conflicting pressures on future land use and agriculture and the associated implications over the next 40 years are explored to assess and identify the possible conflicts and trade-offs between land use choices.

This section sets out four trajectories that explore the implications of an emphasis on a particular policy direction. One of the trajectories is essentially a no change trajectory where current trends continue. Unlike most other sectors discussed in this report,

---

[186] UK GHG Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change*.

[187] Based on Department for Communities and Local Government Land Use Change statistics http://www.communities.gov.uk/planningandbuilding/planningbuilding/planningstatistics/livetables/landusechange/ and Defra Agricultural land use estimates, AUK table 3.1 https://statistics.defra.gov.uk/esg/publications/auk/2008/excel.asp

[188] For example, on rainfall levels and soil quality.

these trajectories are presented as different futures rather than as four increasing levels of ambition. These trajectories are not intended to represent policy options for the future. Rather, they represent plausible futures in order to identify and explore the potential land use changes and associated emissions, and consequences for other sectors. The purpose of the 2050 Pathways Calculator, and of these component trajectories, is to explore the possibilities and trade-offs involved of meeting our legally binding target of reducing emissions by 80% by 2050. This call for evidence looks to stimulate expert debate and the submission of further evidence to refine the initial agriculture and land use assumptions made in the Calculator (some of which are detailed here) and improve the assessment of land use change, resulting emissions and other consequences.

Drivers and enablers

The trajectories described below explore the potential levels of emissions and energy that could be produced under a range of agriculture and land use scenarios. To calculate possible energy and emissions production this report examines the key drivers and enablers: agricultural emissions (including from livestock and soils); land use, land use change and forestry; and bioenergy (from crops as well as agricultural and silvicultural residues).[189]

Compared to other sectors of the economy there is much greater scientific uncertainty in estimating emissions from agriculture and land use and predicting the effects of changing practices and drivers. For example, the amount of N_2O released from spreading fertiliser can depend on soil type, the weather, and when and how the spreading was done. The Government is working with the research community to improve the UK's inventory of GHGs within the agriculture and land use sector so that our future policies are guided by the best evidence available and so farmers and land managers are properly credited for improvements in farming practice.

Agricultural emissions

The agricultural sector emitted over 43 $MtCO_2e$ of greenhouse gases in 2007[190] and reducing these emissions poses a particularly difficult challenge. Most other sectors can look to technological solutions that, to a large extent, do not yet exist within agriculture. For example, there is no technology that can prevent cows from emitting methane (one of the most potent greenhouse gases) through their biological processes. Agricultural emissions are likely to produce a higher proportion of the UK's greenhouse gas emissions as the rest of the UK decarbonises. Without abatement, the Pathways illustrated in this report show that agricultural emissions could comprise up to one third of the UK's total permitted emissions in 2050.

However, substantial reductions in emissions have already occurred. Between 1990 and 2007, total GHG emissions from UK agriculture fell by 20%, of which CH_4 by 17%; N_2O by 23%; and CO_2 by 16%. Much of this reduction was driven by declines in livestock numbers. There has been a 12% reduction in breeding cow numbers in the UK over the

---

[189] Government Office for Science/Foresight (2010) *Land Use Futures: Making the most of land in the 21st century* provides a good summary of drivers, as well as suggest an approach to effective, long term, land use management.

[190] UK GHG Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change*. This figure excludes emissions from energy use by the agriculture sector.

past decade.[191] Reform of Common Agricultural Policy direct payments (formerly paid per head of livestock), has reduced the artificial incentives to keep more stock than required. This trend may continue.

Agricultural emissions comprise emissions from enteric fermentation, manure and soil management (see Box E1). In developing the assumptions for the trajectories in this section, detailed modelling of historical time series data such as wheat and barley outputs and yields and livestock numbers and yields, has been undertaken, including a literature review of reports on the future direction of agricultural production.[192] Some of the changes in yields are substantial but are based on evidence about genetic potential. Assumptions to 2018 are largely based on the FAPRI-UK agricultural models.[193] Despite the uncertainties surrounding soil emissions, the trajectories for this section also make assumptions about the potential to reduce emissions through better tillage and more efficient use of fertilisers. Changes to the climate will also impact on crop production.

The English Climate Change Task Force, comprising the National Farmers Union, Country Landowners Association and Agricultural Industries Confederation has committed to voluntary action to reduce greenhouse gas emissions by three million tonnes of CO_2 equivalent by 2020.[194] An action plan to meet the 2020 target was published in 2010.[195] The plan targets emission reductions from farm-level efficiency gains. All of the trajectories for 2050 in this section assume that the sector meets its 2020 emissions reduction commitments. The assumptions described focus primarily on the changes that could happen within the sector in the 2020-2050 period.

Box E1: Drivers and trends for different sources of agricultural emissions

Enteric fermentation

The overall contribution that enteric fermentation makes to greenhouse gas emissions depends on the number of livestock and the emissions per animal. Livestock numbers have been in historic decline. In the future, demand for dairy and red meat, the degree of Common Agricultural Policy liberalisation and the competitiveness of the UK livestock industry will be the key drivers influencing livestock numbers.

Emissions per animal depend on the species and the system in which the animal is being reared. Livestock rearing is highly diverse in the UK, ranging from intensive indoor systems with a high level of management and compound feeding to hill farming, where nutrition is provided mainly by the natural environment. The scope for reducing emissions in a diverse industry varies widely. It is possible to reduce emissions from enteric fermentation in livestock through

---

[191] http://www.defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/junesurvey/results.htm

[192] These include English Farming and Food Partnerships (2005) *A study of long-term trends affecting the farming industry*; English Farming and Food Partnerships (2005) *Partners for success – a farm regulation and charging strategy*; and ADAS-UK (2007) *Baseline Projections for Agriculture and implications for emissions to air and water.*

[193] Patton, M et al (2010) *Projecting Greenhouse Gas Emissions from Agriculture in England, Wales, Scotland and Northern Ireland: A Methodology using the FAPRIUK Modelling System.*

[194] The English targets are relevant to the UK as a whole. The Government and the devolved administrations are working to ensure that the different policy approaches to reducing emissions in each part of the UK benefit from shared research and development.

[195] Agriculture Industry GHG Action Plan: Framework for Action, 10 February 2010.

diet. There is also evidence that some feed additives may help reduce methane, but it may not always be economic or practical to use these in farm-level situations. Selective breeding or changes to lower emitting breeds could have a role, but breeding decisions need to take into account a wide range of criteria, including production efficiency and consumer demand.

A focus on efficiency and realising the genetic potential of livestock will help reduce emissions per unit of production. For example, by optimising feed rations and enhancing health and welfare, it may be possible to reduce the time it takes for livestock to reach a finishing weight, thus the emissions per kilo of meat produced could be minimised.

Assumed rates of decline in enteric emissions intensity differ between the four agriculture and land use trajectories, and are detailed in the 2050 Pathways Calculator.

Manure

Manure emissions will also be driven by the number of livestock and by the amount of manure produced per animal.

Manure produces CH_4 emissions when allowed to decompose anaerobically, and also N_2O emissions when applied to the land. By changing manure management practices, manure emissions could be reduced – options include better storage, improved timing of application of manure to the land, and greater use of anaerobic digestion plants. The potential abatement from uptake of these practices is currently unknown and research is under way. It should be noted that manure management can involve a cost for farmers to put in place covers for slurry stores and anaerobic digestion plants. Anaerobic digestion plants may yield a return in terms of power generation if the livestock unit is big enough to sustain it.

Soil

The dominant source of agricultural N_2O emissions is the breakdown of fertilisers and manures applied to the soils (33%), with significant contributions from indirect sources, notably from leaching and runoff (26%). Significant reductions to agricultural N_2O emissions have been achieved since 1990,[196] largely through more efficient use of fertilisers and reduced application to grasslands.[197] The current methodology employed to estimate emissions of N_2O from soil in the UK inventory is imprecise – soil characteristics, land use and fertiliser type are not currently differentiated and calculations are based on total tonnes of nitrogen applied. There is therefore much uncertainty around soil emissions. Approximate assumptions have been made within the trajectories for this section, but this remains an area where further work is needed to improve the analysis.

---

196 A reduction from 33 to 25 Mt of N_2O in CO_2 equivalent from 1990 – 2007 (approximately 24%). UK GHG Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change*.

197 Over the last 10 years large reductions in application rates of mineral N to grasslands have been recorded, while application rates to arable crops remained roughly constant. Source: Thomas (2008) *The British survey of fertiliser practice: fertiliser use on farm crops for crop year 2008*, Defra, York, UK.

Land use, land use change and forestry (LULUCF)

Carbon sequestered within the soil may be released when it is disturbed. Land use and land use change is therefore associated with CO_2 emissions, which can be substantial in organic soils. Some sources argue that soil emissions from planting short rotation coppice (SRC) crops on permanent grassland can, in certain circumstances, cancel out the emissions saved by burning biomass instead of fossil fuels.[198] In contrast, SRC crops planted on land previously used for food crops can help to increase carbon stores, as the soil will no longer be tilled and fertilised every year (though if this leads to greater agricultural imports then this might means there is no positive impact on global soil emissions). There is also currently significant uncertainty about the contribution that grasslands and mixed farming methods can make to meeting the sector's future emissions targets through soil carbon sequestration.

UK forests currently sequester more carbon than they emit, resulting in a net removal of CO_2 from the atmosphere. However, UK forests are projected to soon become net emitters of CO_2 as the large number of trees planted between the 1950s and 1980s mature and become available for harvesting.

Simplified estimates of LULUCF emissions are included in this report. More detailed analysis of LULUCF emissions up to 2050 will be developed during 2010.[199] Land use change emissions from land converted to settlements have been assumed to remain constant.[200] Emissions from land remaining and converted to cropland and grassland have been assumed to vary relative to the overall area of land assigned to these uses.[201] Emissions from land converted to SRC crops have been assumed to be zero due to the uncertainties in this area.[202] The Forestry Commission has provided estimates up to 2050 for forestry emissions under four different tree planting scenarios.

Domestic bioenergy

This section looks at specially grown bioenergy crops as well as agricultural and silvicultural by-products collected for bioenergy, including manure, straw and woodland residues (see Box E2).

The amount of energy available from bioenergy crops in the years to 2050 will be determined by the amount and type of land given over to the crops (itself determined by relative and absolute crop prices), as well as any assumed increases in yield. There is potential to produce a relatively significant amount of bioenergy domestically. However, above a certain level of production,[203] bioenergy crops will begin to displace food

---

[198] Environment Agency (2009) *Minimising greenhouse gas emissions from biomass energy generation.*

[199] Centre for Ecology and Hydrology analysis for DECC (forthcoming).

[200] The rate of conversion of land to settlements (17 kha per year) follows the historical average and is assumed to remain constant out to 2050. Therefore, the land use change emissions have also been assumed to remain constant. Since 1990, emissions from land changed to settlements have decreased by just over 10%, (UK GHG Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change*). Therefore, this estimate may be conservative.

[201] Up to half of LULUCF emissions result from historical (pre-1990) land use change. There are significant annual land use changes to and from cropland and grassland. It is assumed that as areas of cropland and / or grassland decline, these annual changes and will also reduce.

[202] For example, E4Tech states that energy crops planted on pasture land are assumed to be no till and therefore not to have land use change emissions. (E4Tech (2009) *Biomass supply curves for the UK.*)

[203] Most sources agree that 350 kha or more could be given to bioenergy production with little or no impact on food production. For example, Rural Economy and Land Use (2009) *Assessing the social, environmental and economic impacts of increasing rural land use under energy crops*.

production. This could increase net imports of food to the UK, increase the carbon footprint of UK food consumption and impact on global food prices. Bioenergy crop production can also have wider environmental impacts: on biodiversity, water resources, the visual landscape and through land use change emissions.

Box E2: Drivers and trends for different bioenergy sources

Bioenergy crops

The levels of bioenergy produced from specially grown crops will depend on the amount and type of land allocated to this purpose and on the yield per hectare, as well as the efficiency of the chosen energy conversion technology (see Section F of this report). This report looks at oil seed and starch grain crops (for example, oil seed rape and wheat) and other energy crops (primarily SRC and miscanthus). It is assumed that SRC and miscanthus crops are planted on the vast majority of land dedicated to bioenergy, and that farmers are incentivised to make a long term commitment through longer-term contracts. It is also assumed that some oil seed and starch grain crops continue to be used for bioenergy up to 2050, because some farmers could continue to be reluctant to commit to the longer harvesting cycles of SRC crops.

Yield increases of up to 1.5% pa are assumed on the basis that research is likely to identify higher yielding strains.[204] Other factors such as weather, nutrient input, incidence of pests and disease and breeding will also contribute to changes in yield.

Manure

Energy available from manure will depend on the amount of manure produced and the proportion of this manure that is collected, as well as the efficiency of the energy conversion process. The amount of manure produced will be driven by the number of livestock and horses, the amount of manure produced per animal and the feeding regime.

At least 50% of manure produced is dropped in the fields during grazing. It is assumed that the maximum proportion of manure that can be collected for anaerobic digestion is 45%.[205]

Straw

Energy available from straw will depend on the amount of land cropped, the proportion of straw collected for energy and the quality of the feedstock. Straw can usefully be recycled as livestock bedding or ploughed back into the fields, however it is estimated that an average of three oven dried tonnes (odt) per hectare of straw per year are potentially available for energy use at present, without detracting from these uses.[206] This also allows for the logistics of collection. The level of available straw is assumed to rise or fall with conventional cereals production.

---

[204] E4Tech (2009) *Biomass supply curves for the UK,* commissioned by DECC, assume annual increases of 1-2% depending on scenario. When extending the trajectory out to 2050, a more moderate 1.5% per annum has been used as the maximum.

[205] For wet manures, E4Tech supply curves assume that 1% is currently used as a feedstock for AD, rising to 10% in 2010, 50% in 2015 and 100% in 2020. Wet manure available is less than 50% of the total produced. Therefore, 45% is assumed to be the maximum proportion of total manure sent to AD. Source: E4Tech (2009) *Biomass supply curves for the UK.*

[206] DTI, DfT, Defra (2007) *UK Biomass Strategy*, Annex A.

Woodland residues

This report assumes that forests are generally not grown for the specific purpose of producing wood for biomass. However, it assumes that thinnings and other wood residues from managed forests can be collected and used to produce energy, predominantly in the form of wood pellets or woodchip. The amount of wood residue available will again depend on the area of managed woodland and the proportion of residues collected. It is assumed that a higher proportion of newly planted forest will be managed woodland, and hence the proportion of harvesting residues used as a source of bio-energy will be higher.[207] The energy content of woody species varies significantly, as does the energy required to convert it for use as a bioenergy feedstock.[208]

The trajectories

Four trajectories have been developed for agriculture and land use in order to stimulate debate and a call for further evidence to develop 2050 scenarios further. These are summarised in Table E1.[209]

Table E1: Summary of the four agriculture and land use trajectories

Trajectory	Description
A	Current trends and drivers in agriculture and land use largely continue
B	A trajectory where there is a policy priority to increase food production and the least focus on bioenergy crops and forestry
C	Explores the possibility of securing lower emissions from the agriculture sector through significant investment in technology and knowledge transfer, as well as an increasing emphasis on bioenergy crop production and woodland creation
D	A trajectory where there is a substantial policy priority to increase domestic bioenergy production, and carbon sequestration through extensive woodland creation

Figures E1, E2 and E3 illustrate the agricultural emissions, LULUCF emissions and bioenergy produced respectively of the four trajectories described in this section. The assumptions behind the four trajectories (A, B, C and D) are detailed in the 2050 Pathways Calculator, some of which are also described below.

---

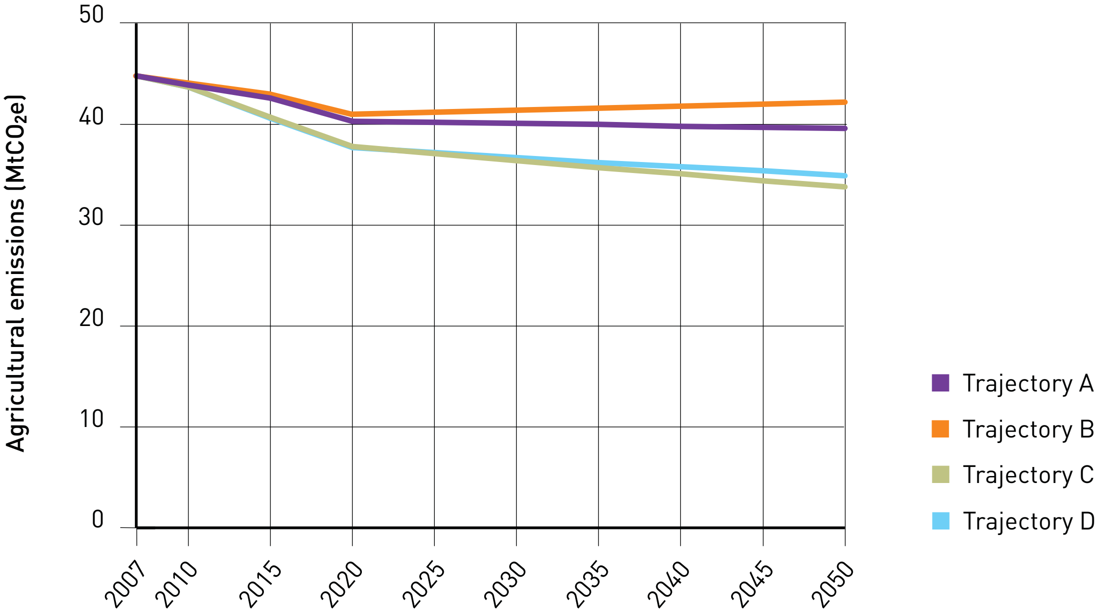
[207] Read et al (2009) *Combating Climate Change – A role for UK Forests* and Forestry Commission (2007) *A Woodfuel Strategy for England*, both set out plans for increased woodland residue collection within new and existing woodlands.

[208] The Forestry Commission produced estimates of the amount of additional woodfuel that could be produced from new woodland. Assumptions about woodland residues per hectare, for different types of tree and woodland management system, are embedded within these.

[209] The trajectories were detailed following: detailed modelling on the basis of historical time series data (eg, wheat and barley outputs and yields, livestock numbers and yields), a literature review of reports on the future direction of agricultural production and expert option within Defra through meetings and a workshop.

Trajectory C would result in the lowest agricultural greenhouse gas emissions (see Figure E1). However, by 2050, agricultural emisisons have fallen by only 26% from the 2007 baseline. This underlines the challenges of reducing emisisons in this sector where, despite assumed significant investment in technology to reduce emissions, the abatement potential of diverse and complex biological systems is currently believed to be limited (compared to many other sectors).

Figure E1: Agricultural emissions produced in the four trajectories



The shape of the LULUCF emissions trajectories (see Figure E2) illustrate a decline in removals of atmospheric CO_2 through sequestration in growing forest biomass during the first part of the period. This is a result of the marked decline in afforestation since the 30,000 ha per year planting rates experienced in the 1970s to 1980s, coupled to these large areas of woodland approaching maturity and harvest. The current, low, rates of woodland creation will result in a rapid decline in the level of abatement provided by forest land up to 2020. This pattern is broadly the same across the devolved administrations, but is particularly marked in Scotland as a result of the large-scale planting from the 1950s to 1980s. High tree planting rates within trajectories C and D lead to increased removels through forestry from 2030, with trajectory D eventually bringing the LULUCF sector as a whole back down to negative emissions.

Figure E2: LULUCF emissions produced in the four trajectories

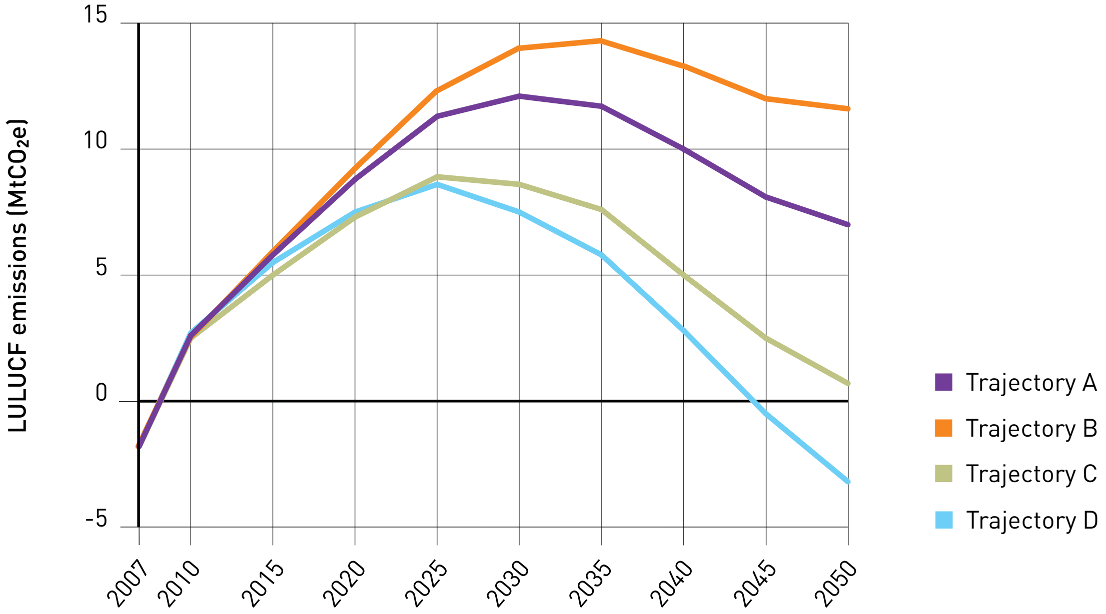
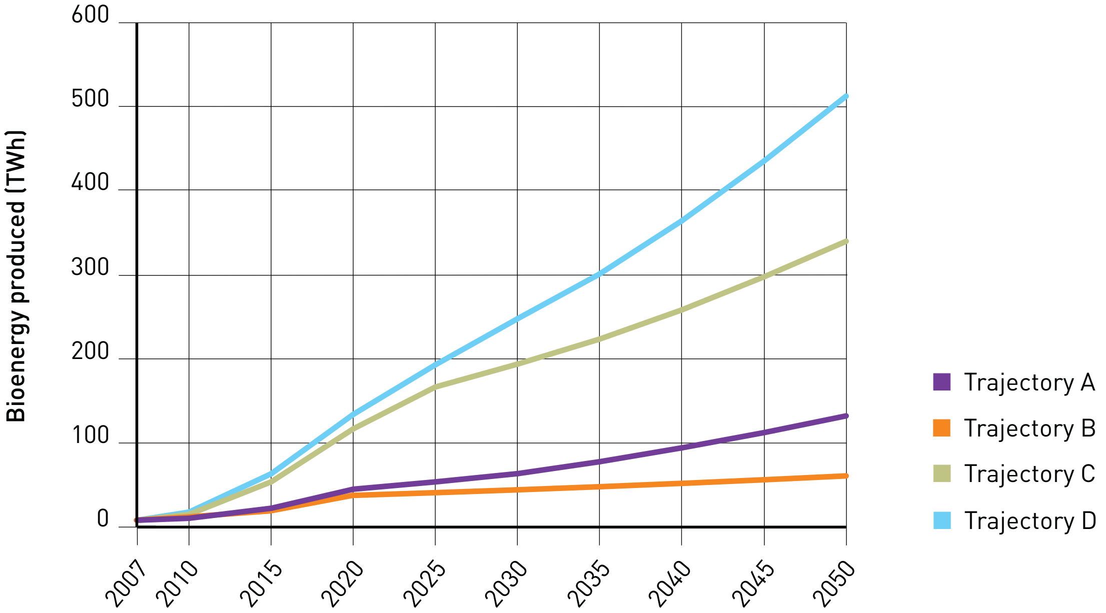


Figure E3 shows the amount of bioenergy produced in each of the trajectories. Trajectory B assumes the lowest levels of bioenergy production – due to a focus on farming for food – whereas in trajectory D there is a major push on domestic bioenergy production.

Figure E3: Domestic bioenergy produced in the four trajectories



The details and specific assumptions for each trajectory are described below.

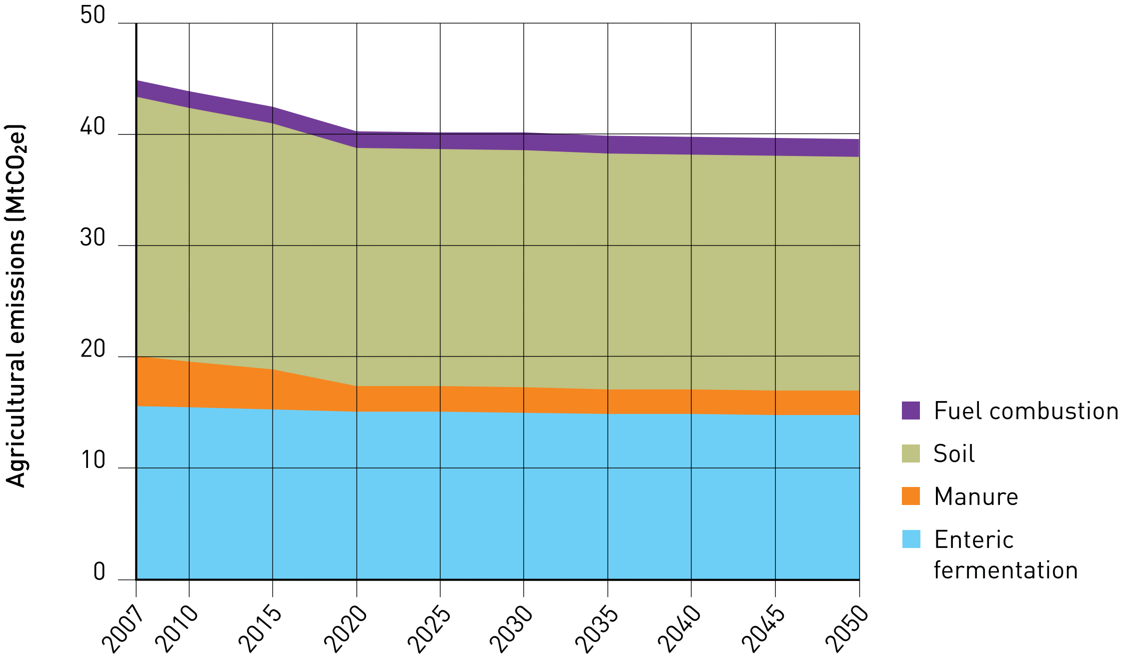
Trajectory A

Trajectory A describes a scenario where current trends and drivers in agriculture and land use largely continue.

Agriculture

This trajectory describes a scenario where the agriculture sector meets its 2020 emissions reductions target.[210] Improvements in the efficiency of livestock and crop production result in a reduction of emissions per production unit, improving returns on-farm and realising the genetic potential of crops and livestock. However, some of these improvements flatten out later in the period. Population increases lead to a rise in demand for food. While there may be a modest shift towards reduced consumption of red meat and dairy products in a proportion of the population, overall demand remains high and export opportunities for red meat continue, or may increase as the industry positions itself to be a more competitive trading entity. Livestock numbers remain constant from 2007 levels. UK agriculture remains competitive and production keeps pace with the increase in UK population, with the proportion of consumed food that is produced domestically remaining constant. Figure E4 illustrates the breakdown of agricultural emissions in trajectory A.

Figure E4: Trajectory A agricultural emissions[211]



The following specific agricultural assumptions are made:

- Livestock numbers remain constant.
- Enteric emissions intensity per animal declines by 5% by 2050 as a result of improved animal nutrition, and other husbandry improvements that contribute to livestock meeting their genetic potential (optimising the emissions produced per production unit), for example effective management of common endemic diseases.

---

[210] A reduction in emissions from agriculture of 3 $MtCO_2e$.

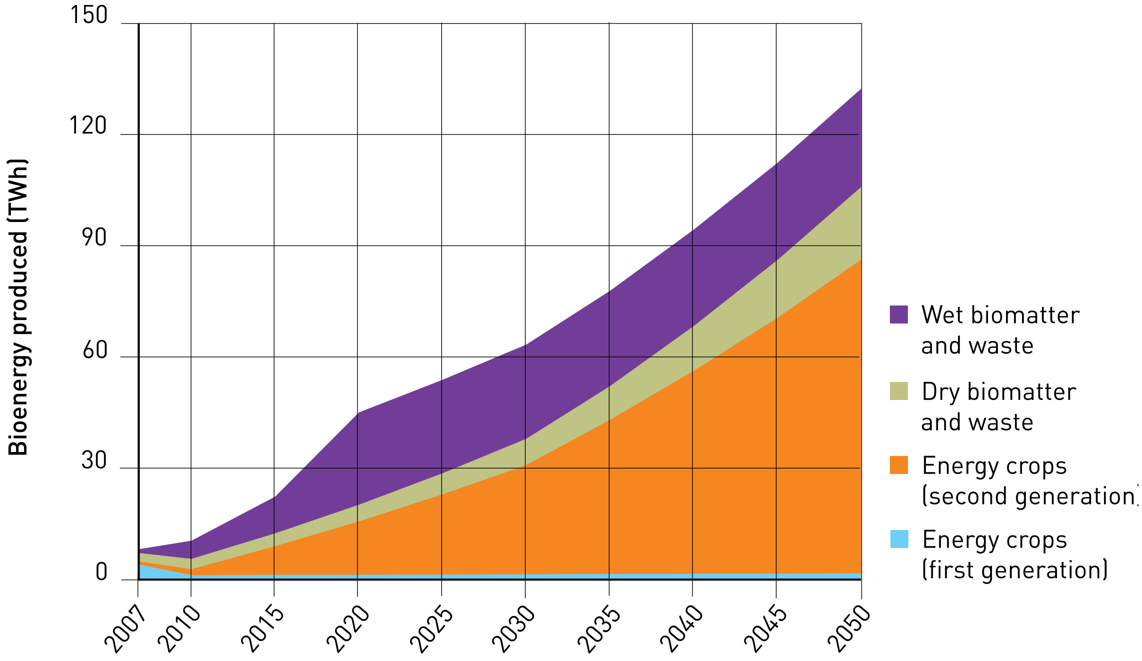
[211] Excluding net forestry emissions.

- Manure emissions intensity declines by 10% by 2050, through the implementation of improvement of manure management and application on-farm. Manure produced per animal increases by 0.2% per year due to improved nutrition that is supporting yield increases. And 25% of manure is collected for anaerobic digestion from 2020 onwards.[212]
- Soil N_2O emissions decline by 10% by 2050, through continued improvement in nutrient management practices on farm.
- Crop production efficiency continues to increase with crop-breeding, soil management and pest control developments keeping up with climate change, with steadily incremental improvements in yields.

Bioenergy

As the area used for growing food crops declines by around 550kha by 2050, this land is instead used to grow bioenergy crops. Some temporary grassland (620 kha) is also converted. Bioenergy is also produced from the collection of manure, straw and woodland residues, with up to a quarter of these by-products used for energy by 2050. Figure E5 shows the amounts and breakdown of bioenergy in trajectory A.

Figure E5: Trajectory A bioenergy produced



The following specific bioenergy assumptions are made:

- Almost 1.2 million hectares (5% of UK) are used for growing bioenergy crops by 2050.[213] The vast majority of these are woody crops such as short rotation willow. Yields increase by 1% per annum to 15 odt per hectare by 2050.
- Proportions of manure, straw and woodland residues collected rises to 15-24%.

---

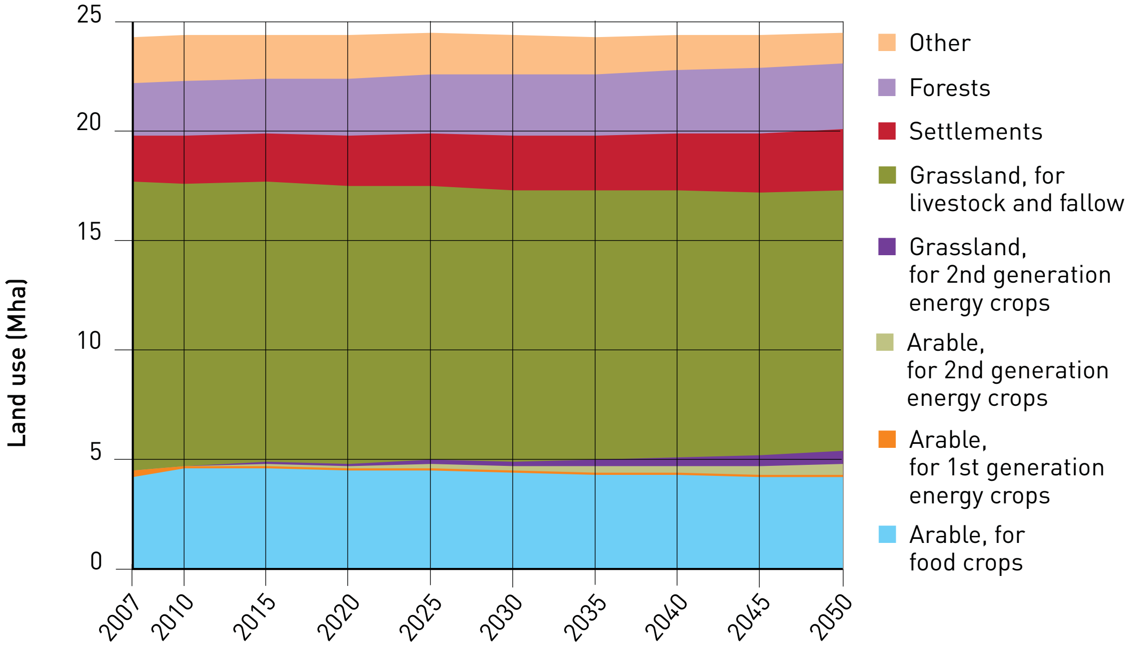
[212] This assumes collection rates at half the collection rate in the E4Tech supply curves (2009).

[213] European Environment Agency (2006) *How much bioenergy can Europe produce without harming the environment?* assumes that by 2020, the UK will have 1.1 m hectares available for bioenergy crop production. This figure is quoted within the UK Biomass Strategy (DEFRA, 2007).

Land use

Figure E6 illustrates the land use changes that occur by 2050.

Figure E6: Trajectory A land use change



Changes by 2050	
Food crops	550 kha of cropland changes to produce bioenergy instead of food. Overall cropland area remains constant.
Grassland	Decreases by 1.3 million hectares which includes most temporary grasslands and other under-used pastures.
Forest	Increases by 596 kha (15 kha per year)[214]
Settlement[215]	Increases by 731 kha (17 kha per year)

Trajectory B

Trajectory B describes a scenario where there is a policy priority to increase food production and the least focus on bioenergy crops and forestry. It explores the highest levels of emissions that the agriculture and land use sector might produce.

Agriculture

Trajectory B assumes that UK food production outpaces UK population growth. This is likely to be driven by rising demand for food globally and by the UK's comparative advantage in this sector. Food production remains the focus and there is little incentive to produce bioenergy, either from crops or agricultural by-products. Diets do not change much and demand for meat remains high. There is very little land use change.

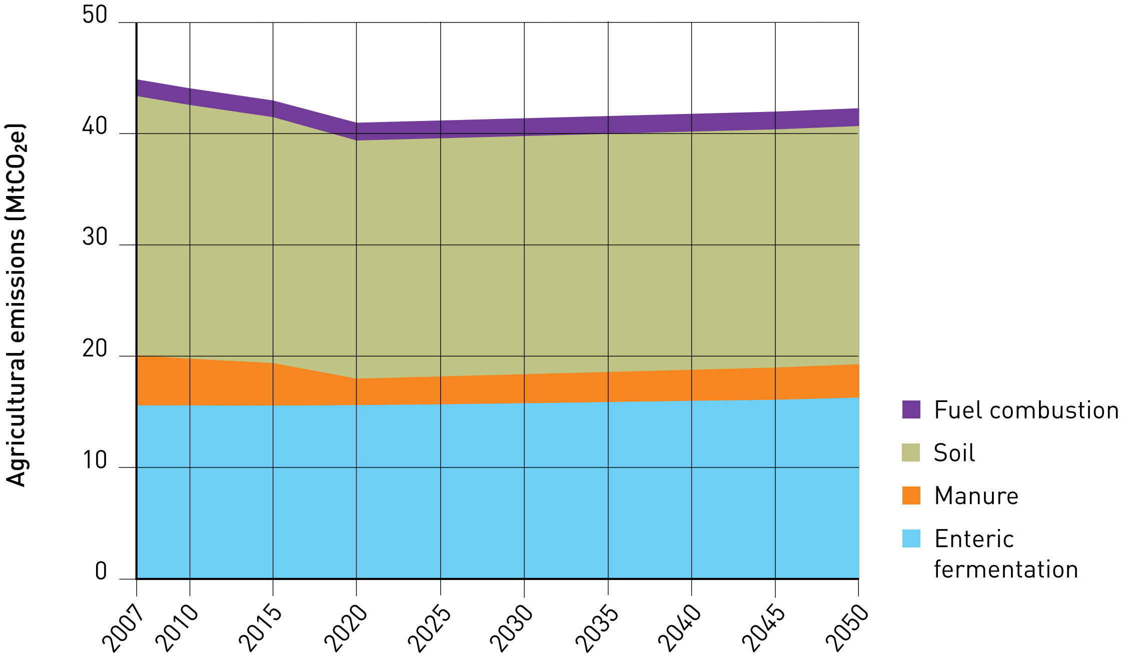
---

[214] This assumes that conventionally managed broadleaf and conifer woodland is planted, with broadleaf:conifer ratios remaining constant.

[215] Settlements increase in line with historical trends (as set out in the GHG Inventory, 2009).

Livestock numbers increase and emissions per animal reduce by only a little. Yield increases are high (up 85% by 2050), but continued use of fertilisers means that soil emissions improvements flatten out after 2020. Figure E7 illustrates the breakdown of agricultural emissions in trajectory B.

Figure E7: Trajectory B agricultural emissions[216]



The following specific agricultural assumptions are made:

- Livestock numbers increase by 0.2% a year, a total of 10% by 2050.
- Enteric emissions intensity per animal declines by 5% by 2050, as in trajectory A.
- Manure emissions intensity decline by 5% by 2030 then flattens out. Manure per animal increases by 0.5% per year due to yield increases. And 25% of manure is collected for anaerobic digestion from 2020 onwards.[217]
- Soil N_2O emissions decline by 8% by 2020, through continued improvement in nutrient management practices on farms, then flatten out.
- Crop production efficiency continues to increase with crop-breeding, soil management and pest control developments keeping up with climate change, with steadily incremental improvements in yields. Food crop yields grow at a faster rate than in trajectory A.

Bioenergy

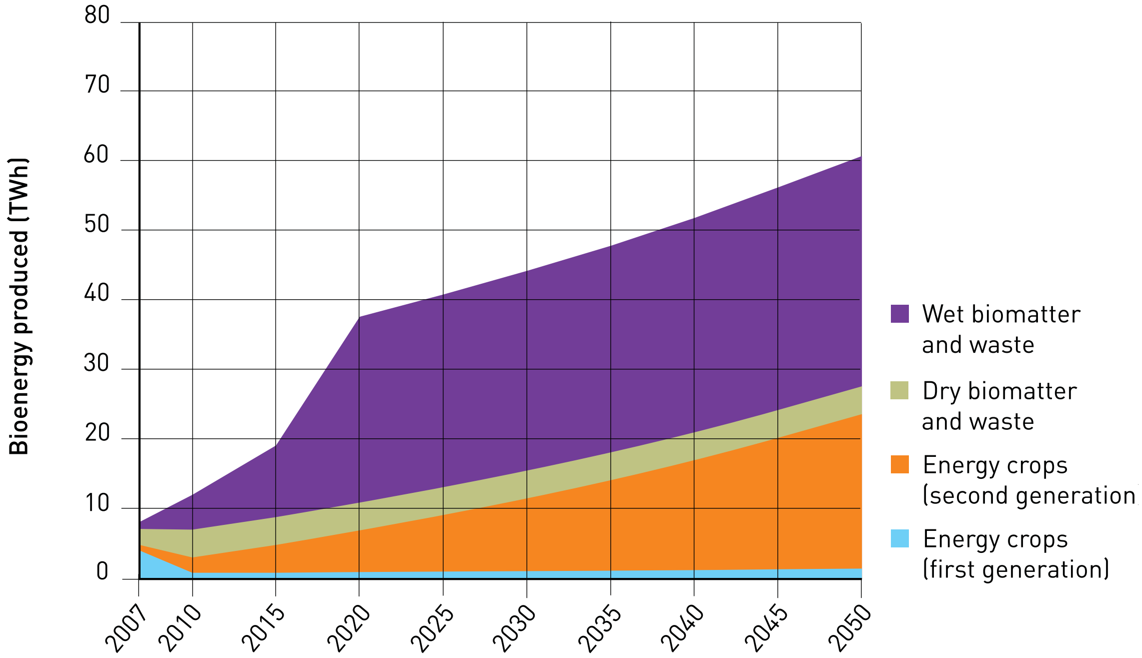
Figure E8 shows the amounts and breakdown of bioenergy in trajectory B.

---

[216] Excluding net forestry emissions.

[217] This assumes collection rates at half the collection rate in the E4Tech supply curves (2009).

Figure E8: Trajectory B bioenergy produced



The following specific bioenergy assumptions are made:

- In total, 350 kha (1.5% of the UK) is assumed to be used for bioenergy crops, which is slightly higher than 2007 levels.[218] However, unlike in 2007, it is assumed that the majority of this area would consist of woody biomass crops.
- Proportions of manure, straw and woodland residues collected are assumed to remain low and flat.

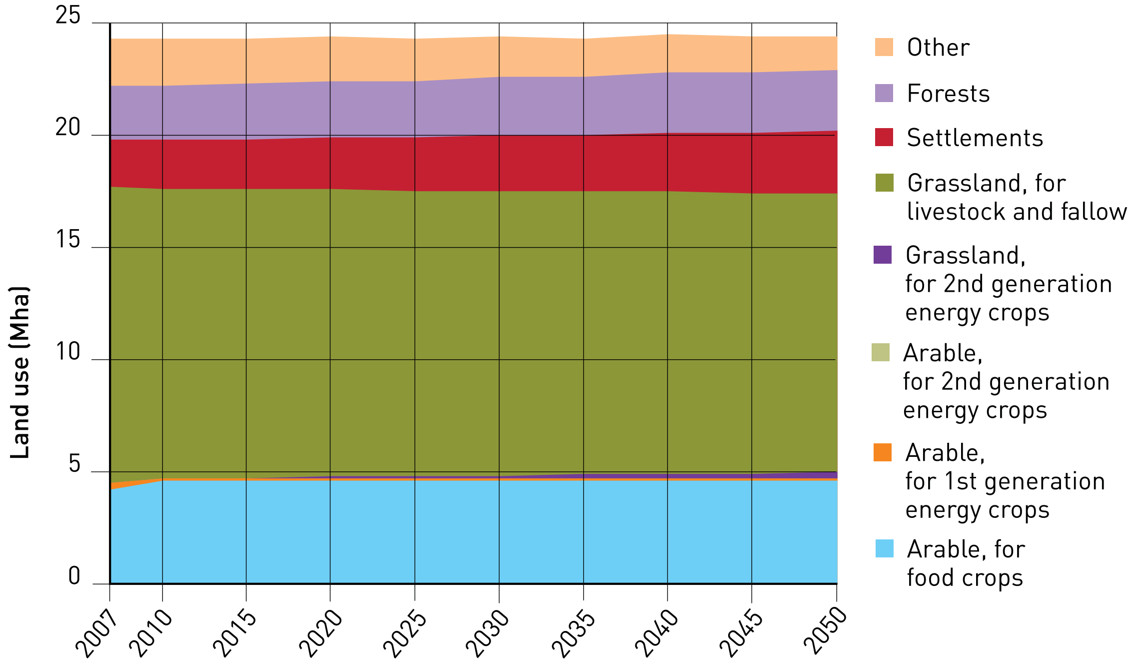
Land use

Figure E9 illustrates and describes the land use changes that occur by 2050.

---

[218] Rural Economy and Land Use (2009) *Assessing the social, environmental and economic impacts of increasing rural land use under energy crops* suggests that 350 kha could be used for bioenergy with very little impact on food crops.

Figure E9: Trajectory B land use change



Changes by 2050	
Food crops	Land for food crops and overall cropland remains constant
Grassland	Decreases by 767 kha by 2050
Forest	Increases by 294 kha (8.36 kha per year)[219]
Settlement[220]	Increases by 731 kha (17 kha per year)

Trajectory C

Trajectory C explores the possibility of securing lower emissions from the agriculture sector through significant investment in technology and knowledge transfer, as well as an increasing emphasis on bioenergy crop production and woodland creation.

Agriculture

Trajectory C assumes high levels of investment in research and development to improve livestock and crop genetics and management systems, resulting in improvements in production efficiency and agricultural emissions. Technological advance results in declining enteric emissions from livestock and minimisation of soil emissions of N_2O. Manure emissions decline by more than 90%, assuming that almost all manure decomposes aerobically on the land, or is collected for anaerobic digestion.

Livestock numbers decrease, partly in response to production efficiency being optimised due to uptake of new technologies resulting in yield improvements, and partly because demand for red meat and dairy products decreases as a result of a consumer shift to healthier diets. Land for food crops decreases by 0.9 million hectares

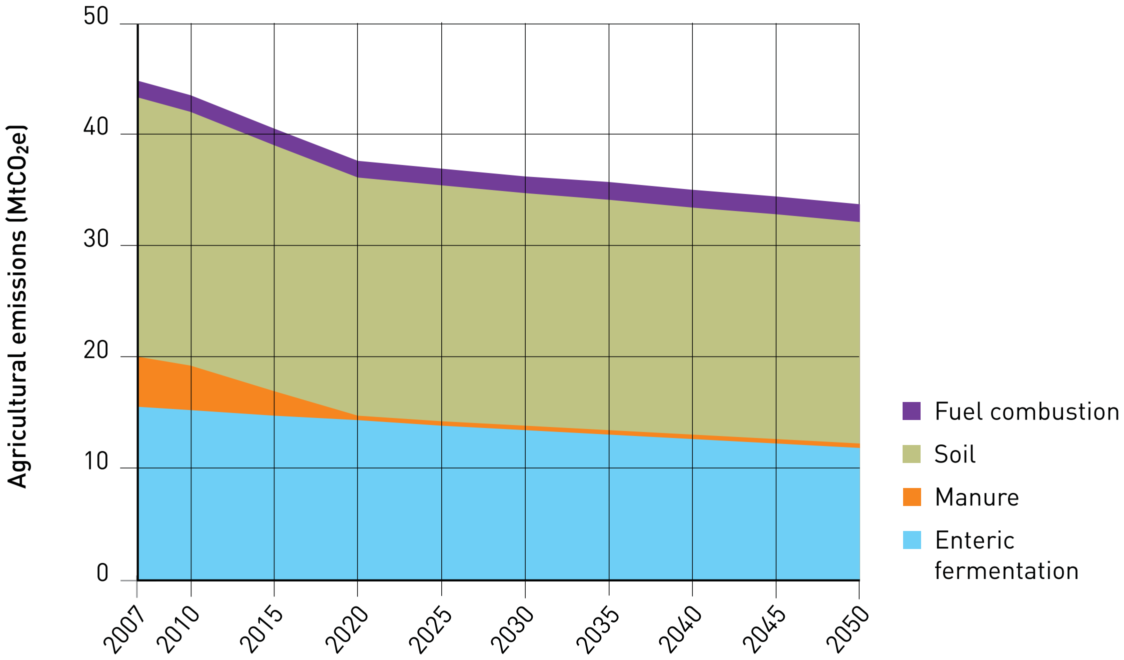
---

[219] Forest planting rate continues current trends. This assumes that conventionally managed broadleaf and conifer woodland is planted, with broadleaf conifer ratios remaining constant.

[220] Settlements increase in line with historical trends (as set out in the GHG Inventory, 2009).

from 2007, although overall food production still increases due to increasing yields (which rise 1.1% per year). This cropland is instead used to grow bioenergy crops. 1.9 million hectares of predominantly temporary grassland is also converted to bioenergy crop production and forestry by 2050. Figure E10 illustrates the breakdown of agricultural emissions in trajectory C.

Figure E10: Trajectory C agricultural emissions[221]



The following specific agricultural assumptions are made:

- Livestock numbers decrease by 10% by 2050.
- Enteric emissions intensity per animal declines by 15% by 2050 as a result of significant advances in technology, breeding, disease control and improved animal nutrition.
- Manure emissions intensity declines by 15% by 2050, through the implementation of improvement of manure management and application technologies on-farm. Manure produced per animal increases by 0.2% per year due to improved nutrition that supports yield increases. And 45% of manure is collected for anaerobic digestion from 2020.[222]
- Soil N_2O emissions decline by 15% by 2050, through improvement in nutrient management and application technologies on-farm.
- Crop production efficiency continues to increase with crop-breeding, soil management and pest control technologies keeping up with climate change.

---

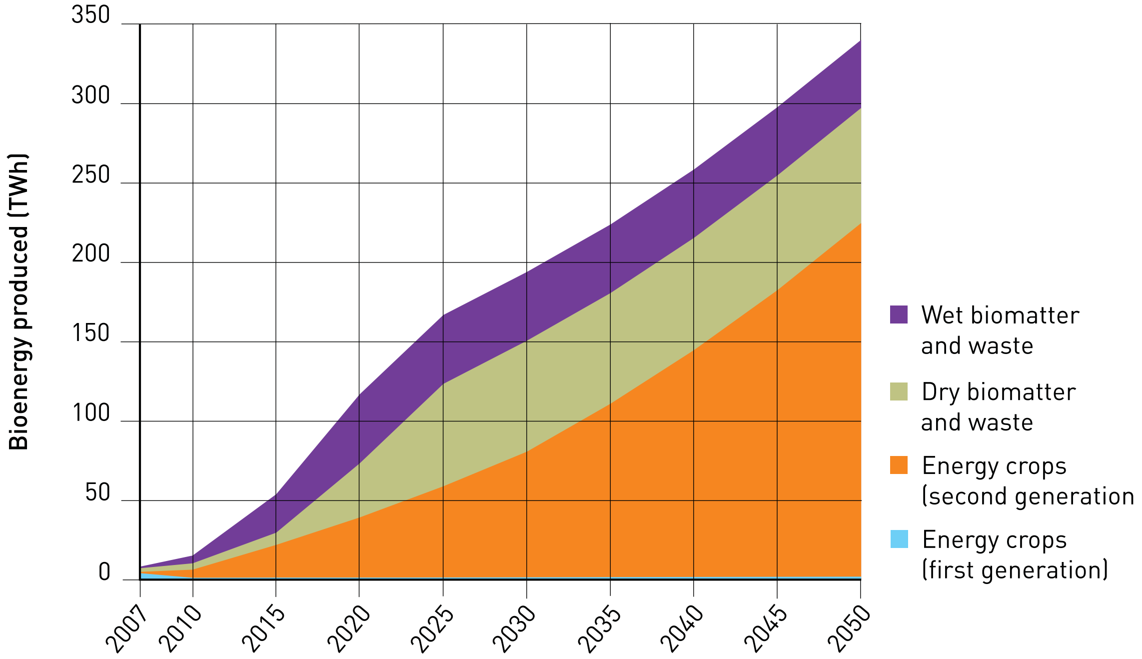
[221] Excluding net forestry emissions.

[222] This assumes collection rates in line with the collection rate in the E4Tech supply curves (2009).

Bioenergy

Trajectory C also assumes an increasing emphasis on bioenergy and high rates of woodland creation. Figure E11 shows the amounts and breakdown of bioenergy in trajectory C.

Figure E11: Trajectory C bioenergy produced



The following specific bioenergy assumptions are made:

- By 2050, 2.4 million hectares (10% of the UK) are used to grow bioenergy crops.[223] This assumes that bioenergy crops take the place of some food crops as yield increases allow the area cropped to decline. By 2050, 1.5 million hectares of arable cropland plus 0.9 million hectares of temporary grassland and other under-used land are used for growing bioenergy crops.
- SRC yields increase by 1.5% per year, up to 19 odt per hectare by 2050.[224]
- Maximum proportions of manure (45%), straw (all available) and woodland residues (80%) are collected from 2030.

Land use

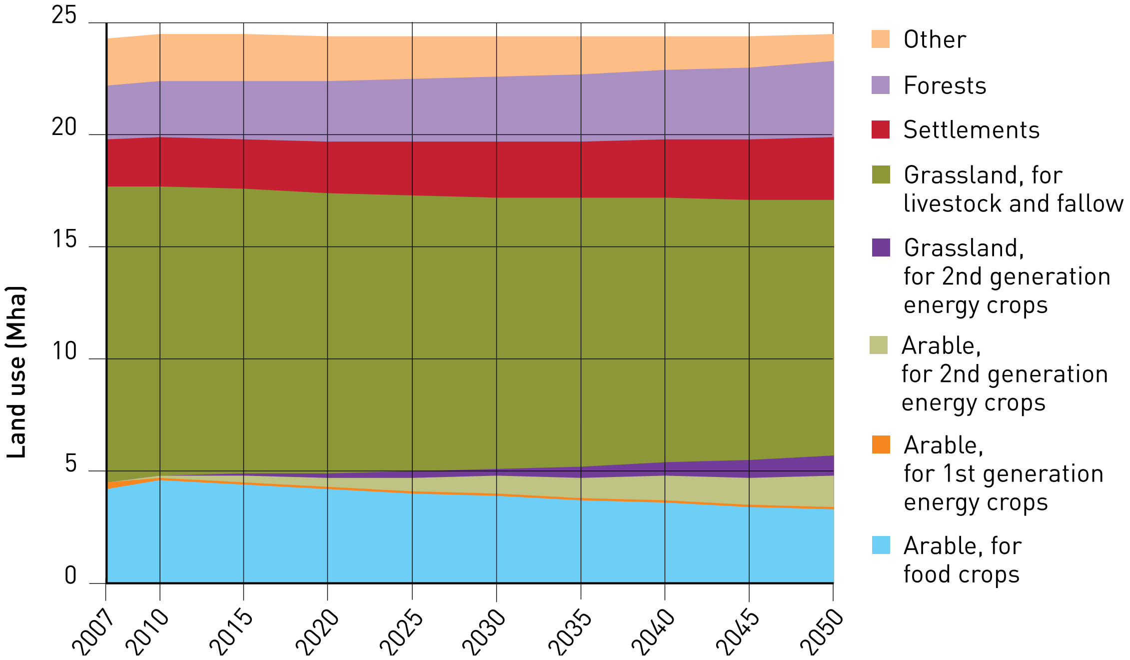
Figure E12 illustrates and describes the land use changes that occur by 2050.

---

223 E4Tech Biomass Supply Curves (2008) assume yield increases of up to 2% per annum. The report takes a more conservative assumption, of 1.5% per annum but applies it for a longer period. 2.4 million hectares are assumed to be available in forthcoming research by the Energy Technologies Institute (ETI). The following report calculates that over 3 million hectares of land in England are suitable for miscanthus growth – Lovett A et al (2009) *Land Use Implications of Increased Biomass Production Identified by GIS-Based Suitability and Yield Mapping for Miscanthus in England*.

224 Baseline 2nd generation yields of 10odt per hectare is a conservative interpretation of yield averages set out in Bauen, A et al (2009) *Modelling supply and demand of bioenergy from short rotation coppice and miscanthus in the UK*

Figure E12: Trajectory C land use change



Changes by 2050	
Food crops	Overall cropland area remains constant. 1.2 mha of food cropland changes to bioenergy.
Grassland	Decreases by 1.7 mha.
Forest	Increases by 1 mha (23 kha per year)[225]
Settlement[226]	Increases by 731 kha (17 kha per year)

Trajectory D

Trajectory D involves a substantial policy priority to increase domestic bioenergy production, and carbon sequestration through extensive woodland creation. The amount of land used to grow bioenergy crops rises to almost 4.2 million hectares by 2050. This is almost equivalent to the area of land currently used to grow food crops. An ambitious expansion in woodland coverage also means that trajectory D involves dramatic land use change. 30% of existing grassland is converted to either bioenergy crops, such as SRC or woodland and this drives reductions in livestock numbers.

Agriculture

30% of land currently used for food crops switches to bioenergy crop production. As in trajectory C, by 2050 almost all agricultural by-products are collected and turned into energy. Yield increases maximise levels of bioenergy and minimise impacts on food

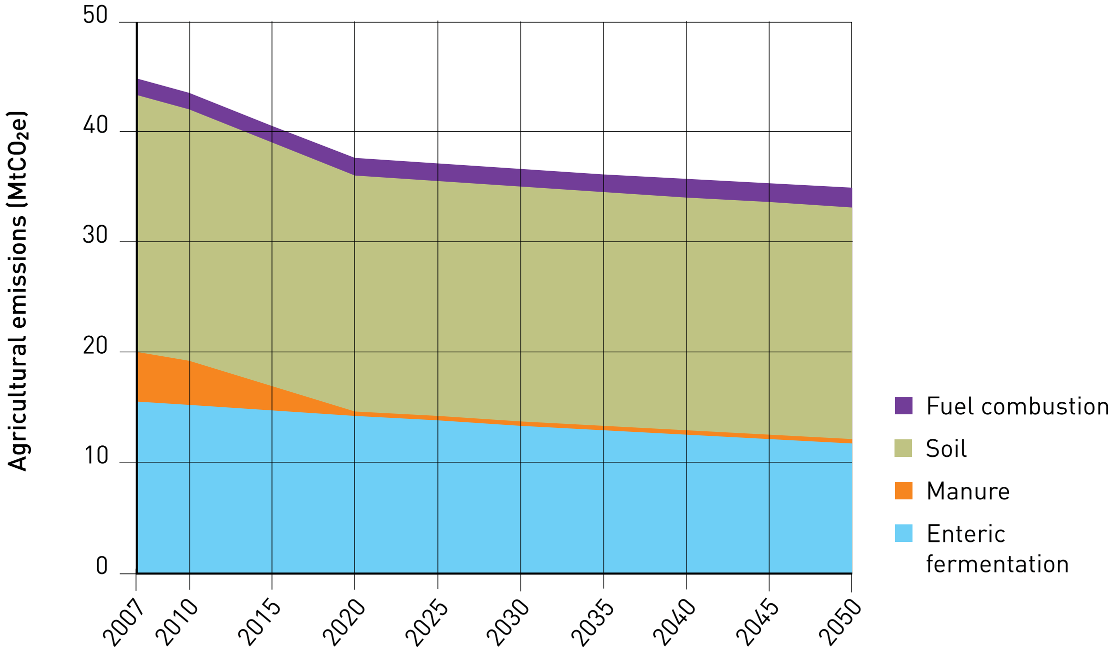
---

[225] Forest is planted at 23.2kha per year, as outlined in Read et al (2009) *Combating Climate Change – A role for UK Forests*. The breakdown of tree types also follows this report, including 1500 ha/yr energy forests in England; the remainder conventionally managed woodland (conifer and broadleaf), including both managed 'farm woodland' and native woodland managed for biodiversity (and not woodfuel or timber production).

[226] Settlements increase in line with historical trends (as set out in the GHG Inventory, 2009).

production. However, this trajectory is likely to see food production in the UK starting to fall by the end of the period. Figure E13 illustrates the breakdown of agricultural emissions in trajectory D.

Figure E13: Trajectory D agricultural emissions[227]



The following specific agricultural assumptions are made:

- Livestock numbers decrease by 20% by 2050, due to a changed emphasis.
- Enteric emissions intensity per animal declines by 5% by 2050, as in trajectory A.
- Manure emissions intensity declines by 10% by 2050, through the implementation of improvement of manure management and application on-farm. Manure produced per animal increases by 0.2% per year due to improved nutrition that supports yield increases. And 45% of manure is collected for anaerobic digestion from 2020.[228]
- Soil N_2O emissions decrease by 10% by 2050 through continued improvement in nutrient management practices on farm (declines are limited by an increase in bioenergy crop land).
- Crop production efficiency continues to increase with crop-breeding, soil management and pest control technologies keeping up with climate change.

Bioenergy

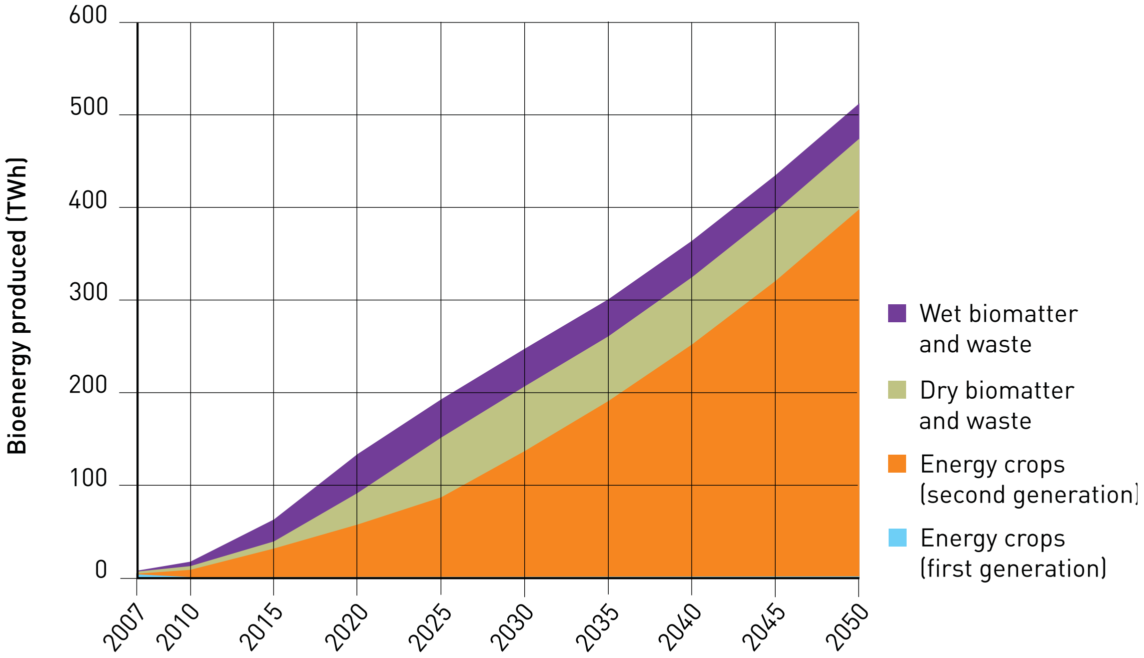
Figure E14 shows the amounts and breakdown of bioenergy in trajectory D.

---

[227] Excluding net forestry emissions/removals.

[228] This assumes collection rates in line with the collection rate in the E4Tech supply curves (2009).

Figure E14: Trajectory D bioenergy produced



The following specific bioenergy assumptions are made:

- Almost 4.2 million hectares (20% of UK) are used for growing bioenergy crops.[229] 100kha continues to be used for starch grain or oil seed bioenergy crops and the rest grows energy crops such as SRC or miscanthus.
- SRC yields increase by 1.5% per year, up to 19 odt per hectare by 2050.[230]
- Maximum proportions of manure (45%), straw and woodland residues (80%) are collected from 2030.

Land use

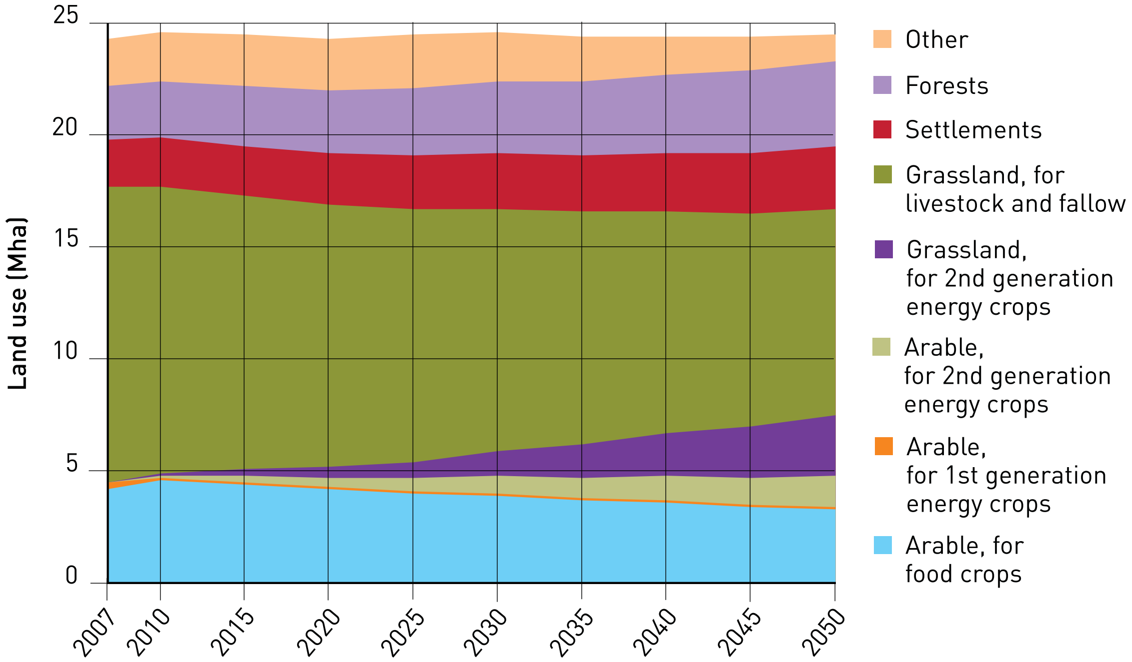
Figure E15 illustrates the land use changes that occur by 2050.

---

229 Assessment of the availability of 'marginal' and 'idle' land for bioenergy crop production in England and Wales (FERA and ADAS for DECC, December 2009) states that up to 10.25 million hectares of land was identified in England and Wales as being potentially available for bioenergy cropping (excluding grade 1 land). However, the environmental and landscape impacts and the consequences for food production have led to the assumption of a 4.2million hectare high scenario.

230 Baseline 2nd generation yields of 10odt per hectare is a conservative interpretation of yield averages set out in Bauen, A et al (2009) *Modelling supply and demand of bioenergy from short rotation coppice and miscanthus in the UK.*

Figure E15: Trajectory D land use change



Changes by 2050	
Food crops	1.2 m ha of food cropland given over to bioenergy. Overall cropland area remains constant.
Grassland	Decreases by 4m ha. This involves the conversion of a significant proportion of permanent grassland.
Forest	Increases by 1.4 m ha (34kha per year)[231]
Settlement[232]	Increases by 731 kha (17kha per year)

Conclusions

It should be emphasised that the four trajectories described in this section are not intended to represent policy options. In order to explore future abatement potential from different land use and land management practices, which are inherently complex, it is necessary to explore scenarios that are significantly different from each other to identify key implications for this and other sectors in the run up to 2050. It is important to explore scenarios that involve dietary change or reductions in livestock numbers or food crop production areas (though offset to varying degrees through increases in yields) through a modelling process to inform future debate about the contribution that potential shifts in trends can make to reducing greenhouse emissions, against an increasing population, a finite land surface area and where the ability to produce food in certain regions will be affected by climate change.

It should also be recognised that there is significant uncertainty about the contribution of different components of agriculture and land use change to the release of greenhouse gases. While agriculture releases a disproportionate amount of nitrous

---

[231] The breakdown of tree and forest types is as per trajectory C, but scaled up proportionally.
[232] Settlements increase in line with historical trends (as set out in the UK GHG Inventory, 2009).

oxide and methane compared to other sectors of the UK economy, they are an inevitable consequence of biological processes such as enteric fermentation and manure production in ruminant livestock, and of the use of fertilizers, although the levels of such greenhouse gases can be reduced to some extent through various practices. This uncertainty is being addressed through research to improve this part of the greenhouse gas inventory.

The trajectories illustrate that UK land area has a finite capacity to deliver a number of beneficial products – food, bioenergy and carbon sequestration. These cannot be considered in isolation to other important benefits, including landscape and biodiversity. A reduction in area dedicated to food production in favour of bioenergy increases reliance on food imports in order to sustain an increasing population, which could result in UK export of emissions if imported food cannot be produced efficiently. This has not been considered in detail in these trajectories, but does require further quantification and modelling in order to explore the implications.

While there is clearly scope to realise significant improvements in efficiencies in production to reduce emissions per unit of production, the initial analysis in this section suggests that the scope to reduce emissions in the agriculture and land use sectors may be limited compared to other sectors. This could mean that the proportion of UK emissions from agriculture is likely to increase towards 2050. The 2050 Pathways Calculator shows that this could mean agriculture makes up a significant proportion of allowed emissions in 2050. However, since this is based on incomplete data sets, it is important that understanding of this sector and abatement potential should be refined. The trajectories set out in this section are a useful starting point for inviting expert input via this call to evidence to improve the evidence base and refine input data, assumptions and methodologies before broadening the debate.

Section F: Bioenergy and waste

Bioenergy – context

Bioenergy is a flexible resource, which through various conversion processes can be applied to meet a variety of types of energy demand, including transport, heat or power. However, bioenergy resources are limited, and the precise level of their future availability is uncertain. Deciding how best to use limited bioenergy resources is influenced in part by the comparative efficiency of the conversion processes which are used – minimising energy losses is clearly desirable. Another important factor is the relative value to the wider energy system of having bioenergy in one form or another. This latter factor will be influenced by developments elsewhere in the energy system. This section explains the framework through which the various possible uses of bioenergy were explored, and which led to four different types of choice in the 2050 Pathways Calculator in addition to the related choice in Section E regarding the amount of land to give over to bioenergy crops and woodland. This section does not set out a definitive 'best' use of bioenergy, which is dependent on a range of system-wide factors.

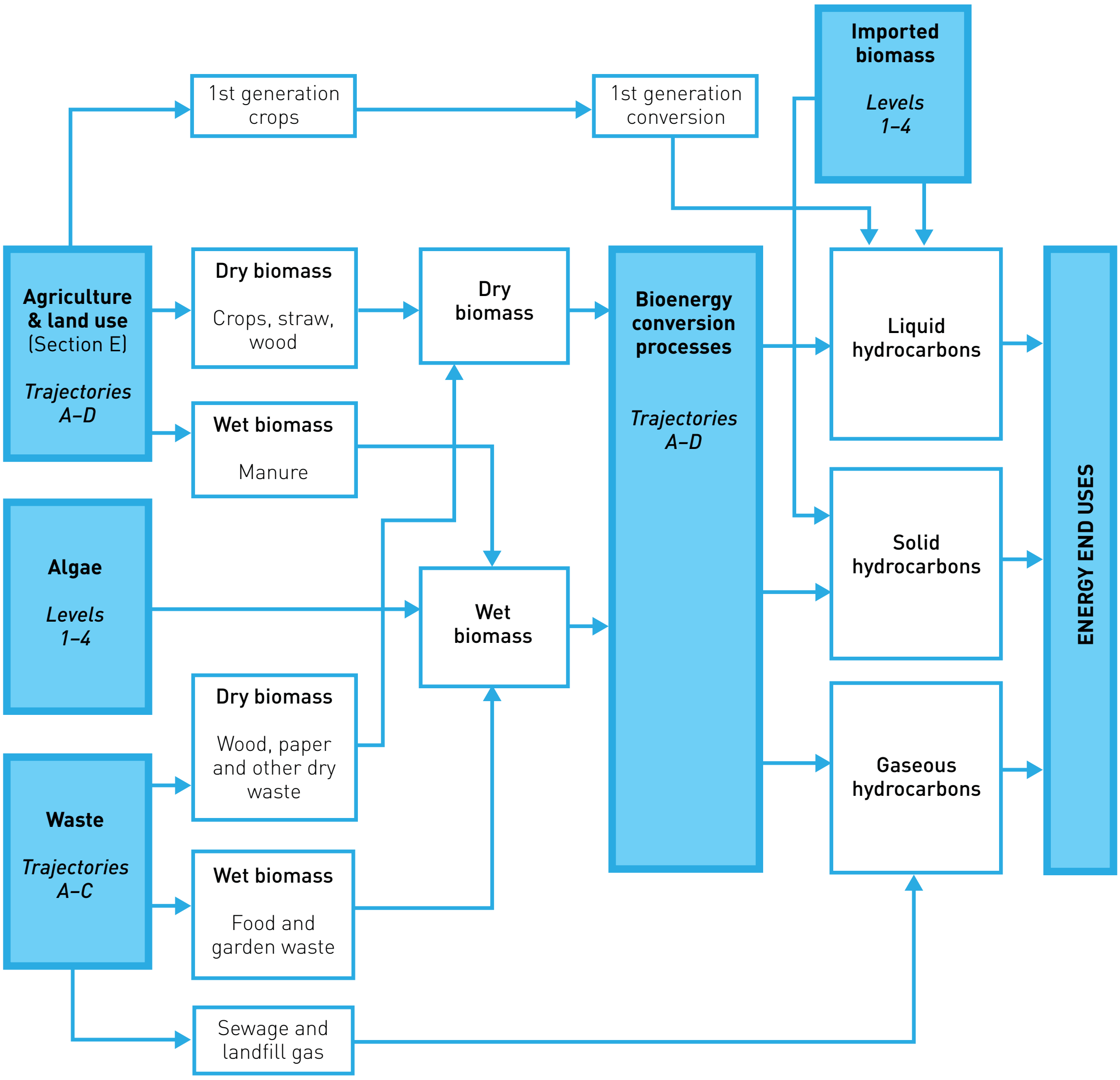
Sector segmentation used

Biomass resources can arise from a wide variety of sources, and can be used in a wide range of energy and other applications. This section describes the approach employed in the consideration of bioenergy for the 2050 Pathways Calculator.

Figure F1 is a schematic representation of the treatment of bioenergy resources and conversion processes within this analysis. The cultivation, collection and eventual deployment of bioenergy resources was considered to be affected by a total of five separate sets of trajectories or levels (highlighted in Figure F1): land use and agriculture trajectories (already considered in Section E of this report); as well as

1. waste trajectories;
2. algae levels;
3. bioenergy conversion route trajectories; and
4. imported biomass levels.

Figure F1: Summary of biomass arising, inter-conversion and end use fuel destinations



The amount of biomass cultivated, collected or arising within the UK is described by land use and agriculture trajectories A-D (described in Section E) as well as:

1 waste trajectories A-C; and

2 algae levels 1-4.

The combination of these trajectories and levels selected in any pathway will produce an overall amount of domestically sourced biomass which can be used for energy. The majority of the biomass arising falls into one of two broad categories of raw biomass resources: dry biomass or wet biomass. In addition, they produce two further kinds of resource which can be directly used as fuels. The land use and agriculture trajectories produce liquid biofuels from '1st generation' processes, and the waste trajectories produce biogas collected from landfills and sewage treatment works.

Raw wet and dry biomass resources are not directly usable as fuels, and must undergo conversion processes before they become usable as solid, liquid or gaseous hydrocarbons. The choice as to which biomass resources are converted into which of these three fuel types is made in an additional set of trajectories:

3 bioenergy conversion route trajectories A-D.

In addition to the domestically produced bioenergy resources, possible levels of imported biomass to the UK are quantified by:

4 imported biomass levels 1–4.

These imported resources are treated as already refined and usable fuels, and are assumed to be either solid hydrocarbons or liquid hydrocarbons (imports of biogas is not considered).

As Figure F1 shows, the combination of trajectories or levels selected through each of the five choices gives rise to different levels of biomass-based fuel available to the energy system, within the three broad fuel categories of solid, liquid or gaseous hydrocarbons. As distinct from fossil resources, the combustion of biomass resources in these categories are treated as 'zero-carbon' in the analysis.

The biomass fuels being made available through these trajectories will be used by end-use technologies in a variety of sectors – for example, industrial processes or aircraft. The trajectories and levels described in this section account only for the quantities of biomass-based fuel which accumulates within the three broad fuel categories (solid, liquid, gaseous). These trajectories do not include choices about the final use of biomass fuels within particular end-use technologies – such choices are made in the relevant end-use sectoral trajectories.

The agriculture and land use trajectories are described in more detail in Section E. The remainder of this section describes in more detail the other four sets of bioenergy trajectories and levels highlighted above: waste, algae, bioenergy conversion processes, and imported biomass resources.

Drivers and enablers

Agreements and targets at the national and international level provide important drivers for the development and production of bioenergy. The EU's Renewable Energy Directive (RED) sets an EU target of 20% of energy from renewable sources by 2020, and also includes a target for transport fuels of 10% renewable sources by the same date.

This Directive has been transposed into UK law through a number of instruments. The Renewables Obligation scheme incentivises the generation of electricity from renewables. Under the banded Renewable Obligation Certificates (ROCs) approach, different biomass-to-electricity processes qualify for different incentives (see Table F1).

Table F1: ROCs awarded per MWh under the Renewables Obligation in 2009 for biomass electricity generation technologies[233]

Technology	ROCs awarded per MWh
Landfill gas	0.25
Sewage gas	0.5
Co-firing	
Co-firing, dedicated energy crops	1
Energy from waste with CHP	
Co-firing with CHP	
Standard gasification	
Standard pyrolysis	
Dedicated biomass plant	1.5
Co-firing, dedicated energy crops and CHP	
Advanced gasification	2
Advanced pyrolysis	
Anaerobic digestion	
Dedicated biomass plant with energy crops	
Dedicated biomass plant with CHP	
Dedicated biomass plant with energy crops and CHP	

The Renewable Transport Fuels Obligation (RTFO) is the mechanism for increasing the blending of biofuels in road transport fuel. Its 2008-09 level was 2.5% by volume, and the target for 2009-10 is 3.25% by volume. In line with the EU RED, the obligation is intended to rise to ensure that renewable transport fuels account for 10% by energy of total transport demand by 2020. However, by the end of 2014 the European Commission will undertake a review to establish, among other things, whether this target can be met sustainably and cost effectively.

Constraints on the development of bioenergy supply may arise due to uncertainty and lack of confidence in supply chains and markets. Such uncertainties can arise from concerns about the sustainability of bioenergy chains, and the effectiveness of the greenhouse gas emission reductions relative to fossil fuels, over their whole life cycle. Uncertainties may also be felt by potential producers and suppliers of bioenergy resources, who may be unwilling to risk scaling up their own production in the absence of confidence in a clear demand for the products.

---

[233] Perry, M and Rosillo-Calle, F (2009) *IEA Task 40 – Country Report for United Kingdom.*

1. Bioenergy from waste

The waste sector is both a source of greenhouse gas emissions and a producer and consumer of energy. This work has developed three trajectories to identify how the management of waste could develop over time and the impact that this could have on the emissions generated and the energy potentially available from the waste sector.

In 2007, direct greenhouse gas emissions from waste were 22.9 $MtCO_2e$ overall, accounting for around 4% of total UK emissions.[234] Around 90% of these emissions come from landfills where biodegradable wastes[235] decompose, often over many decades, to release landfill gas which is roughly 60% methane and 40% CO_2. A proportion of this gas is captured for energy recovery or flaring,[236] but a significant amount escapes into the atmosphere. The rest of the emissions from the waste sector come from the incineration of wastes, or dealing with waste water at sewage treatment works.

In 2007, the waste sector in the UK generated an estimated:[237]

- 11 TWh of energy (of which 6 TWh was the biodegradable fraction) from waste used at energy-from-waste facilities (including anaerobic digestion);
- 18 TWh of energy in landfill gas from landfill sites; and
- 2.5 TWh of energy in sewage gas from sewage treatment works.

Drivers and enablers

The Government's overall objective is to work towards a zero waste economy where resources are fully valued – financially and environmentally – throughout the economy where we move towards zero waste to landfill. By prioritising waste management activities according to the 'waste hierarchy' (Figure F2) the Government aims to break the link between economic growth and the environmental impact of waste. Management activities towards the top of the hierarchy are more sustainable ways of managing waste than those lower down – for example, preventing waste from being created in the first place is more resource and carbon efficient than recycling it or disposing of it in another way. Disposal to landfill should be the very last option for dealing with waste.

---

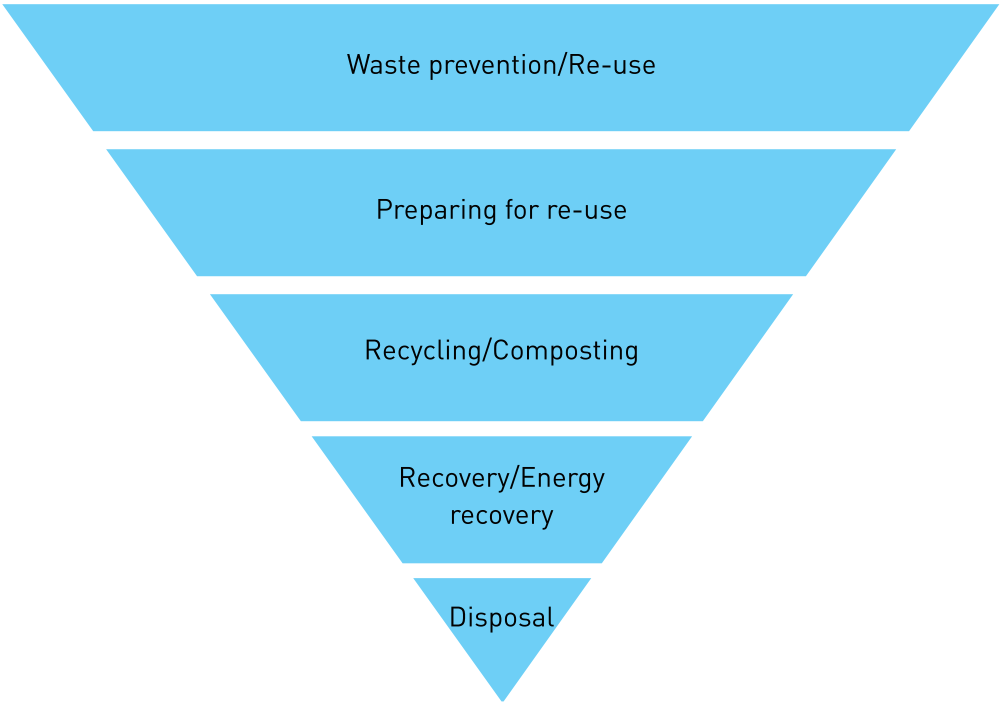
[234] UK Greenhouse Gas Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change.*

[235] Biogenic materials, such as food, wood, paper, and green waste, which decay through the action of bacteria.

[236] Methane flaring: the direct conversion of methane to CO2 through burning, but without energy recovery.

[237] Perry and Rosillo-Calle (2009) *IEA Bioenergy Task 40 – Country Report for United Kingdom.*

Figure F2: The waste hierarchy[238]



Recent studies[239] have indicated that the waste hierarchy remains a good guide to the relative environmental benefits of different waste management options, but that there will be exceptions to the hierarchy for particular materials and particular circumstances. Under the revised EU Waste Framework Directive, departures from the hierarchy will be allowed where this is justified by life-cycle analysis on the overall impacts of the generation and management of such waste.[240]

Direct greenhouse gas emissions from the waste sector have fallen by 57% compared to 1990 levels and are expected to fall further to 21.1 MtCO$_2$e (60% of 1990 levels) by 2020.[241]

The Government is looking for an increase in energy from waste through anaerobic digestion. This will form part of the Government's wider Review of Waste Policies. This will look at all waste policy and waste management delivery in England. The aim of the Review will be to ensure policies are aligned with the objective of moving towards a zero waste economy, while maximising the contribution waste prevention and management can make to the economy.

---

[238] Directive 2008/98/EC on waste (Waste Framework Directive)

[239] (1) Defra's Environmental Report published alongside the Consultation Document in February 2006, available at http://www.defra.gov.uk/environment/waste; (2) ERM (with Golder Associates (March 2007) *Carbon Balances and Energy Impacts of the Management of UK Wastes*, Final Report report for Defra, available at http://www.defra.gov.uk/science/project_data/DocumentLibrary/WR0602/WR0602_4750_FRP.pdf; (3) WRAP (May 2006) *Environmental Benefits of Recycling: An international review of life cycle comparisons for key materials in the UK recycling sector*, www.wrap.org.uk/applications/publications.

[240] The revised Waste Framework Directive requires in law the application of the waste hierarchy in priority order.

[241] UK Greenhouse Gas Inventory (2009) *Annual Report for Submission under the Framework Convention on Climate Change.*

The trajectories for waste

The waste trajectories presented here reflect three possible outcomes that could happen in the waste sector. The trajectories differ according to how effective an implementation of the waste hierarchy they represent. Underlying the trajectories is the assumption that the primary aim of waste policy is the reduction of waste, not the production of bioenergy. However, although they accommodate the major waste and landfill targets, these trajectories are high level and not intended as simulations of specific waste policies.

As a starting point for long-range waste trajectories, waste arisings and waste management activities were established for the base year of 2007. The trajectories consider municipal solid waste (MSW), commercial and industrial (C&I) waste and wood waste arisings from construction and demolition (C&D) waste. Sewage sludge is also considered.

The waste trajectories necessarily reflect the waste policies that were in place earlier in the year. The Government will be looking separately at future waste scenarios as it works out its new approach through the Government's Review of Waste Policies, and which will reflect the Government's ambitions to work towards a zero waste economy and an increase in the use of anaerobic digestion.

Waste arising

The 2007 levels of waste arising in the UK are shown in Table F2.

Table F2: Waste arising in selected waste streams in 2007 by waste type

	WASTE ARISING (million tonnes)				
WASTE STREAM	Biogenic dry	Biogenic wet	Non biogenic combustible	Non combustible	TOTAL
Municipal solid waste[242]	9.7	11.5	4.9	8.7	34.8
Commercial and industrial[243]	10.0	7.6	29.1	29.9	76.6
Construction and demolition[244]	2.3	–	–	–	2.3
TOTAL	47.0	13.2	2	47.4	107.4

---

[242] Total MSW from Eurostat (Available at http://epp.eurostat.ec.europa.eu). Proportional composition of MSW derived from Resource Futures (2009) Municipal Waste Composition: A review of municipal waste component analyses. Report to Defra, code: WR0119.

[243] Total C&IW from Waste Statistics Regulation return for 2006, projected to 2007 – original source is EA survey of C&I 2002/03. Proportional composition of C&IW from Defra C&I Waste Type and Management Data.

[244] C&D biogenic dry from total waste wood from construction and demolition sources, as reported in WRAP (2009) Wood waste market in the UK. Other categories of wood waste discounted to avoid double counting with C&I and MSW, and to account for competing (non-energy) uses of wood.

Waste management

Table F3 below sets out what assumptions were made in the trajectories about how the waste arising in 2007 was managed.

Table F3: Assumed waste management in 2007 by waste stream

	WASTE MANAGEMENT *(% of total waste arising)*		
WASTE STREAM	Re-use/recycle	Energy recovery	Landfill
Municipal solid waste	32	8	60
Commercial and industrial	40	10	50
Construction and demolition	0	0	100

The assumed waste management figures in Table F3 were derived from the following data:

- percentage sent to landfill – in 2007, 20.06 Mt of MSW and 38.91 Mt of C&I waste went to landfill;[245]
- percentage energy recovery (MSW) – the UK's 15 energy-from-waste plants handle around 3 Mt of municipal waste;
- percentage energy recovery (C&I) – according to Environment Agency figures, 6% of C&I waste was recovered for energy in 02/03.[246] 10% was assumed for 2007 to allow for growth in EfW; and
- percentage re-used/recycled – the waste arising that was not landfilled or recovered was assumed to be re-used/recycled.

The capture rate of landfill gas was assumed to be 75% in 2007. Half of this was assumed to be flared, and half used for energy, in order to match the levels of landfill gas recovered for energy as reported by DUKES.[247]

Developing the three waste trajectories

Starting from this base year data, three waste trajectories were developed, describing levels of waste arising, landfilled, recovered for energy or landfilled out to 2050. The trajectories are defined by the following key variables:

- total levels of waste arising – driven up by rising population and GDP, but mitigated through waste reduction policies;
- level of recycling – including anaerobic digestion of wet waste, which also produces energy in the form of biogas;
- level of energy recovery;
- level of waste to landfill – the remainder of total waste arising from the above two variables; and
- level of capture of landfill gas and use for energy or flaring.

---

[245] AEA (2009) UK Greenhouse Gas Emissions Inventory.

[246] EA (2004) *Environmental Agency Survey of Commercial and Industrial Waste 2002/03* .

[247] DECC (2009) *Digest of UK Energy Statistics.*

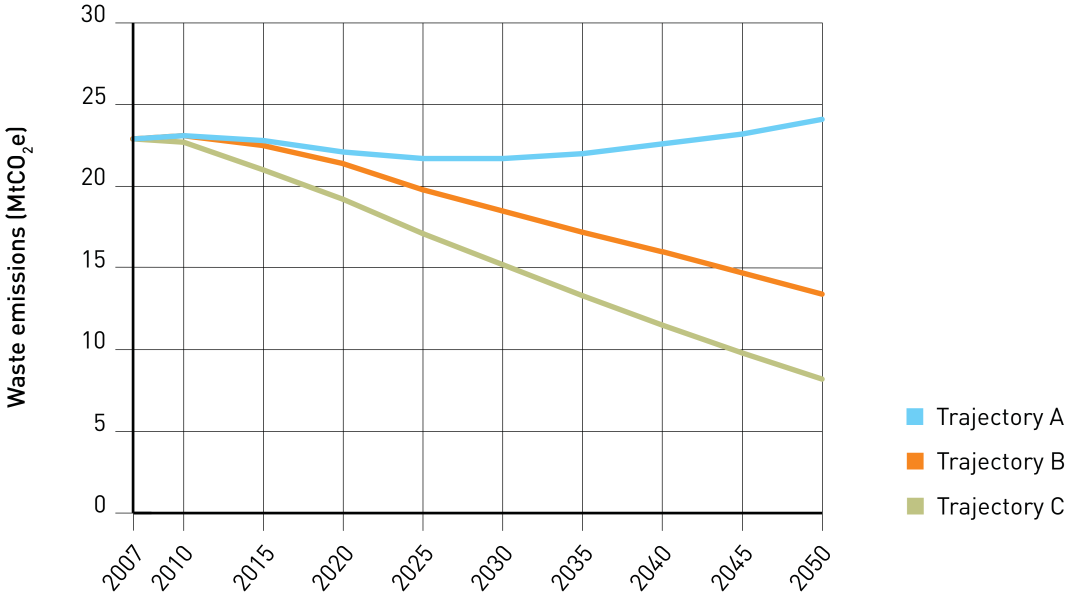
The assumptions under each of these variables form the basis of the three waste trajectories and are summarised in Table F4.

Table F4: Waste management assumptions for the three waste trajectories[248]

Trajectory	A		B		C	
Year	2020	2050	2020	2050	2020	2050
Waste growth (%)	1.5	1	0.75	0.5	0	0
Recycling (%)	50	50	50	65	60	80
Energy recovery (%)	20	20	30	30	20	20
Landfill (%)	30	30	20	5	20	0
Methane capture (%)	75	75	75	80	75	85

The assumptions in Table F4 give rise to three trajectories with the emissions over time to 2050 shown in Figure F3.

Figure F3: GHG emissions from waste under three waste trajectories

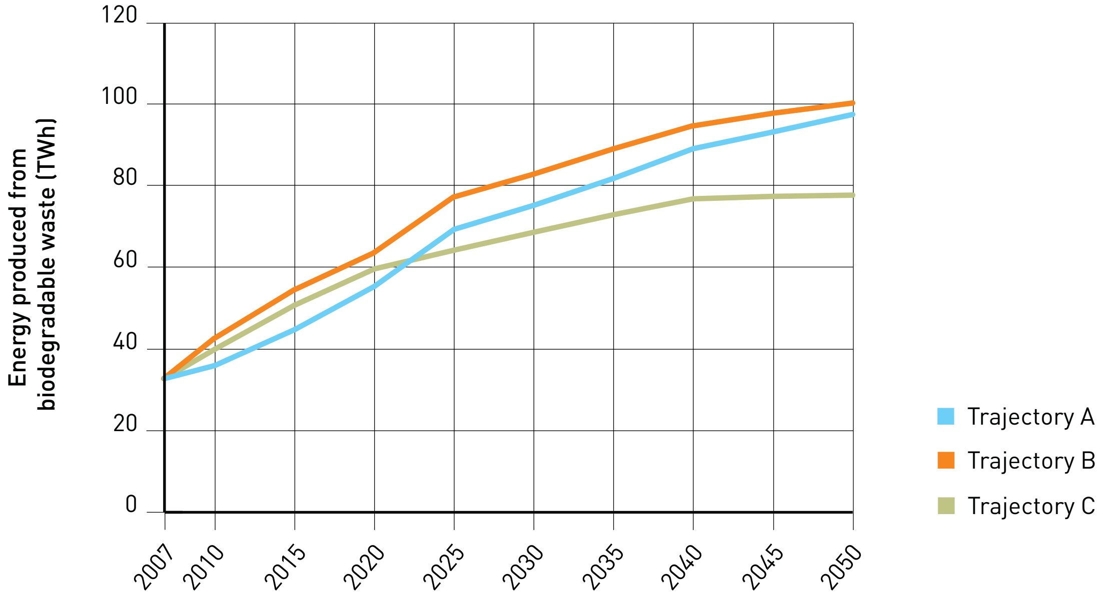


And Figure F4 shows the amount of energy produced from biodegradable waste under the three trajectories. This includes energy from anaerobic digestion, landfill gas and sewage treatment works.

---

[248] Waste growth: the percentages for 2020 refers to the period from now until 2020, the figure for 2050 refers to 2020-2050.

Figure F4: Energy production from biodegradable waste only under three trajectories

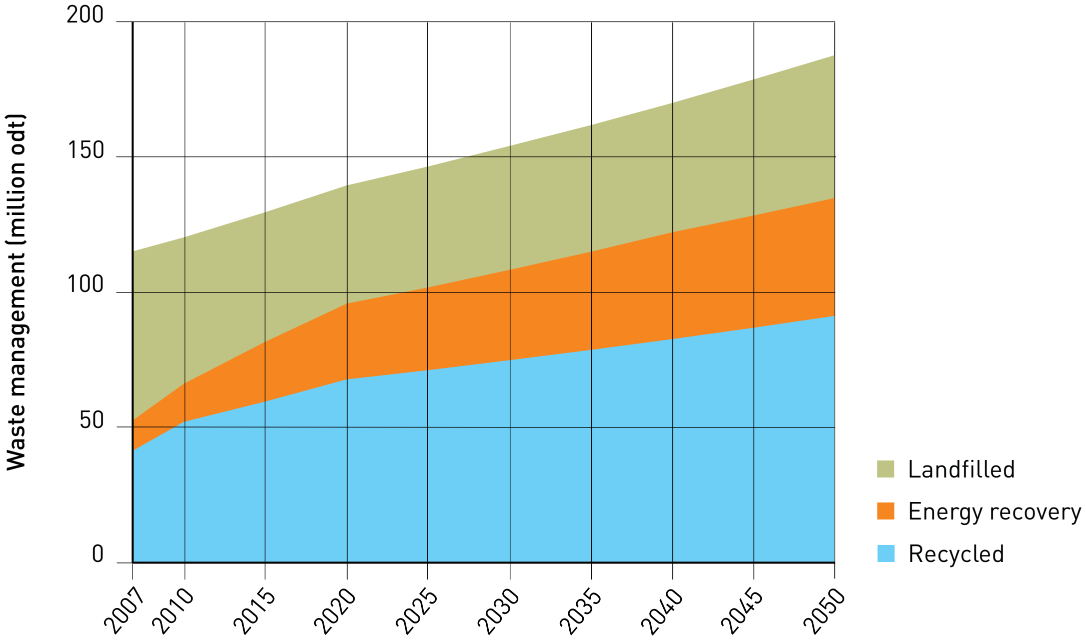


Waste trajectories A-C are described in more detail below.

Trajectory A

Trajectory A (Figure F5) reaches current 2020 recycling and recovery targets, although there is no increase in recycling and recovery beyond this. At the same time, overall waste arisings continue to grow at close to historic rates. Consequently this trajectory sees only moderate progress in reducing amounts of waste to landfill by 2020. Beyond 2020 recycling and recovery rates do not improve further, with the result that levels of waste to landfill begin to rise again. Emissions from landfill decline slightly in the initial period, but increase again beyond 2020, and by 2050 are higher than 2007 levels. Energy from biodegradable waste, landfill and sewage gas amounts to just under 100 TWh in 2050 (Figure F4).

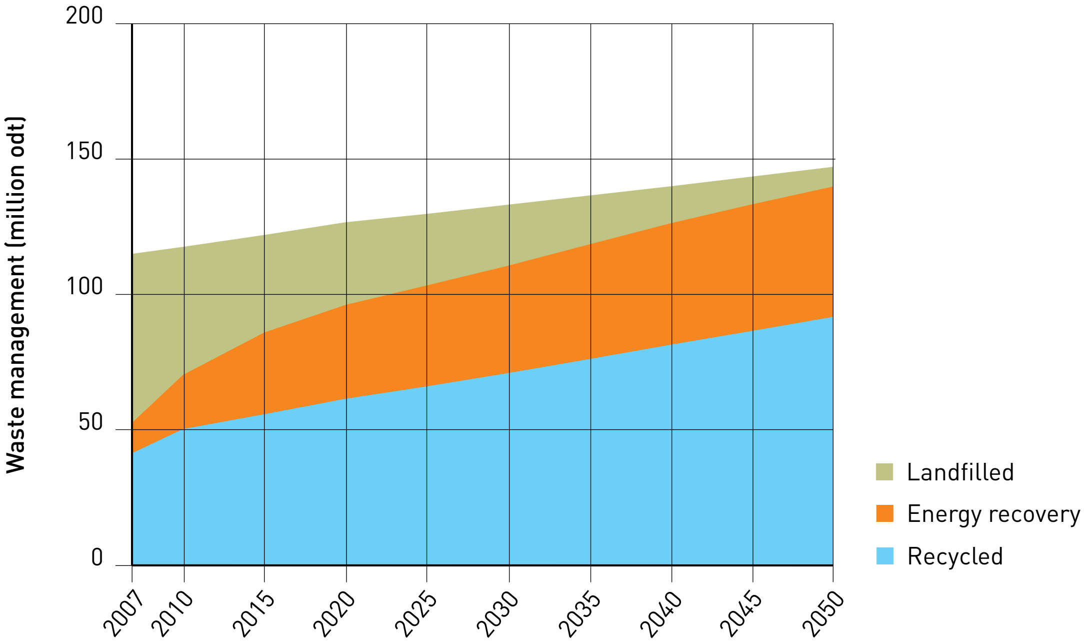
Figure F5: Waste management under trajectory A



Trajectory B

Trajectory B sees significant reductions in the amount of waste going to landfill compared to trajectory A (see Figure F6). This is initially driven by a strong focus on energy recovery (reaching almost 30% by 2020) and then subsequently by an increase in recycling (reaching over 60% by 2050). There are also greater efforts to decouple total waste arising from population and economic growth. Emissions from waste decline strongly in the first decade, ensuring that the 2020 emissions reduction target is met, after which emissions continue to decline at a similar rate (Figure F3). Energy from biodegradable waste, landfill and sewage gas amounts to just over 100 TWh in 2050 (Figure F4).

Figure F6: Waste management under trajectory B



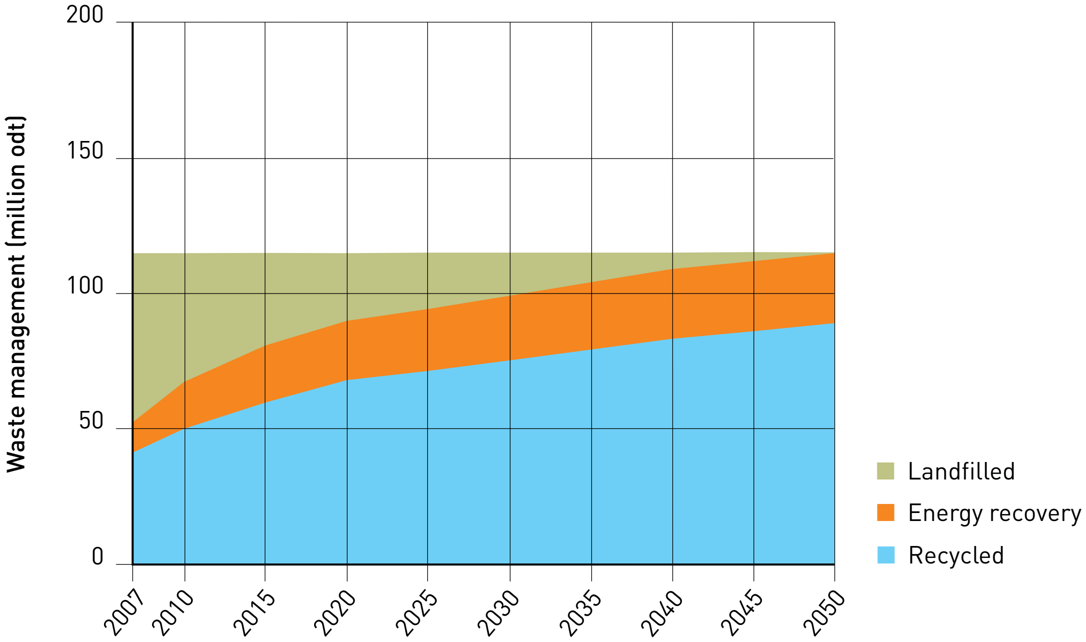
Trajectory C

Trajectory C (Figure F7) represents a possible path to 'zero' waste to landfill by 2050,[249] achieved through zero waste growth between 2007 and 2050 (therefore implying a significant decoupling from economic and population growth) and ambitious recycling levels which reach 60% by 2020 and almost 80% by 2050. In 2050, emissions in Trajectory C are around 60% of those in trajectory B (Figure F3). Energy from biodegradable waste, landfill and sewage gas amounts to just under 80 TWh in 2050 (Figure F4).

---

249 It is expected that some waste will continue to be sent to landfill (such as residues from energy-from-waste facilities, construction/demolition/mining wastes etc) but these are ignored for the purposes of these waste trajectories as they are inert.

Figure F7: Waste management under trajectory C



2. Bioenergy from algae

Algae are divided into two broad classes: macro-algae (such as seaweed) and micro-algae (microscopic plants which are generally free floating and found in both freshwater and saline habitats).

Macro-algae can be farmed, attached to lines or other floating structures, in ocean environments. Macro-algae could also be used in anaerobic digestion plants to produce biogas for combustion or production of biomethane for injection into the gas grid. As with other plant material, it is possible to ferment algae to produce bioethanol.

Micro-algae can be grown in open ponds and enclosures or in concentrated photobioreactors (PBRs). Cultivation of micro-algae is currently practised on a small scale to provide feedstocks for health supplements and other high-value products. Several types of micro-algae can yield an oil which can be used as biodiesel or other transport fuels. The potential for micro-algae production of biofuels on a large scale is believed by many to have long term potential globally. However, the lower levels of sunlight in the UK prevent the large scale commercial production of micro-algae in open ponds. PBRs are extremely expensive and currently seem unlikely to offer a realistic source of energy, though some small scale PBRs are in existence for production of high value products. Micro-algae yields can be improved through the addition of CO_2 or nutrients, for example from power stations, factories or waste water treatment plants.

Due to the generally perceived lack of suitability of conditions in the UK for producing micro-algae on a scale required to make a significant contribution to energy supply, this section focuses on the production of macro-algae. Micro-algae is considered one of the processes which could contribute to the higher levels of global supply of biofuels considered in trajectory 4 of the bioenergy imports section below.

Drivers and enablers

The drivers of macro-algae production are the area of algae grown and harvested, yields and energy content. Areas around the north-west coast of Scotland are considered highly suitable areas for macro-algal production, as evidenced by the extent of natural standing stocks. The heavily indented fjordic coastline and relatively pristine water mean that Scotland is home to over 95% of UK aquaculture by value and volume, and hence the skill base for large aquaculture initiatives is here. The levels described in this project therefore focus on this area as an indicative basis for assessing the potential of scaling up macro-algae cultivation. The total area of the natural standing stock of macro-algae in Scottish waters is 1,125 km^2 (112,509 hectares),[250] and this figure is used as a comparative reference point. However, in each case it is assumed that the natural reserve itself will not be harvested. The figures refer to additional farming of areas further offshore.

The levels for algae

In all levels the yield of macro-algae begins at 15 dry tonnes per hectare per year and rises to 20 dry tonnes per hectare per year by 2025.[251] Energy content of macro-algae is held at 3.9 TWh per million dry tonnes.[252]

The four levels differ from each other in the following respects:

- **Level 1** entails no development of macro-algae cultivation in the UK.
- **Level 2** considers the cultivation of macro-algae rising to a farmed area equivalent to half that currently occupied by Scotland's natural standing reserves of macro-algae – 562.6 km^2 – by 2050.
- **Level 3** considers the cultivation of macro-algae rising to a farmed area equivalent to 100% of the Scottish natural standing reserve – 1125 km^2 – by 2050.
- **Level 4** considers the cultivation of macro-algae rising to a farmed area equivalent to 100% of the Scottish natural standing reserve, plus an additional area of offshore development equivalent to the area proposed for the Hornsea Round Three offshore wind development area – 4735 km^2 – by 2050.

If focussed on the west coast of Scotland, the deployment described in Level 4 would represent a considerable expansion into offshore areas around the outer Hebrides. A lesser impact on coastal activities in any one area could be achieved if this total area was distributed around other sites suitable for macro-algae cultivation in the UK. The comparison with the size of the Hornsea Round Three offshore wind development area primarily offers a general scale-comparison to other offshore renewable energy engineering activities. However, this comparison also acknowledges the suggestion which has been made that large scale offshore macro-algae cultivation could use offshore wind farms to provide structures on which to anchor their lines in offshore environments.[253] This is, however, an as yet a speculative proposition. Key obstacles for major offshore macro-algae cultivation would include:

---

[250] Kelly, M and Dworjanyn, S (2008) *The potential of marine biomass for anaerobic biogas production*. Report to The Crown Estate.

[251] Reith, H, Huijgen, W, Van Hal, J and Lenstra, J (2009) *Seaweed potential in the Netherlands*. Presentation to Macroalgae – Bioenergy Research Forum, Plymouth, UK, 2nd June 2009.

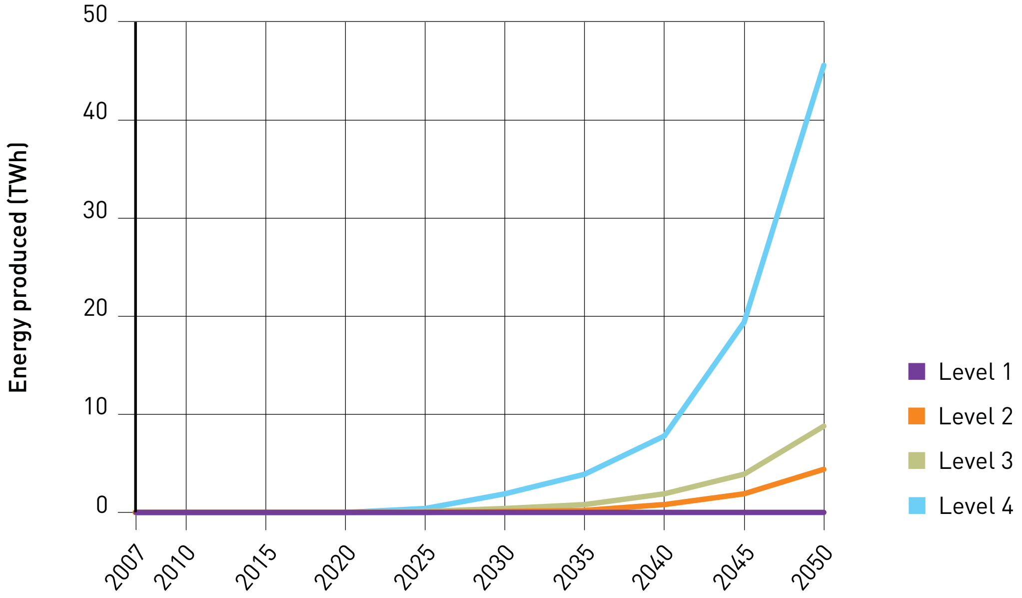
[252] Ibid.

[253] Ibid.

- interference with shipping routes – or if linked to offshore wind turbines, interference with access of turbine maintenance vessels; and
- rougher conditions in offshore areas, which could disrupt or destroy algae lines.

Figure F8 shows the total energy output in TWh from macro-algae levels1, 2, 3 and 4.

Figure F8: Energy output from macro-algae under four levels



3. Bioenergy conversion routes

As shown in Figure F1, the raw wet and dry biomass which arises from UK waste, algae, land use and agriculture activities must undergo conversion processes to be rendered into one of three forms of useable fuel: solid hydrocarbons; liquid hydrocarbons and gaseous hydrocarbons.

For any given amount of bioenergy resource, there are different conversion route options as shown in Table F5. The Table demonstrates that biomass resources are flexible and inter-convertible – raw dry and wet biomass can be converted to fuels in solid, liquid, or gaseous form (although it is not assumed here that wet biomass would be converted into dry solid fuel).

Table F5: Conversion options and efficiencies for transforming raw biomass resources into generic useable fuels

RAW BIOMASS RESOURCE		END STATE OF USEABLE BIOMASS FUEL		
		Solid	Gas	Liquid
Dry biomass	**Overall efficiency**	90%	58.5%	64%
	Summary of process	Accounts for various solid fuel process losses: Chipping Pelletting Lower efficiency of solid waste incineration	Gasification/ methanation	Gasification followed by Fischer Tropsch (FT) synthesis
Wet biomass	**Overall efficiency**	–	80%	44%
	Summary of process	–	Anaerobic digestion/ clean-up to methane	Anaerobic digestion/ autothermal reforming/FT synthesis

A more detailed description of the energy conversion processes which make up the routes summarised in Table F5 is given in Table F6, along with references for the efficiencies assumed at each stage (the overall efficiencies in Table F5 represent in some cases combined efficiencies of two or more of the stages listed in Table F6).

Table F6: Efficiencies of bioenergy conversion processes[254]

Process	Description	Efficiency	Reference /comments
Various mixed dry biomass to homogenous dry solid fuel conversions	Homogenisation of solid dry biomass to facilitate combustion. Includes pelletisation, chipping. Also accounts for the around 10% lower average efficiency of burning waste compared to clean, homogenous biomass	90%	Thornley, P, Tomei, J, Upham, P (2008) 'Supergen Biomass and Bioenergy Consortium Theme 6 Resource Assessment Feedstock Properties' – 10% energy loss in pelletisation IEA (2006) *Energy Technology Perspectives* – gives 22% electrical efficiency for MSW incineration
Gasification	Thermal conversion of solid dry biomass to syngas	90%	IEA (2008) *Energy Technology Perspectives*
Methanation	Conversion of syngas to methane	65%	Mambre, V (2009) 'Biomass Gasification for Production of "Green Energy"' – World Gas Conference 2009 – energy efficiency of biomass to SNG, 55-65%
Anaerobic digestion	Controlled decomposition of biogenic material to produce biogas	80%	Twidell, J and Weir, A (2006) *Renewable Energy Resources*, Second Edition
'1st Generation' biofuels production	Biodiesel production from oil seed rape	1100 litres diesel equivalent per hectare per year	IEA (2008) *Energy Technology Perspectives*
Clean up	Upgrading of biogas to pure methane	100%	Assumed energy losses too minor to quantify
Auto-thermal reforming	Thermal conversion of methane to a syngas suitable for FT synthesis	78%	Halabi, M, De Croon, M, Van Der Schaaf, J., Cobden, P, Schouten, J (2008) *Modelling analysis of autothermal reforming of methane to hydrogen in a fixed bed reformer*, I, 137 (3) 568-578; IEA (2006) *Energy Technology Perspectives* – gives efficiency for auto-thermal reforming plus FT synthesis as 55%
Fischer Tropsch synthesis	Thermal conversion of syngas to diesel fuel	71%	Boerrigter, H (2006) *Economy of biomass to liquid plants – an engineering assessment*, ECN, Netherlands

---

[254] Efficiency = (energy content of output fuel or vector / energy content of original feedstock).
Syngas = gas of approximate content: 40% CO, 24% H2, 23% H2O, 10% CO_2, 1.5% CH_4 and trace gases.
Biogas = gas of approximate content: 60% CH_4, 40% CO_2

The conversion processes specified above are not intended to be an exhaustive list of all possible conversion options for bioenergy resources. Rather, the processes outlined above should be considered as representative of a broad range of conversion processes which could be applied for the conversion of the raw biomass resource to the three broad fuel categories. The routes specified are simply those for which highest conversion efficiencies were found reported in available literature. This is not a definitive judgement that these particular processes will in every situation be the optimal choice.

In this work four simplified trajectories were considered, representing different combinations of options for converting raw biomass resources into different proportions of useable fuel types.

- **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 as well as dry biomass as solid fuel, with all wet biomass making gas.
- **Trajectory C** uses all available resources to make liquid fuel.
- **Trajectory D** uses all resources to make gas.

The trajectories represent, at a high level, choices which can be made regarding the use of biomass resources. In reality, the preferred conversion routes will be the result of a number of choices made by various actors – suppliers, fuel processes, power companies and other users – as well as influenced by policy signals.

4. Bioenergy imports

At a global scale, bioenergy is by some margin the largest source of renewable energy at present. Energy from biomass accounts for approximately 12,500 TWh per year – around 10% of current global primary energy demand. Two thirds of this is currently accounted for by traditional biomass use, such as burning of wood, dung or straw in open fires and stoves, which is the primary energy source for the world's poor.[255]

In larger scale uses, consumption of biomass and waste for heat and industry was estimated in 2005 at around 1,250 TWh. Biomass was thought to supply around 1% of transport fuels and over 1% of fuel for electricity generation.[256]

Estimates of the future potential availability of biomass resources for energy vary over a wide range. A recent review by the International Energy Association (IEA) suggested a mean global potential of 55,000 – 111,000 TWh. The same review produced a full range of 11,000 – 305,500 TWh, depending on the assumptions made as to the extent of land made available for energy farming and the yields of energy crops – which in turn depend both on technological developments and the quality of land devoted to energy crops.[257]

---

[255] IEA (2008) *Energy Technology Perspectives* – global biomass consumption quoted as 45 (+/-10) exajoules (EJ).

[256] Ibid.

[257] IEA Bioenergy (2007) *Potential Contribution of Bioenergy to the World's Future Energy Demand* – mean global potential given as 200 – 400 EJ, full range given as 40 – 1100 EJ.

Drivers and enablers

Factors which could increase the potential future global availability of biomass for energy include: increasing amounts of land devoted to production of energy crops; improved yields; increased collection of wastes and residues; and improved efficiencies of thermo-chemical and bio-chemical conversion processes and technologies – all of which could be given greater or lesser impetus by the development of markets and supply chains.

Factors which could limit the increase in the potential future global availability of biomass for energy include: land constraints; concerns about the life cycle greenhouse gas emissions associated with global bioenergy supply chains; and concerns about wider impacts upon food production, biodiversity, communities and livelihoods. The availability of biomass will also depend on competing demands for food products, including growth or decline in levels of meat consumption.[258]

The extent of growth of global markets in bioenergy is therefore uncertain. However, the growth of a UK bioenergy industry has to be placed in the context of a global market and hence competition for resources. Bearing in mind such competing demands on open markets, this project has adopted a simple approach for estimating levels of biomass which could potentially be accessible to the UK.

In the IEA's 'Blue Map' Scenario presented in the 2008 Energy Technology Perspectives Report, up to 41,700 TWh per year of primary biomass 'is projected to be potentially available for energy purposes in 2050'. In this scenario, 19% of this is projected to be used as transport fuel and 20% for power. The remainder is accounted for by the building sector, industrial uses, and conversion losses.[259]

For present purposes we have assumed that it is the fuels which go to the power and transport sectors within the IEA breakdown that will be available to be traded on global markets. These are assumed to be in the form of liquid fuels for transport (approximately 8,300 TWh per year), and solid combustible fuels for power (approximately 8,300 TWh per year). An estimate of the likely market share accessible to the UK was made on the basis of its relative population size, using 2050 population estimates of 9 billion globally, and 75 million for the UK. This calculation produces an estimated UK market share of these projected resources of 70 TWh of liquid transport fuels, and the same amount of solid biomass fuels for combustion.

Levels for bioenergy imports

The IEA global resource availability of bioenergy for power and transport is used as a marker for establishing four possible levels of bioenergy imports to the UK. These differing levels of bioenergy imports are described below:

- **Level 1** assumes that biomass products imported to the UK for energy decline to zero by 2050. This level represents the possibility of very minimal development of global bioenergy trade, for example in a world where such trade is stalled by serious sustainability concerns which lead to very high restrictions on internationally traded bioenergy.

---

[258] IEA (2008) *Energy Technology Perspectives*; Hoogwijk, M, Faaij, A, Eickhout, B, de Vries, B, Turkenburg, W (2005) 'Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios' *Biomass and Bioenergy*, 35 (4) 225 – 257.

[259] IEA (2008) *Energy Technology Perspectives* – potentially available primary biomass reported as 150 EJ.

- **Level 2** assumes that imported liquid biofuels and solid combustible biomass fuels rise to the equivalent of half of the UK's projected market share by 2050, based on IEA figures. This may be seen as a cautious development of an international bioenergy trade, which perhaps may be held back to relatively lower levels due to limitations placed on the large scale development of energy crops, due to concerns relating to competition with food or other impacts.
- **Level 3** assumes that imported liquid biofuels and solid combustible biomass fuels rise to the equivalent of 100% of the UK's projected market share by 2050, based on IEA figures. This may be seen as the result of concerted and coordinated international efforts to overcome food competition and sustainability issues, and to address trade barriers, as well as continued improvement in the efficiencies of solid to liquid biomass conversion processes, such as sugar fermentation, lignocellulosic fermentation, and Fischer-Tropsch synthesis.
- **Level 4** assumes that imported liquid biofuels and solid combustible biomass fuels rise to the equivalent of 200% of the UK's projected market share by 2050, based on IEA figures. This may be seen as representing not only the successful resolution of trade barriers and sustainability concerns, but also a step-change in the yields-per-hectare of bioenergy production processes. This could include developments in second generation processes, or the development and commercialisation of the production of biofuels from algae.

These assumptions produce figures for available bioenergy imports, beginning from 2007 quantities, and extending on a 'straight line' basis to the 2050 quantities described in the levels above. Figure F9 shows the four levels of solid combustible biomass fuel imports.

Figure F9: Imports of solid biomass fuels under four levels

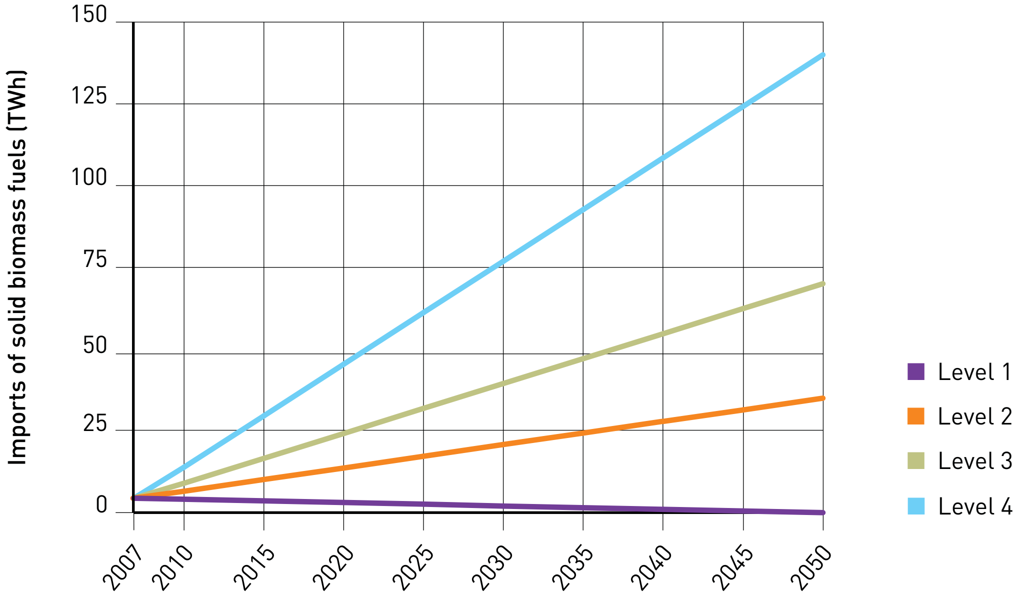
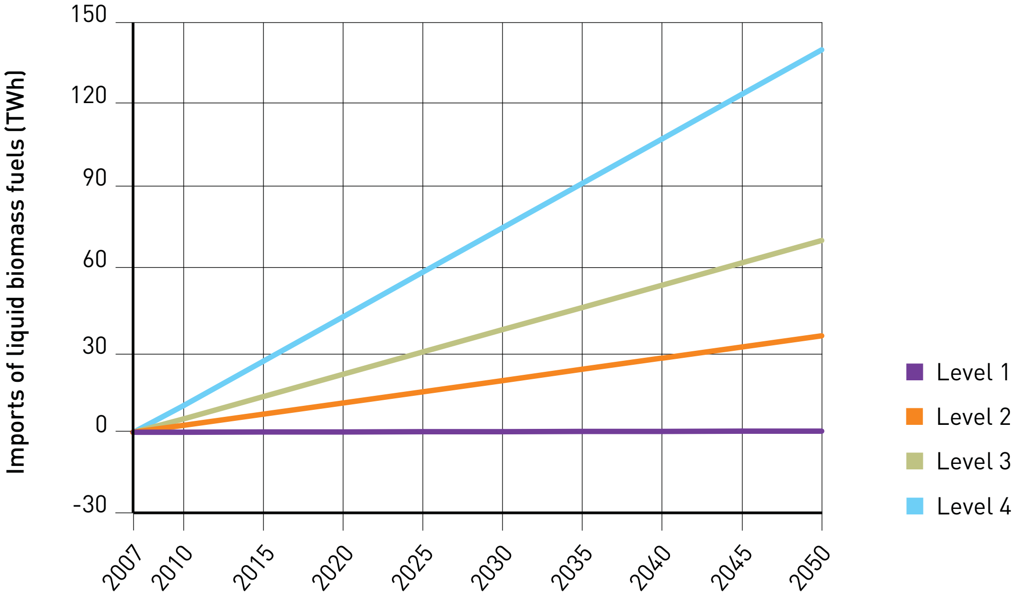


Figure F10 shows the four levels of liquid biomass fuel imports.

Figure F10: Imports of liquid biomass fuels under four levels



These levels describe imports only – they are additional to the domestic biomass resources which are produced or arise in other levels or trajectories, as shown in Figure F1, and described in this section and Section E.

There are clearly some simplifications inherent in the approach used here. We have not built a global model for this project, neither is our approach driven by cost optimisation and price-based supply curves. Hence these import resource levels are not intended as an attempt to represent or simulate the potential dynamics of global supply chains and markets in their full complexity – they are simply presented as possible future levels of imports, as a means to inferring different implications for the UK energy system.

A further simplification is that for this project, all imported biofuels are treated as zero-carbon. In fact, analysis suggests that depending on the process and distance of transport, the carbon savings achieved by different forms of bioenergy can vary widely – some bioenergy chains would actually result in increased carbon emissions compared to fossil based energy equivalents.[260] In this respect, the GHG emissions savings used in the Calculator are likely to be overestimates.

It is outside the current scope of this project to address these issues in detail. This is by no means to imply, however, that such issues are insignificant. If the UK did import significant quantities of biomass in the future, there would clearly be a pressing need to ensure the development of sustainable, low carbon and secure bioenergy supply chains. Therefore, the UK is continuing to work within the EU and international context towards establishing sustainability criteria for international trading of bioenergy.

---

[260] Renewable Fuels Agency (2009) *Annual Report and Accounts*; Environment Agency (2009) *Minimising greenhouse gas emissions from biomass energy generation.*

Section G: Nuclear

Context

The last nuclear power station to be built in the UK was Sizewell B which began generation in 1995. At the beginning of 2010 there were 17 nuclear reactors operational with a combined installed capacity of over 10 GW. All of these are due to close by 2025, except Sizewell B which has an installed capacity of just over 1 GW.

Although new build has not taken place in the UK since the late 1980s, plausible installation rates for nuclear power can be estimated from a comparison with what has been achieved historically in other countries. A good example is what happened in France following their decision in 1974 to expand the use of nuclear power in their energy mix after the first oil shock. The higher end of these build rates was in the ten years between the beginning of 1979 and the end of 1988 where on average 4.5 GW of new nuclear capacity was commissioned each year.[261]

Government policies aim to remove unnecessary barriers to new nuclear in the UK without providing public subsidy. Government does this by taking action on planning, Regulatory Justification, Generic Design Assessment and waste and decommissioning finance, as well as by developing a strong and competitive supply chain in the UK. This should enable energy companies to:

- make applications for development consent in line with the framework set out by the Planning Act 2008 and the National Policy Statement for Nuclear Power;
- begin construction of the first new nuclear power station between 2013 and 2014; and
- start operating the first new nuclear power station from 2018.

In the UK, industry has already started to demonstrate its commitment to new nuclear. In 2009 EDF Energy acquired British Energy and announced plans to build around 6 GW of new nuclear capacity at Hinkley Point and Sizewell. Horizon Nuclear Power (a joint venture between RWE and E.ON) bought land at Oldbury and Wylfa from the Nuclear Decommissioning Authority and announced plans to build at least 6 GW of new nuclear. A third developer (a joint venture between Iberdrola, GDF Suez and Scottish and Southern Energy) also entered the UK market by securing an option to purchase land for the development of a new nuclear power station at Sellafield and announcing plans to build up to 3.6 GW of new nuclear capacity in the UK.

Drivers

The plausible build rates for nuclear power are most affected by industry confidence that they will get a sufficient return on any investment made and the availability of suitable sites, rather than specific technical limitations. The levels of nuclear installed capacity described at the end of this section were developed following a review of a

---

[261] World Nuclear Association Reactor Database: http://www.world-nuclear.org/rd/

wide range of published studies and discussions with industry experts and, as far as possible, they reflect their views about alternative assumptions to 2050.

Confidence that new build will proceed

It is fundamental that companies have confidence that, in common with all low carbon technologies, they will be able to make a return on their investments and this is underpinned by confidence that new build will be able to proceed in a timely fashion.

However, this confidence is affected by factors including:

- Government support for new nuclear as demonstrated through public statements and actions, including progress on removing unnecessary barriers to new nuclear in the UK;
- the level of public acceptability;
- regulatory certainty about the acceptability of reactor design and clarity over lead times prior to operation; and
- market certainty, whether in terms of a carbon price or clear targets. This is necessary in time to invigorate the supply chain and skills base, and enable operators to order with long lead times in order to meet construction deadlines.

The last point was raised by industry experts during a workshop to explore the potential deployment rates for new nuclear power in the UK. They felt that in order to develop and maintain build rates at the higher levels of ambition described at the end of this section there needed to be a continuous flow of projects, in order that the supply chain and skills base did not erode once established.

Availability of sites

The draft National Policy Statement (NPS) for Nuclear Power, the consultation period for which closed in February 2010, identified 10 sites which were considered to be potentially suitable for the deployment of new nuclear power stations by 2025.[262] The draft Nuclear NPS states that although it is not possible to predict whether or not there will be more than one reactor at each of the 10 sites, a single reactor at each of the sites would result in 12-17 GW of nuclear capacity, depending on the reactor chosen.[263] Responses to this consultation are currently being considered prior to a revised Nuclear NPS being designated.

Enablers

Government policy

The Government believes that it is in the public interest that nuclear power should continue to play a role in the UK's energy mix.[264] The Government's view is that it is for private sector energy companies to construct, operate and decommission new nuclear plants. However, the Government will take active steps to remove unnecessary barriers

---

[262] Department of Energy and Climate Change (2009) *Draft National Policy Statement for Nuclear Power Generation.*

[263] Ibid.

[264] Department for Business Enterprise and Regulatory Reform (2008) *Meeting the Energy Challenge: A White Paper on Nuclear Power.*

to this investment. These steps include reforming the planning system so that those aspects of siting which are strategic in nature are considered at the national level, with only site specific criteria considered at the local level, and the introduction of a form of pre-licensing called the Generic Design Assessment. The Government will not subsidise new nuclear development.

Clarity over planning and licensing timescales

In the past the planning system has been inefficient, costly and lengthy (for example it took Sizewell B six years to secure planning consent, costing £30 million) and as such may have dissuaded investors in coming forward with planning applications for new nuclear power stations.[265]

The reforms to the planning system introduced by the Planning Act 2008 (including publication of the Nuclear NPS as part of a suite of energy NPSs) will mean that there is greater clarity over which issues are to be considered when, and the overall timetable for achieving consent.

This will give promoters a clearer framework with a higher degree of predictability in which they can make investment decisions with confidence. It is intended that in most circumstances applications will be decided within a year of the validation of the application.

Clarity over arrangements for the management and disposal of waste

The Government has stated that before development consents for new nuclear power stations are granted, it will need to be satisfied that effective arrangements exist or will exist to manage and dispose of the waste they will produce.[266]

Geological disposal was recommended as the best option for the long term management of existing higher activity waste by the independent Committee on Radioactive Waste Management in 2006.[267] Geological disposal is internationally recognised as the preferred approach. It is being adopted in many countries, including Canada, Finland, France and Sweden, and is supported by a number of UK learned societies.[268] Separate disposability assessments undertaken by the Nuclear Decommissioning Authority in 2009 support the Government's view that it would be technically possible and desirable to dispose of both new and legacy waste in the same geological disposal facilities.

Following extensive consultation with experts, stakeholders and the public, the Government has a clear policy of geological disposal coupled with safe and secure interim storage and ongoing research and development. A framework to implement that policy was set out in 2008 with the first step being an Expression of Interest from communities which may be interested in talking to the Government about the siting process for a geological disposal facility.[269] To date three local authorities have expressed interest. The Government continues to promote the invitation and will leave

---

[265] Ibid.

[266] Ibid.

[267] Committee on Radioactive Waste Management (2006) *Managing our Radioactive Waste Safely.*

[268] In the UK, geological disposal is supported by the Royal Society, the Royal Society of Chemistry, and the Geological Society.

[269] Department of Energy and Climate Change (2008) *Managing Radioactive Waste Safely.*

open the option for communities to come forward and talk to the Government for the foreseeable future.

Identification of suitable sites

As discussed above, the draft Nuclear NPS has identified 10 sites potentially suitable for the deployment of new nuclear power stations by 2025. The draft NPS is currently under review, but will be finalised and designated as soon as possible. The Nuclear NPS would need to be reviewed and a further strategic siting assessment (SSA) considered if further sites are required. The Nuclear NPS does, however, provide that applications for development consent for sites not listed in the NPS can come forward for consideration against the SSA criteria.

Capability of the supply chain and availability of appropriate skills base

The development of the UK supply chain and skills base to support new nuclear was seen by industry experts as something that would flow from increased clarity around the longer term prospects for nuclear power in the UK and globally, but as something that could not develop overnight. For the development of higher levels of nuclear capacity some of these experts thought that at least 10 years of clear Government signalling was required.

As part of invigorating the supply chain the Government has publicised the potential opportunities presented by new nuclear and supported strategic investments where appropriate. These have included capital investment to establish a Nuclear Advanced Manufacturing Research Centre that combines the knowledge, practices and expertise of manufacturing companies with the capability of universities; and strengthening the Manufacturing Advisory Service to support British based suppliers to the nuclear industry.

In the development of skills the Government has been working closely with the Nuclear Decommissioning Authority, Cogent,[270] the National Skills Academy for Nuclear, and the nuclear industry itself to ensure that there is a clear, shared understanding of the key skills priorities for the nuclear sector and how skills demands can be met. Cogent, in partnership with the Government and others, has produced a skills report which provides information on the likely skills requirements to deliver a programme of new build together with strategic recommendations on how we can act now to close potential skills gaps.[271]

---

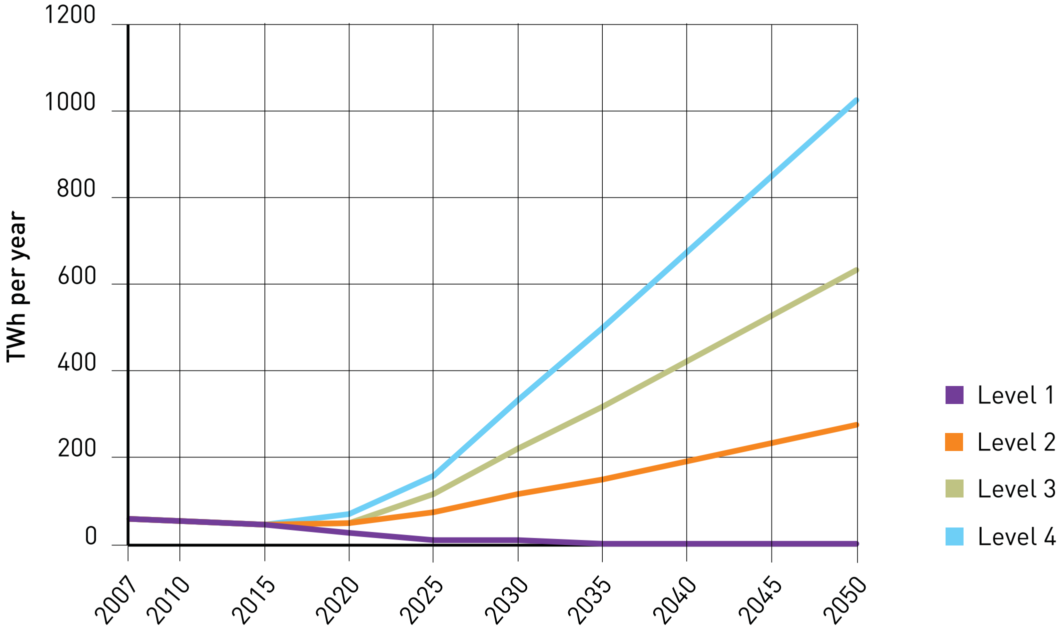
[270] The Sector Skills Council for the chemicals, pharmaceuticals, nuclear, oil and gas, petroleum and polymer industries.

[271] Cogent (2010) *Next Generation: Skills for New Build Nuclear.*

The levels

Figure G1 below illustrates four trajectories for nuclear power under four levels of deployment, which are described below.

Figure G1: Trajectories for electricity generation from nuclear power



Level 1

This level of deployment shows a baseline. It assumes that implementation of the four facilitative actions on planning, Regulatory Justification, Generic Design Assessment, and waste and decommissioning finance falter. It assumes that the Government no longer wishes to take new nuclear forward and that a lack of clarity over planning and licensing timescales would lead to no planning applications coming forward and potentially the suspension of activities at sites where planning applications had been submitted. However, it is by no means certain that this would apply over the longer term if, as with other low carbon technologies, considerations of security of supply and the potential for rising fossil fuel costs are taken into account. In addition, the momentum already built towards new nuclear, including the investments already made by utilities, led some stakeholders to think this level highly improbable.

Level 2

This level of deployment assumes that there would be continued Government and public support for new nuclear and that the facilitative actions would progress in accordance with the indicative timeline.[272] The build rate of just over 1 GW/year is technically achievable in comparison with other historical build rates and is similar to what France achieved in the early part of its nuclear programme in the 1970s. A report by consultants Parson Brinckerhoff also suggests that at the current time and in the

---

[272] Department for Business Enterprise and Regulatory Reform (2008) *Meeting the Energy Challenge: A White Paper on Nuclear Power.*

current environment the indicative maximum build rate for nuclear power in the UK is 1.5 GW/year.[273]

Some industry experts thought it plausible that the sites identified in the draft Nuclear NPS could eventually provide the total capacity of 39 GW under this level although there may be the need to consider the identification of additional sites. Experts also thought that there would need to be carbon price certainty at a level that made nuclear power attractive in comparison to fossil fuel generation for this level of build to progress. The total capacity of 39 GW at 2050 is calculated to deliver 275 TWh of electricity per year.

Level 3

Given the long lead time for the development and construction of new nuclear power stations even an increased level of Government intervention is unlikely to affect what is achievable by 2020. However, quick and effective implementation of the facilitative actions and clear signals over a carbon price and future requirements for nuclear power by 2015 (in the context of wider market reform) could mean that a build rate of 3 GW/year is achievable from 2025 onwards as it gives developers, the supply chain and skills base the opportunity to respond.

This is technically achievable as it is still less than the 4.5 GW/year that France achieved on average in the ten years between the beginning of 1979 and the end of 1988, albeit in a nationalised market. However, during an industry workshop the view was expressed that given the challenge for a developer to work on multiple sites simultaneously there would need to be at least three separate developers active in the UK market, each building 1 GW/year, to achieve this build rate. The total capacity under this level assumes that the first wave of plants coming forward will be successful in the planning process and that new sites can be identified and obtain development consent at a rate that would support a continuous flow of projects.

The 16 GW predicted by 2025 under this level reflects industry announcements of plans to build 16 GW of new nuclear by 2025. The total capacity of 90 GW at 2050 is calculated to deliver 633 TWh of electricity per year.

Level 4

Government interventions would be needed to deliver this level of deployment. It seems technically possible to bring forward initial build so that 6 GW is operational by 2020 and then maintain a build rate of 3 GW/year until 2025 before increasing to a maximum of 5 GW/year thereafter. However, some in the sector pointed out that this early increase in build rate would require ordering long lead items and equipment on the assumption of securing consent, and so as well as the ongoing incentives described under level 3 the Government might also need to be prepared to underwrite the sunk costs of developers.

Although these build rates are technically achievable (France managed to commission over 5 GW/year four times in the 1980s) maintaining such a build rate would be challenging and the likelihood of international competition for resource at this level of ambition means that a UK supply chain able to build new nuclear plants independently of the global supply chain could be necessary to achieve these rates. Supply chain

---

[273] Parsons Brinkerhoff (2009) *Powering the Future, Mapping our low carbon path to 2050.*

development and skills programmes would need to be set up by 2015 on a scale that reflects the estimated build rates.

As with the previous level of deployment, the total capacity under this level assumes that the first wave of plants coming forward will be successful in the planning process and that new sites can be identified and obtain development consent at a rate that would support a continuous flow of projects. Given that an increased number of nuclear power stations would also lead to an increased level of waste, there would also need to be greater capacity for geological disposal which might require plans for a second facility to be developed. The total capacity of 146 GW at 2050 is calculated to deliver 1025 TWh of electricity per year.

Possible technology developments

Most of those questioned during the industry workshop did not think that the availability of fuel would be a limiting factor during the timescale considered and this is supported by analysis carried out by OECD and the Euratom Supply Agency.[274,275]

Even if existing resources were exhausted it was pointed out that the relatively small contribution of fuel costs to the overall cost of nuclear generation made it likely that other, potentially more expensive, sources of uranium could be considered.

If there were a decline in fuel supply, utilities could also begin to consider reprocessing and other reactor technologies. Given that the transition to other reactor technologies was something that those at the workshop thought was unlikely over this time period it was felt that any such developments would be so far in the future that their introduction could be phased so that it did not affect the overall build rate, although this would be more difficult to achieve at the higher levels of ambition.

---

274 Organisation for Economic Co-operation and Development Nuclear Energy Agency (2008) *Nuclear Energy Outlook 2008.*

275 Euratom Supply Agency (2008) *Annual Report 2008.*

Section H: Fossil fuel Carbon Capture and Storage

Context

Carbon Capture and Storage (CCS) consists of separate processes for capturing, transporting and storing carbon dioxide, each of which are currently deployed separately in a range of industrial processes. The International Energy Agency (IEA) has estimated that storage of carbon dioxide through CCS will be needed to deliver about 20% of the abatement required if global carbon dioxide emissions are to be reduced to 50% of the 2005 level by 2050.[276,277] This will require an annual global capture rate exceeding 2Gt/year in 2030, increasing to about 10Gt/year by 2050, and would involve over 3000 projects by 2050, with CCS being applied to coal and gas power generation and to large industrial emission sources such as iron and steel, cement and oil refineries. Currently there are no projects anywhere in the world undertaking the full CCS chain at the scale necessary for commercial electricity production.

The technical challenges to attaining widespread commercial deployment of CCS are a combination of scaling-up and achieving reliable integrated operation of the three components of capturing, transporting and storing carbon dioxide in a way that does not compromise the underlying production process. This is one reason why the G8 and IEA have called for 20 full-scale demonstrations to be announced by 2010, and why the European Union has introduced measures to provide financial support for up to 12 such demonstrations.[278] Other key objectives of the demonstrations are to reduce costs and increase investor confidence. Other developed economies have announced similar support programmes.

The Government has committed to a programme of support for the demonstration of CCS technology on four power stations, this includes the current competition for what is intended to be one of the world's first full-scale demonstrations of CCS on a coal-fired power station. The purpose of these projects is to prove CCS both technically and economically by 2020, and thereby accelerate the availability of fossil fuel power stations incorporating CCS for further deployment in the UK and worldwide. The four demonstration projects alone will mean the UK will have close to 2 GW of CCS power generation by 2020 capturing about 9 MtCO$_2$/year. The full installation of CCS to these units would more than double this capacity by 2025.

All new coal fired power stations in England and Wales are required to demonstrate CCS on at least 300 MW (net) of total capacity as a condition of consent, with an expectation that coal fired power stations consented under these arrangements will fully install CCS by 2025.[279] In 2010 the Government committed to the introduction of an

---

[276] International Energy Agency (2008) *Energy Technology Perspective 2008 – Scenarios and Strategies to 2050.*

[277] A 50% reduction is consistent with limiting global temperature rise to 2-3 degrees Celsius; Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: Synthesis Report.*

[278] International Energy Agency / Carbon Sequestration Leadership Forum (2010) *Report to the Muskoka G8 Summit – Carbon Capture and Storage – Progress and Next Steps.*

[279] Department of Energy and Climate Change (2009) *A framework for clean coal.*

Emissions Performance Standard that will prevent coal fired power stations being built unless they are equipped with sufficient CCS to meet that standard. Furthermore, the Government will produce a CCS roadmap and there will be a rolling review, which is planned to report by 2018, to consider the regulatory and financial framework needed to further the deployment of CCS.

The UK has also taken the lead in developing the licensing and regulatory frameworks necessary for controlling the transport and storage of carbon dioxide. Health and Safety and Environmental legislation has been reviewed, and the Energy Act 2008 provides one of the world's first regulatory regimes for permitting the permanent storage of carbon dioxide. In 2009 the EU introduced the *Directive on the geological storage of carbon dioxide* which aims to take CCS forward by requiring all combustion plants with a capacity of 300 MW or more to be built so that CCS can be retrofitted at a later date; the so-called Carbon Capture Ready (CCR) requirement.[280] A CCR requirement has been part of the permitting arrangements for new combustion power stations in the UK since 2009 for all new combustion power stations over 300 MW. The Government has consulted on the arrangements for transposing the Directive's requirements for licensing exploration and operation of carbon dioxide storage in the UK Continental Shelf, and a response is in preparation. The EU Directive also set out minimum requirements for encouraging a European transport and storage infrastructure, including provision for third party access and the Government has outlined its plans to achieve this.[281] As no commercial scale fossil CCS power generation projects have been built anywhere in the world the plausible levels of deployment can only be estimated via an assessment of the key drivers and enablers.

The next step in the development of CCS is a series of commercial scale demonstration projects aimed at proving the system both technically and economically. Accordingly the Government has committed to a UK demonstration programme of four such projects.

The Government recognises that the demonstration programme alone will not be enough to take us to the point of commercial deployment. The Office of Carbon Capture and Storage has been established to guide the UK's efforts on CCS both domestically and internationally. An important step in this process will be the production of a roadmap setting out the steps necessary for CCS to be a commercially deployable technology.

Drivers

Commercial viability

Beyond the demonstration projects, the Government's policy is for further deployment of CCS to be determined by the carbon price, with CCS competing against other low carbon options. The Government's ambition is to accelerate the commercialisation of CCS in order to have the technology ready for wider deployment from 2020, although the Government recognises that this will be very challenging.

CCS is not a mature technology and there are opportunities for substantial innovation-driven reductions in both the capital and operating costs which should increase its commercial competitiveness. Roughly two thirds of the costs of CCS lie in the capture

---

280 Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.

281 Department of Energy and Climate Change (2009) *Clean coal – an industrial strategy for the development of carbon capture and storage across the UK.*

process, and it is here that the greatest opportunities for savings lie.[282] Therefore, in parallel with the commercial demonstration programme, the Government is supporting research and development and prototype trials to develop improved and lower cost processes and equipment.

Market position of CCS

The longer term deployment of CCS will depend on its cost competitiveness compared to other low carbon power generation technologies including renewable energy and nuclear power. CCS is capital intensive and therefore will be most cost effective if deployed as base-load generation. However, it could be displaced from this role by nuclear power and by intermittent renewable sources such as wind energy, which with much lower marginal cost should always be used when available. This means CCS could be required to operate at intermediate load, providing a low carbon back-up to a large intermittent renewable energy capacity. In these circumstances the commercial success of CCS will depend on the technology having the operational flexibility to undertake this role (see below), and the electricity market being able to provide investors with a sufficient return to make it worthwhile investing in CCS.

Providing a flexible back-up to intermittent renewable energy sources

It is expected that early commercial deployment of CCS in the UK will be on coal fired generation because this is expected to be the lowest cost option. However, CCS on gas may be important for three reasons:

1. CCS on gas could be cost competitive with CCS on coal if new sources of gas, such as shale gas, increase supplies and reduce gas prices.
2. CCS on coal may still release about 10% of the carbon dioxide into the atmosphere, and this may not be acceptable as carbon abatement targets are tightened.[283] The efficiency of carbon dioxide capture technology may increase above 90% in future, or the carbon dioxide released could be accounted for by co-firing with biomass (see further detail on Bio-Energy with CCS (BECCS) in Section Q). However, it is likely that in future a significant amount of gas fired generation will be available for CCS retrofit, and since gas with CCS will only have about half the residual carbon dioxide emissions of coal, this could be an attractive option.
3. CCS on gas fired generation is less capital intensive than CCS on coal, therefore CCS on gas could be the more economic option when fossil power generation is required to provide a low carbon back-up to intermittent renewable energy sources.

---

[282] Department of Energy and Climate Change (2009) *Impact Assessment of Coal and Carbon Capture and Storage requirements* in 'A framework for the development of clean coal' consultation document.

[283] Intergovernmental Panel on Climate Change (2005) *Carbon Dioxide Capture and Storage: Special Report.*

Finally, the retention of gas generation will increase the UK's diversity of electricity supplies. Therefore it is possible, particularly under the most ambitious levels 3 and 4 (described below), that gas fired generation could take a significant share of CCS capacity.

Enablers

Assuming the demonstration projects are successful in proving CCS, there are five key factors that will influence future commercial deployment of CCS:

1. consenting conditions for new fossil fuel electricity generation;
2. availability of transport networks and storage capacity;
3. availability of sites for CCS power stations;
4. operational flexibility; and
5. establishment of a competitive equipment supply chain.

Consenting conditions for new fossil fuel electricity generation

The Government recognises that investors require a clear policy framework in which to plan for the future. This is why it has committed to introducing a floor price for carbon, an Emissions Performance Standard to help drive CCS deployment and a CCS roadmap. The Government is also working with the regulatory agencies including the Health and Safety Executive and the Environment Agency to establish a clear regulatory framework to control the licensing and operation of CCS.

Availability of transport networks and storage capacity

The UK is well placed to be an early mover on CCS because the North Sea, and to a lesser extent the Irish Sea, offers significant capacity for carbon dioxide storage in depleted oil and gas reservoirs, and there may also be a substantially greater capacity in saline aquifers (geological formations consisting of water permeable rocks saturated with salt water).

Estimates of the total offshore storage capacity available on the UK Continental Shelf are wide ranging, largely because of uncertainties in the current geological understanding of aquifers. In a study for the Department of Energy and Climate Change, the British Geological Survey estimated capacity of about 7.5 Gt in depleted oil and gas fields and, on a theoretical basis, almost 15 Gt in aquifers, but this assessment did not consider aquifers in the central and northern North Sea.[284] More recently an assessment by the Scottish Centre for Carbon Storage has estimated that the aquifers in the central and northern North Sea could take between 4.6 and 46 Gt.[285] Overall current knowledge suggests that the UK Continental Shelf should be able to store at least 10 Gt of carbon dioxide and probably substantially more. 10 Gt is about 80 years' worth of emissions from current UK coal fired power stations.

Two technical factors that could have an impact on the pace of CCS deployment are:

---

[284] British Geological Survey (2006) *Industrial carbon dioxide emissions and carbon dioxide storage potential in the UK.*

[285] Scottish Centre for Carbon Storage (2009) *Opportunities for CO2 storage around Scotland; an integrated strategic research study.*

1. the injectivity of the carbon dioxide stores (that is, how quickly carbon dioxide can be pumped into geological formations); and
2. the provision of pipeline capacity.

The Government is currently examining how the first of these can be addressed either through the CCS demonstration programme's choice of storage sites or through a linked geological survey.

On the second point, transporting several hundred million tonnes of carbon dioxide per year appears to be a formidable undertaking. However, a standard 36 inch diameter pipeline can carry about 25 Mt/year, therefore it would only require about thirteen such 'trunk' pipelines to carry the output from 50 GW of coal fired generation fitted with CCS. Since the transportation distances are relatively small, of the order of 300-600km, this represents a total pipeline length of about 6,000-10,000km. This would be a network of a similar size to the existing network of offshore oil and gas pipelines, which is clearly feasible over the next 40 years – though still a very large industrial undertaking.

Availability of sites for CCS power stations

In principle the availability of sites for CCS power stations should not be an issue. At the beginning of the 1990s the UK had over 50 GW of coal and oil fired generation, and although this fell to 28 GW by 2007 many of the sites remain available for redevelopment. Furthermore over 23 GW of gas fired generation has been added to overall UK electricity generating capacity suggesting that sufficient sites should be available.

The location of CCS power stations will be determined by factors relating to the power station itself (for example, proximity to demand, grid connection, availability of cooling water and transportation of fuel supplies), and also the availability of transport infrastructure to take the carbon dioxide to a storage site. Because most of the UK's storage capacity is located off the East Coast this is likely to favour the location of power stations near to this coastline since there may be limited options for routing onshore pipelines around centres of population. For example a study by Pöyry for the Committee on Climate Change concluded that it may be desirable to consider clustering CCS units at coastal sites or at existing sites within 100km of a coastal gas terminal, if it is problematic to obtain consent for onshore carbon dioxide transport pipelines.[286] Pöyry found that 15 GW of existing coal fired generating stations and a further 19 GW of other generating stations already met this criterion.

UK deployment of fossil fuelled power stations, and particularly coal, has tended to cluster in a limited number of locations (for example, the Thames estuary, Humberside, Tyne-Tees, Forth estuary, Merseyside, South Wales). This could encourage the development of regional infrastructure for the collection and transport of carbon dioxide. The Government is considering how the CCS demonstration programme could help establish such networks.

---

[286] Pöyry (2009) *Carbon Capture and Storage: Milestones to deliver large scale deployment by 2030 in the UK.*

Power station operational flexibility

An important attribute of fossil fuelled power stations is their flexibility in altering supply to meet demand, which makes them ideal for providing back-up generation, thereby ensuring short term security of supply. A key objective of the UK's demonstration programme is to establish whether fossil fuelled power stations will retain this flexibility when fitted with CCS. If this proves to be the case then potential deployment of CCS could be substantially higher than if a power station was confined to base-load operation once fitted with CCS, as it would give a low carbon option for providing back up to intermittent renewable sources.

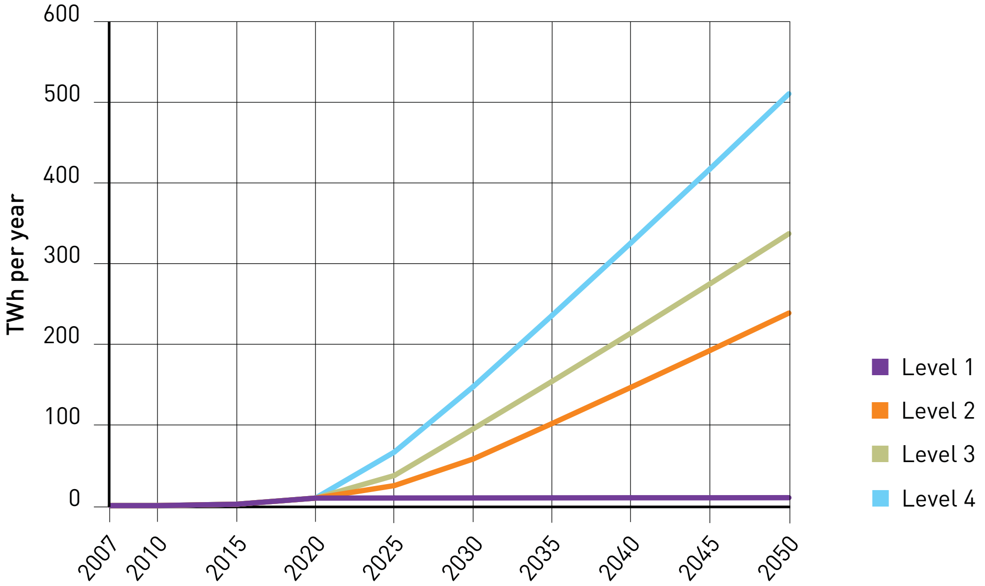
Establish a competitive equipment supply chain

It is important to diffuse the experience and know-how stemming from CCS demonstration projects to establish both technical and price competition between equipment suppliers. This is particularly so for carbon dioxide capture equipment, which, unlike pipelines and injection facilities, does not have an established market.

The levels

Figure H1 below illustrates trajectories for new fossil fuel CCS power under four levels of deployment, which are described below.

Figure H1: Trajectories for electricity generation from fossil fuel Carbon Capture and Storage



This work considers CCS being applied to both gas and coal. However in the 2050 Pathways Calculator itself, in order to simplify the modelling, coal is mainly used. This can give the impression that gas is not expected to be used, but this is not a conclusion of the analysis. The figures provided for CCS on power plant are electricity generation net of own use and parasitic load.

Level 1

This level of deployment assumes all four demonstration projects are implemented before 2018, with the first in operation by 2015. If the demonstration plants don't support the case for commercial deployment then it is assumed that no more CCS plants are built.

Level 2

This deployment level is based on the assumption that demonstration projects are deployed, possibly in two tranches, with the first plant in operation by 2015 and that work is completed to confirm the availability of storage capacity. Assuming successful demonstration projects and a lead time for the first commercial plant of six years from the results of demonstration plants in 2018, then additional CCS capacity could become operational from 2024. The completion rate to 2030 is based on the lower deployment rate in the Pöyry report for the Committee on Climate Change.[287] A completion rate of 1.5GW/year from around 2030 would be comparable to a Parsons Brinckerhoff estimate of the potential build rate of 1 GW/year reflecting the combination of power and process plants.[288] The total capacity of 40 GW at 2050 is calculated to deliver 239 TWh of electricity per year.

Level 3

Making the same initial assumptions as level 2, this level follows a completion rate of 2 GW/year from 2025 based on the 'realistic high deployment' scenario described in the Pöyry report for the Committee on Climate Change.[289] The total capacity of 57 GW at 2050 is calculated to deliver 337 TWh of electricity per year.

Level 4

This level assumes successful demonstration projects and successful confirmation of the storage capacity, with allowance for storage of emissions from other CCS processes. If the lead time is assumed to be six years but early consenting work provides an opportunity for construction on commercial plant from 2018 then additional CCS capacity plant could become operational from 2021. A completion rate of 3 GW/year from around 2030 would be similar to the peak delivery of Combined Cycle Gas Turbine plants in the UK during the 1990s. There may be a preference for locating multiple CCS units at existing or new sites in order to maximise the efficiency of carbon dioxide transportation. The total capacity of 86 GW at 2050 is calculated to deliver 511 TWh of electricity per year.

Possible technology developments

CCS and in particular the capture aspect of the CCS chain are considered to have significant potential for cost reduction through technical development. In the near term CCS demonstration and deployment is likely to use one of three capture options that have been adapted from other processes involving carbon dioxide separation. These are: post combustion capture involving the separation of carbon dioxide from flue

---

[287] Pöyry (2009) *Carbon Capture and Storage: Milestones to deliver large scale deployment by 2030 in the UK.*
[288] From Department of Energy and Climate Change discussions with Parsons Brinckerhoff.
[289] Ibid.

gases; pre-combustion in which fossil fuels are converted to carbon dioxide and hydrogen prior to combustion; and oxy-firing in which combustion takes place in an oxygen/carbon dioxide mixture to yield a flue gas consisting mainly of carbon dioxide. The main opportunities for reducing the cost of these methods are:

- Increasing the power station efficiency so that it uses less fuel per unit of electricity generated. This reduces the amount of carbon dioxide to be captured, which reduces the size of the capture plant (capital cost saving) and the amount of energy needed to operate capture (operating cost saving).
- With present designs the amount of electricity supplied from a coal power station is reduced by about 20% because of the energy needed to run the capture plant and carbon dioxide compressors. Reducing this energy penalty by developing more efficient separation processes and carbon dioxide compressors will yield substantial savings.

Looking further ahead, more novel separation processes which may offer substantial savings in both capital and operating costs are the subject of research and development. These include the use of membranes for both carbon dioxide and oxygen separation, mineralisation, and also chemical looping methods for regenerative carbon dioxide capture.

Section I: Onshore wind

Context

The UK has the largest potential wind energy resource in Europe. With a presence in the UK spanning some 20 years, onshore wind is one of the most established, large scale sources of renewable energy in the UK. Large onshore wind farms and smaller scale distributed and community wind energy projects[290] will continue to contribute to meeting the UK's renewable energy targets.

Commercial scale onshore wind turbines first started appearing in the UK in 1991 in response to the Government's Non-Fossil Fuel Obligation, although since 2002 the Government's key mechanism for increasing all renewable electricity capacity has been the Renewables Obligation. By 2008, the UK produced 5.5% of its electricity from renewable sources.[291] In total, wind provided nearly one-third of this, with offshore wind contributing 1.3 TWh and onshore wind 5.7 TWh towards a total renewable electricity generation of 21.6 TWh.

As with other renewable technologies, wind power faces some barriers – financial and non-financial – in maximising the potential opportunities for development. However, the Committee on Climate Change has suggested that wind generation could be a major source of electricity in the UK, possibly providing 30% of electricity by 2020 and more beyond.[292] The Government is pressing forward with policies to maximise the available opportunities from onshore wind deployment.

Table I1: The status of onshore wind as at May 2010[293]

Onshore status	Schemes	Capacity (GW)
Operational	301	3.6
Under construction	37	1.3
Approved but not built	159	3.3
In planning process	282	7.6

---

[290] 'Smaller scale' implies larger than microgeneration.

[291] Department of Energy and Climate Change (2009) *Renewable Energy Strategy.*

[292] Committee on Climate Change (2008) *Building a low carbon economy – The UK's contribution to tackling climate change: The First Report of the Committee on Climate Change.*

[293] Renewable Energy Statistics Database for the UK (2010) (NB includes all onshore turbines greater than or equal to 10kW).

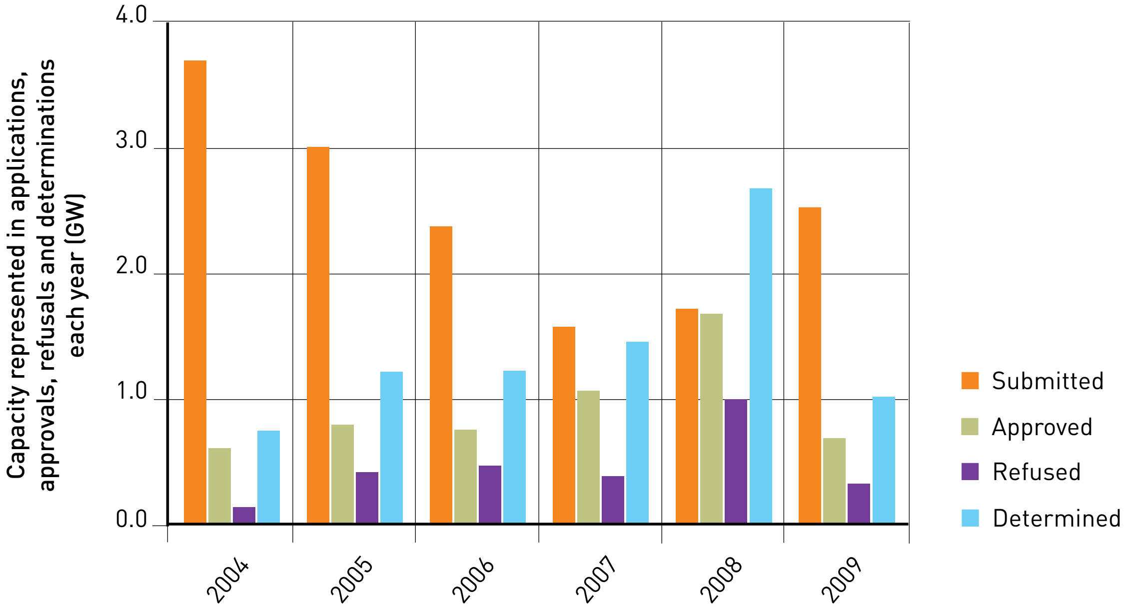
Drivers

Onshore wind farms have been under development in the UK for over twenty years. One way to assess the plausible levels of deployment of this technology looking ahead to 2050 is via the rate at which new sites have been submitted for planning permission and the success rate in taking them forward for approval (a 'bottom up' approach). Another method would be to estimate the potential practical resource in order to predict potential total capacity (a 'top down' approach).

The planning process varies by location and scale of development, but broadly speaking, applications for onshore wind farms of less than 50 MW are processed by local planning authorities, whereas applications for larger wind farms are handled at national level. In both cases (under the existing system), planning decision makers have to assess applications against a range of social and environmental criteria, taking into account both local impacts and the national need for renewable energy.

Planning applications

Figure I1: UK planning applications and decisions for onshore wind capacity[294]



The rate of UK planning applications being submitted had been gradually declining over recent years, until a surge of new submissions in 2009. When decisions on planning applications for new onshore wind capacity were made during the period 2004–9 there was a consistent rate of between 60% and 80% of capacity being approved (including projects approved after appeal), with an average approval rate of 69% for all sizes of projects across the UK. This rate did vary across different parts of the country and for local as opposed to national consenting bodies. For example, the approval rate for decisions made at a local level in England over the same period is 50%, although in terms of absolute numbers of submissions (rather than capacity) it is 62%.[295]

---

[294] Calculations by Department of Energy and Climate Change, based on data from the Renewable Energy Statistics Database for the UK.

[295] Ibid.

Practical resource

If we consider the UK's land area as a whole and exclude land where wind farms would not be built for land use or ecological sensitivity reasons, then one estimate of the remaining accessible resource could lead to the construction 110 GW capacity of wind turbines.[296] However, this was reduced to a maximum practical resource of 28 GW based on assumptions of clustering and proximity constraints.[297] Using a different methodology extrapolating from regional planning assessments, the estimate of the resource is 31 GW for 2020 or later.[298]

If the density of onshore wind farms in the UK (MW/per 1000km^2) was similar to the current density in Denmark then it is estimated that the total capacity would be around 16 GW.[299] This is only a theoretical comparison of capacity and does not take account of factors that could affect the actual deployment, for example, differences in land use, ecological sensitivity, wind resource or planning policy.

Enablers

Planning decisions

The Government has committed to retaining a fast-track process for onshore energy developments over 50 MW, but with decisions being made by Ministers rather than by the Infrastructure Planning Commission. For installations below 50 MW, decisions are taken by local planning authorities; the Government has stated that a new national planning framework for England will be introduced in due course.

While planning is largely a devolved issue, the Devolved Administrations of Northern Ireland, Scotland and Wales also pursue a positive approach to the development of onshore wind. Scottish planning policy supports and encourages the continued growth of all renewable technologies and the Scottish Executive has a target of 40% renewable electricity by 2020 with the majority coming from onshore wind and hydropower. The Welsh Assembly also has an aspiration that by 2025 it will generate more electricity from renewable energy than it consumes, and is aiming to deliver 800 MW of onshore wind by the end of 2010.

Renewables Obligation and loan financing

The Renewables Obligation is the Government's key mechanism for increasing new renewable electricity generating capacity, including onshore wind, allowing renewable technologies to compete in the market against more established fuels in order to deliver against long term carbon and security of supply goals.

Access to finance in tighter credit conditions has been problematic for some wind farms. The European Investment Bank (EIB), in collaboration with BNP Paribas Fortis, Lloyds Banking Group and Royal Bank of Scotland has set up and is running a scheme to enable the small and medium sized segment of the renewable energy market, initially focussing on onshore wind, to secure access to finance for their projects. UK

---

296 Energy Technology Support Unit (ETSU) R-99 as reported by Enviros Consulting Limited (2005) *The Costs of Supplying Renewable Energy.*

297 Ibid.

298 Ibid.

299 As estimated by the Department of Energy and Climate Change.

renewable and energy projects are benefitting from up to £4 billion of new capital from the EIB. The specific lending scheme for onshore wind will help finance project costs of up to £1.4 billion in order to bring consented small and medium sized UK projects to deployment. The 48 MW Hill of Towie wind farm in Scotland, which will become operational in summer 2011, was the first project to secure financing under the lending scheme in March 2010.

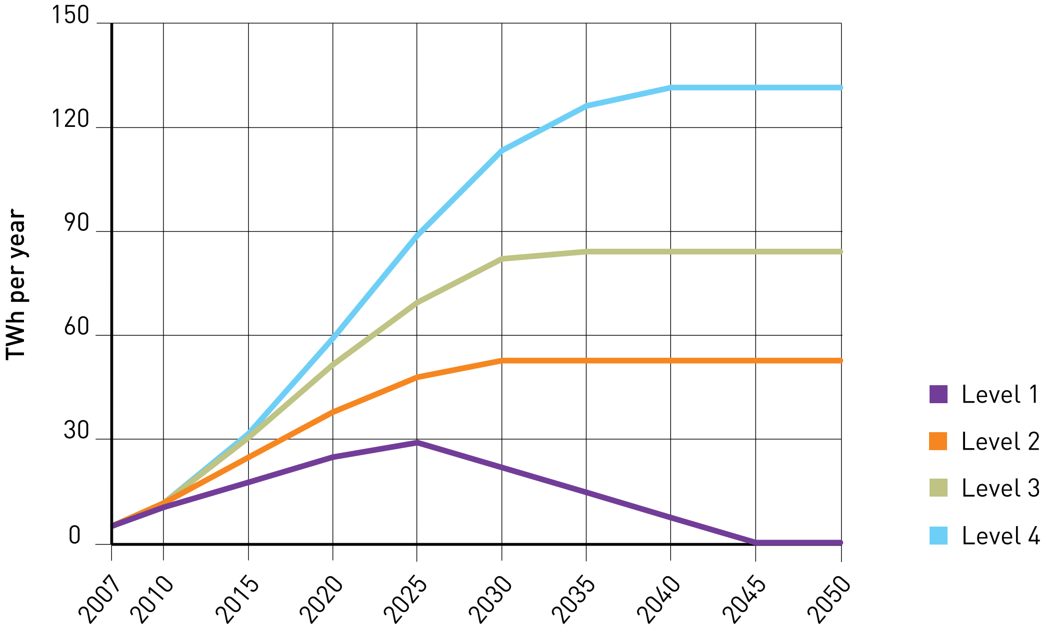
Wind turbines and aviation

Wind turbines can have significant effects on aviation radar which, unresolved, could potentially have an impact on national security or aviation safety, and limit the deployment of onshore and offshore wind. The Department of Energy and Climate Change and other Government departments are working with aviation and industry stakeholders to resolve this significant and challenging issue. An Aviation Plan was published in September 2008, alongside a Memorandum of Understanding between all relevant stakeholders which commits to working together to identify solutions based on both ways of working and new technological systems.

The levels

Figure I2 below illustrates trajectories for onshore wind power (including existing schemes) under four levels of deployment, which are described below.

Figure I2: Trajectories for electricity generation from onshore wind



In this assessment it has been assumed that wind turbines are decommissioned after 20 years of operation. This means that even though new turbines are installed at the same time as decommissioning, the cumulative installed capacity levels off over time. It has also been assumed that the load factor is a constant 30%.[300]

---

[300] Department of Energy and Climate Change (2009) *Digest of United Kingdom Energy Statistics.*

Level 1

The capacity achieved at this level of deployment has been based on continuation of the average build rate over the past four years, which was approximately 0.55 GW/year. It is assumed that there will be a continuous pipeline of projects for construction. The total maximum capacity of around 11 GW in 2025 would require around a 50% approval rate of the sites currently submitted for planning permission, assuming all the approved projects are built.

It has been reported that currently the onshore wind supply chain is capable of a build-rate of around 0.85 GW/year in the UK.[301] It is assumed that continuation of the build rate and availability of the supply chain is not affected by significant expansion of either onshore wind or offshore wind in other countries.

For this level it is assumed that sites are not replanted when the turbines are decommissioned.

Level 2

This level of deployment assumes that applications for a further 2 GW are submitted in 2010 but then submissions decline at the rate of 0.2 GW/year, for example, as the availability of sites decreases over time. If the approval rate of planning submissions is 70% and all the projects are built then the total capacity, including projects already submitted, approved or operating, would be around 20 GW by 2030 and maintained at that level. This capacity of 20 GW is calculated to deliver 53 TWh of electricity per year.

As there are already projects that have gained consent and are awaiting construction, it is assumed there is no lead time and that a continuous pipeline of projects is available to support a build rate of 1 GW/year. A build rate of around 1 GW/year is similar to the build rates in the Pöyry 'alternative scenario' or the Sinclair Knight Merz (SKM) report's 'medium build' scenario but requiring earlier delivery.[302,303]

This build rate would deliver around 14 GW of installed capacity by 2020, which is considered achievable by the industry, but nonetheless would still be challenging. The British Wind Energy Association highlighted in May 2009 that:

"The build rate required to meet this objective (of 14 GW by 2020), under 1 GW per year, is less than has been achieved in both Germany and Spain for nearly a decade, so on the face of it there is no reason why the supply chain cannot deliver this capacity."[304]

---

[301] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[302] Ibid.

[303] Sinclair Knight Metz (2008) *Quantification of Constraints on the Growth of UK Renewable Generating Capacity.*

[304] Memorandum submitted by the British Wind Energy Association, House of Commons Energy and Climate Change Select Committee (2008-9) *Low Carbon Technologies in a Green Economy.*

Level 3

If it is assumed that planning submissions are submitted at the rate of 2.5 GW/year until 2020 and the success rate is 70%, then the total capacity at 2050 for this level of deployment would be approximately 32 GW, assuming all approved projects are built. This total capacity is calculated to deliver 84 TWh of electricity per year.

As there are already projects that have gained consent and that are awaiting construction, it is assumed that there is no lead time and a continuous pipeline of projects is available to support a build rate of 1.6 GW/year. The build rate is similar to the build rates in the Pöyry 'high feasible scenario' or the SKM 'high build' scenario but requiring earlier delivery.[305,306]

Level 4

The installed capacity for this level of deployment reaches 50 GW, which is below the accessible resource indicated in the Energy Technology Support Unit report but is still likely to require some form of intervention either to reduce constraints or improve public acceptability.[307]

Assuming a planning approval rate of 70% the submission rate would need to be sustained at around 3.5 GW/year to 2025 in order to provide around 2.5 GW/year of projects for construction. In total, around 70 GW would need to be submitted for planning permissions compared to the 18 GW that has been submitted to the end of 2009. The total capacity of 50 GW at 2050 is calculated to deliver 132 TWh of electricity per year.

In Germany in recent years the build rate has averaged around 2.1 GW/year and Spain 1.6 GW/year, with peak capacity exceeding 3 GW/year.[308] Both Germany and Spain have indigenous wind turbine manufacture whereas the UK may be more dependent upon the global supply chain.

---

[305] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[306] Sinclair Knight Metz (2008) *Quantification of Constraints on the Growth of UK Renewable Generating Capacity.*

[307] Energy Technology Support Unit (ETSU) R-99 as reported by Enviros Consulting Limited (2005) *The Costs of Supplying Renewable Energy.*

[308] British Wind Energy Association (2009) *State of the Industry Report.*

Section J: Offshore wind

Context

The UK is demonstrating considerable international leadership in the development of offshore wind. The last decade has seen UK offshore wind progress from an immature technology into a proven technology that is expected be a significant contributor to achieving EU renewables targets.

In 2001, the first leasing round of the UK offshore wind programme resulted in 12 sites being allocated with the potential for around 1 GW of capacity. Following an offshore wind Strategic Environmental Assessment, a second leasing round competition was held in 2003, granting potential capacity of over 7 GW. Opportunities are now being explored to extend some of these planned offshore wind farms by up to 1.6 GW, as well as developing approximately 6 GW capacity within Scottish Territorial Waters.

In 2009, a second Strategic Environmental Assessment concluded that an additional 25 GW of offshore wind capacity by 2020 would be acceptable as long as appropriate mitigation measures were put in place, in addition to existing plans for 8 GW. Following a third leasing round competition in January 2010, The Crown Estate awarded Zone Development Agreements (exclusivity awards) for up to 32 GW of capacity. Following the award of an agreement for lease or a Zone Development Agreement by The Crown Estate, all offshore wind farm developments are subject to the usual planning processes, including the need to seek development consents from the appropriate planning authority prior to construction and generation.

Based on the outcome of Round 3 plus existing plans, the total available offshore wind potential is 47 GW by 2020, if all the ambitions were realised. It is clear that this level of development would require a massive step-change in the rate of deployment. The Government is committed to pressing forward with policies to maximise the available opportunities from this offshore wind deployment.

Table J1: The status of offshore wind as at May 2010[309]

Offshore status	Schemes	Capacity (GW)
Operational	14	1.0
Under construction	4	1.5
Approved but not built	6	2.6
In planning process (includes applications anticipated but not yet submitted)	32	43.7

---

[309] Renewable Energy Statistics Database for the UK (2010).

Drivers

The plausible build rate for offshore wind can be estimated using an understanding of wind turbine size and speed of installation. The build rate will depend on the efficiency of the supply chain, which in turn will be assisted by a clear understanding of the total capacity to be installed, the need to replace turbines ('repowering') and opportunities to re-deploy resources.

Turbine size

As offshore wind technology develops and progresses, the size of turbines has increased from 2 MW on early Round 1 sites in 2003 to 3.6 MW on the most recent installations. The Beatrice demonstration project in the UK has installed two 5 MW turbines. Offshore wind farms in other countries have also installed 5 MW turbines at demonstration sites. By the middle of this decade, it is expected that 5-7 MW turbines will start to be deployed at scale. Clipper Windpower is currently developing and will manufacture a 10 MW offshore turbine in the North East.

Installation rate

As UK offshore wind farms become larger in size and as some sites are locating further from shore or in deeper water, there are a variety of factors to consider that can affect future installation rates. Some of these will be project and location specific, such as seabed conditions and foundation type, turbine size, the type of installation techniques used and the length of construction and operating period. This combination of factors makes it very difficult to estimate the optimal future build rate across the technology as a whole.

Offshore wind turbine construction is dependent upon the availability of jack-up barges. A study in 2008 indicated a potential installation rate per barge of 0.18 GW/year, assuming installation of uniform 3.6 MW wind turbines and full-time usage of a jack-up barge.[310] This equates to an installation rate of around 50 turbines each year per barge. In a later study of future offshore deployment for the Committee on Climate Change the same rate per barge of 0.18 GW/year was proposed, on the basis that as future sites will be located further offshore, the rougher seas will reduce the amount of time during which construction can safely proceed, which negates any additional improvements in technology or installation methods.[311]

Total capacity

The current overall industry ambition could be around 50 GW by 2020 but as an island nation we are in a great position to harness our abundant offshore wind, wave and tidal resources further in the future. The recent Offshore Valuation report used various scenarios to suggest that we could even have the potential to become a net electricity exporter.[312]

---

[310] Sinclair Knight Metz (2008) *Quantification of Constraints on the Growth of UK Renewable Generating Capacity.*

[311] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[312] The Offshore Valuation Group (2010) *The Offshore Valuation: a valuation of the UK's offshore renewable energy resource.*

However, it is important to note that as more wind farms are built there will be an increase in the cumulative impacts on all users of the sea. As part of normal planning considerations, the need for low carbon energy infrastructure will need to be balanced with the security, social and environmental interests in the marine sector, including other energy infrastructure and shipping, fishing, ports and defence activities. Depending on the scale of intervention that is possible, 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. Some industry stakeholders believe that the total capacity could be up to 200-250 GW.

Lifetime and replanting

Offshore wind developers currently anticipate their infrastructure will last about 20 years, therefore probably requiring upgrades and re-planting during the standard 50 year site lease period.

Enablers

Innovation and cost reduction

Deployment of offshore wind provides the opportunity to explore different installation techniques, reduce weight and improve turbine reliability.[313] To ensure that investing in renewables makes financial sense and helps bring down costs in the future, the Renewables Obligation (RO) was introduced in 2002 and awards a pre-determined number of Renewables Obligation Certificates (ROCs) per MWh of electricity generated for each renewables technology, including offshore wind. The Government has committed to extending the RO to at least 2037 in order to provide greater long term certainty to investors and the Coalition Programme explained that the Government would maintain banded ROCs.[314] Any move to a Feed In Tariff would be done with the aim of ensuring the UK is best placed to meet 2020 targets, protecting both investors and consumers.

In addition to the RO mechanisms, the long term cost of offshore wind is likely to reduce to more competitive levels once new technology and improvements in design, installation and maintenance are developed, along with greater competition in the marketplace. Offshore test sites are needed in order to enable the necessary research and demonstration to take place in a cost effective environment.

The Low Carbon Energy Demonstration capital grants scheme was launched in 2009, specifically aimed at bringing forward the demonstration of new components or technology to support the earlier deployment (within 2020 timescales) of large scale multi-MW wind turbines. It also aims to provide a learning experience which can improve confidence and help reduce future costs, and underpin development of the industry by stimulating the UK supply chain. So far around £23 million has been awarded to consortia in order to develop a range of technologies, supporting innovative offshore wind companies in the UK.

---

313 Carbon Trust (2008) *Offshore wind power: big challenge, big opportunity.*
314 HM Government (2010) *The Coalition: Our programme for Government.*

Water depth and distance offshore

To date, 'monopole' turbine structures have been the preferred design for wind turbine foundations in offshore wind farms with water depths below 30-40m in the UK, apart from the Beatrice demonstration project where a jacket structure (several tubular steel legs piled into the seabed) was used at a depth of around 45m. As sites are increasingly established in water depths of between 30m and 60m, a range of other foundation designs may be used, with the potential in the future to consider using floating platforms for water depths greater than 60m.[315] A floating platform demonstration project with a 2.3 MW wind turbine has been installed off the coast of Norway.[316]

Some of the zones in Round 3 – where exploration work began in early 2010 – will require turbines to be installed significantly further from shore than is currently the case. The Government and developers are working hard to consider how this may impact on the reliability of the technology used, installation strategies, the speed of installation processes and the operation and maintenance of the wind farm once constructed.

Competition and opportunity

Some parts of the supply chain are common to both onshore and offshore wind, so a significant increase in demand for onshore wind to meet European renewable energy targets could impact the delivery of the UK offshore market, and vice versa.

To provide the step change required to match the ambitions of the UK offshore wind market, we need a supply chain to deliver the necessary skills, technology, installation capacity, operations, maintenance and related infrastructure. Supply chain pressures in the UK are exacerbated by a global increase in demand from key onshore wind markets, such as the rest of Europe, the US and China, as well as other offshore wind markets from around the world. However it should be noted that whilst a significant response is required from the supply chain industry, the build rate anticipated to fulfil the industry's stated ambition to 2020 and beyond is broadly similar to that achieved for coal powered generation in the 1970s and gas powered generation in the 1990s.

Drawing on experiences with the North Sea oil and gas industry, a new Offshore Wind Developers Forum has been created to bring together the Government and industry to take practical actions to ensure the viability and deliverability of offshore wind in the UK and to identify economic opportunities. The Crown Estate and the Government have also held a series of supply chain events across the UK to raise awareness about the opportunities for businesses in the offshore wind industry.

---

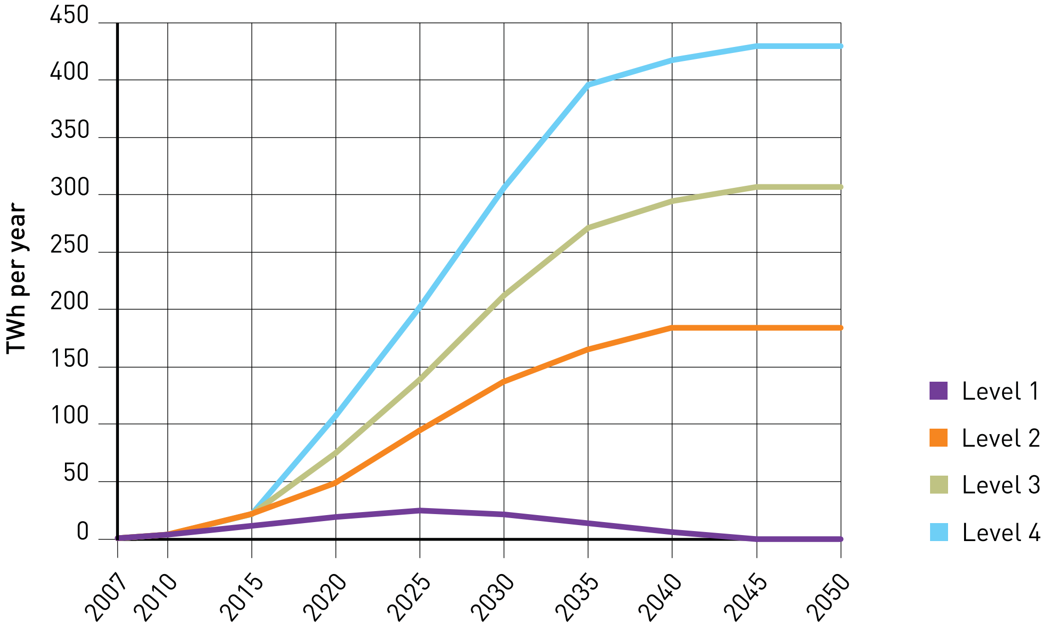
[315] Ibid.

[316] StatoilHydro press releases: www.statoil.com

The levels

Figure J1 below illustrates trajectories for offshore wind power (including existing schemes) under four levels of deployment, which are described below.

Figure J1: Trajectories for electricity generation from offshore wind



In this assessment it has been assumed that wind turbines are decommissioned after 20 years of operation. This means that even though new turbines are installed at the same time as decommissioning the cumulative installed capacity levels off over time. It has also been assumed that the load factor is a constant 35%.[317]

Level 1

This level of deployment assumes that there will be a continuous pipeline of projects for construction. The total capacity of 8 GW assumes a high level of success from Round 1 and 2 sites.

A build rate of 0.5 GW/year has been assumed, which is greater than the historic rate, but this was mainly at the smaller Round 1 sites, and should be achievable if the current supply chain is capable of delivering 0.65 GW/year as estimated in the Pöyry Report for the Committee on Climate Change (CCC).[318] It is assumed that continuation of the supply chain is not affected by significant expansion of onshore wind or offshore wind in other countries.

It is also assumed that sites are not replanted when the turbines are decommissioned.[319]

---

317 Department of Energy and Climate Change (2009) *Digest of United Kingdom Energy Statistics.*

318 Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

319 'Replanting' involves the replacement of the whole offshore structure, a bigger job than repowering (where only the turbine is replaced) and one that would require new planning permission.

Level 2

This level of deployment assumes that there is a continuous pipeline of projects from Rounds 1, 2, 3, extensions and projects within Scottish territorial waters that successfully gain planning permission and are constructed within around 4 years of submitting planning applications.[320] A significant proportion of the total capacity of 60 GW could be achieved from the current sites that have been leased by The Crown Estate. This capacity of 60 GW at 2050 is calculated to deliver 184 TWh of electricity per year.

It is assumed that the supply chain grows to 2020 broadly in line with the 'high feasible' scenario of the Pöyry report for the CCC, increasing to a build rate of 3 GW/year in 2021.[321]

The potential build rate needs to be assessed in the context of the overall credible ambition across a wider geographical area if using a common supply chain. The British Wind Energy Association highlighted this point recently:

'If the delivery of offshore wind in the UK is ramped up to perhaps 3 GW per year in 2020, out of a wider European market of 6-7 GW per year, then it is possible to have 20 GW of operating capacity in that year. Note that this size of industry will require longer term visibility of the market than just to 2020. European Governments will need to articulate their vision for offshore wind to 2030 if the sustained investment required to bring costs down is to be brought forward. However, we believe that the 20 GW figure is a realistic and achievable objective, and that the Government should seek at least this amount in the mix by 2020.'[322]

Level 3

To achieve a total installed capacity of 100 GW at this level of deployment, intervention is likely to be required to ensure additional areas for offshore wind are made available, or sites may need to be developed in deeper water. It is assumed that if additional sites are needed then they will become available in time to support a continuous pipeline of projects for construction, assuming development and approval within four years.

It is assumed that the supply chain grows significantly to 2017, with a build rate from 2017 above the supply chain growth in the 'high feasible' scenario of the Pöyry report for the CCC.[323] This build rate then continues to increase up to 5 GW/year by 2025.

The challenge of delivering the capacity in this level was highlighted by the Carbon Trust:

"Delivering this level of offshore wind power [29 GW] in just over a decade is an immense challenge. It is equivalent in scale to the 90s 'dash for gas' and could require up to £75 billion in investment from industry, on a similar scale to that invested in North Sea oil and gas in the peak decade of its development."[324]

Under this level, around 25 GW of installed capacity would be achieved by 2020, which was above industry expectations prior to The Crown Estate's announcement.

---

[320] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[321] Ibid.

[322] Memorandum submitted by the British Wind Energy Association, House of Commons Energy and Climate Change Select Committee (2008-9) *Low Carbon Technologies in a Green Economy.*

[323] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[324] Memorandum submitted by the Carbon Trust House of Commons Energy and Climate Change Select Committee (2008-9) *Low Carbon Technologies in a Green Economy.*

For example the Renewables Advisory Board had previously forecast that 18 GW would be achievable by 2020.[325] The total capacity of 100 GW at 2050 is calculated to deliver 307 TWh of electricity per year.

Level 4

To achieve a total installed capacity of 140 GW at this level of deployment, intervention is likely to be required to make additional areas available for offshore wind development, or sites may need to be developed in deeper water. It is assumed that if additional sites are needed then they become available in time to support a continuous pipeline of projects for construction, assuming development and approval within four years. The total capacity of 140 GW at 2050 is calculated to deliver 430 TWh of electricity per year.

As with level 3, the build rate to 2020 reflects rapid implementation and a high success rate for the developments proposed under Crown Estate development rounds and is significantly above the 'high feasible' scenario of the Pöyry report for the CCC, expanding further to 7 GW/year after 2025.[326] The peak build rate is comparable to the estimate of 6.8 GW/year by 2020 in a report prepared for The Crown Estate.[327]

Possible technology developments

Although a number of turbine manufacturers are field testing turbines purpose-built for the offshore environment, most offshore wind turbines today resemble 'marinised' onshore wind turbines. Both the European Commission and International Energy Agency have published roadmaps on wind suggesting that further innovation is required to drive down the cost of energy and reliability,[328,329] including:

- deep-water foundations, located at depths greater than 35 metres;
- installation techniques;
- direct drive generators, with machines with no gearbox or drive train potentially leading to reduced noise impact, and improved cost and efficiency of the technology;
- direct current (DC) generation;
- larger offshore turbines and floating turbines (by 2020); and
- condition monitoring, involving testing and performance monitoring of various components of turbines in order to lower the cost of condition monitoring systems and produce more accurate information for operations and maintenance planning.

It has been suggested that in future hydrogen or other clean fuels could be used as conduits for the storage and transport of energy from offshore wind sites.[330] This could require expansion of the offshore wind supply chain to include the production, collection, transfer and distribution of the hydrogen.

---

[325] Douglas-Westwood Ltd for the Department of Business, Enterprise and Regulatory reform (2008) *Supply Chain Constraints on the Deployment of Renewable Energy Technologies.*

[326] Pöyry (2009) *Timeline for Wind Generation to 2020 and a set of progress indicators.*

[327] BVG Associates (2009) *Towards Round 3: Building the Offshore Wind Supply Chain.*

[328] European Commission (2009) *Investing in the Development of Low Carbon Technologies (SET-Plan) A Technology Road Map.*

[329] Organisation for Economic Co-operation and Development / International Energy Agency (2009) *Technology Roadmap Wind Energy.*

[330] British Wind Energy Association (2007) *UK Offshore Wind: Moving up a gear.*

Section K: Tidal range

Context

Tidal range technology uses the height difference in water levels caused by the tide to generate electricity. Tidal range therefore captures potential energy, rather than the kinetic energy of a tidal current, as in tidal stream technology. There are very few tidal range schemes in operation around the world. The only one of a significant size currently operating is the La Rance barrage in Brittany. This has a generating capacity of 240 MW and has been operating continuously since 1966. There is a similar size barrage at Sihwa in South Korea that is due to start operating by the end of 2010 and the Korean Government has recently announced plans for a larger barrage on the Incheon peninsula. There are a number of small scale schemes in Canada, Russia and China.

In the UK there have been studies carried out for various estuaries and bays over the past few decades, but interest has increased over the past couple of years. Currently, a tidal range project that is under 1 GW in size would receive support under the Renewables Obligation to the value of two Renewable Obligation Certificates (ROCs) per MWh of electricity produced. A Government-commissioned report is currently looking at the cost of and financial support for wave and tidal generation in the UK, and this is likely to feed into any future review of ROCs.[331]

In 2007, the Sustainable Development Commission (SDC) published a report investigating tidal power opportunities across the UK which concluded, with conditions, that there is a strong case for a sustainable Severn Barrage from Cardiff to Weston, and also potential for barrages in other locations such as the Mersey, Wyre and Thames.[332] Building on the SDC's recommendation, the Government carried out a two-year (2008-10) feasibility study of tidal power in the Severn Estuary. The feasibility study explored the costs, benefits, impacts and risks of a tidal power scheme, and includes a Strategic Environmental Assessment of the environmental and social impacts of five potential tidal power schemes. The Severn Tidal Power feasibility study has also looked at potential support measures for schemes over 1 GW, which are currently outside the scope of the Renewables Obligation. The Severn Estuary is a unique environment and is designated under several pieces of international and national environmental legislation for the species and habitats within it. In addition, work was carried out on the regional economic impacts, supply chain, financing and development of new tidal range/stream technologies.

The feasibility study is due to report in 2010 on whether the Government should support a scheme in the Severn and if so on what terms. Following the conclusions of that report, the Government will announce whether it can support a project in the Severn Estuary and, if so, the terms of that support. The figures presented here do not pre-judge the conclusions of the feasibility study but instead use indicative volumes of

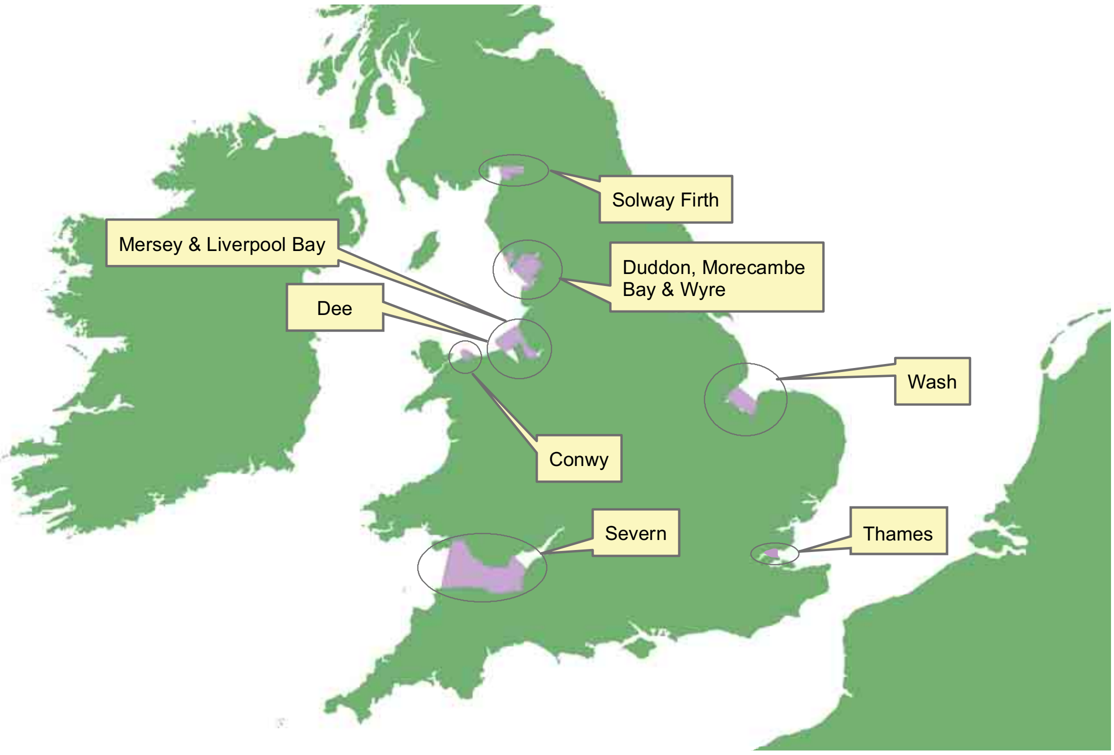
---

[331] Department of Energy and Climate Change and Scottish Government (2010, not yet published) *Cost of financial support for wave, tidal stream and tidal range generation in the UK.*

[332] Sustainable Development Commission (2007) *Turning the Tide, Tidal Power in the UK.*

the UK's total tidal range resource, which may or may not include a scheme in the Severn Estuary at some point before 2050. In 2010 feasibility studies were also underway for the Mersey, the Solway Firth, and the Duddon, and additional studies are also planned for the Wyre and at several sites along the North Wales Coast.

Figure K1: Potential tidal range sites around the UK[333]



Drivers

Resource

The UK has one of the best natural tidal range resources in the world, with estimates that tidal range could meet 13% of our total electricity demand if fully exploited.[334] The schemes that are currently being considered under feasibility studies only represent a fraction of this potential. Table K1 is based on the view of the SDC and other experts of the tidal range resource available. Most of the exploitable resource is located down the west coast, though there are also some possible sites on the east coast. The largest single site is the Severn Estuary, one of the top locations in the world for tidal range, which could, if harnessed, generate 5% of UK electricity demand. The five schemes studied in detail by the Government's feasibility study are set out in Table K2.

---

333 Department of Energy and Climate Change, adapted from Sustainable Development Commission (October 2007) *Tidal Power in the UK – Research Report 1 – UK Tidal Resource Assessment;* original figure by Metoc.

334 World Energy Council (2004) *Survey of Energy Resources.*

Table K1: Potential tidal range resource outside the Severn Estuary[335]

Location	Mean tidal range (m)	Estimated installed capacity (MW)	Predicted annual energy output (TWh)
Solway Firth	5.5	7,200	10.25
Morecambe Bay	6.3	3,000	4.63
Wash	4.45	2,400	3.75
Humber	4.1	1,080	1.65
Thames	4.2	1.120	1.37
Mersey	6.45	620	1.32
Dee	5.95	840	1.16

Table K2: Tidal range schemes being considered in the Government's Severn Tidal Power Feasibility Study[336]

Scheme	Mean tidal range (m)	Estimated installed capacity (MW)	Predicted annual energy output (TWh)
Cardiff-Weston Barrage	8.3	8,640	16.80
Shoots Barrage	9.15	1,050	2.77
Beachley Barrage	9.3	625	1.67
Welsh Grounds Lagoon	8.7	1,360	2.31
Bridgewater Bay Lagoon	8.05	1,360	2.64

Established technology

The technology for tidal range is very similar to hydroelectric projects and is well understood. The most efficient form of operation is one-way generation (ebb only). The incoming tide is allowed to pass through sluices and this body of water is then held back by the barrage/lagoon as the tide ebbs. When the water level on the seaward side is low enough, the water behind the embankment is released back to the seaward side through the turbines, generating electricity. Alternatively, the impoundment can be operated in two-way mode, making use of both the flood and the ebb tide, but this requires more expensive turbines and large caissons.[337]

---

[335] Binnie and Partners Report (1989) *The UK Potential for Tidal Energy from Small Estuaries.*

[336] Department of Energy and Climate Change (2009) *Severn Tidal Power, Phase One Consultation.*

[337] A 'cassion' is a large box or chamber, usually of steel but sometimes of wood or reinforced concrete, used in barrage construction.

Extended lifetime

Tidal range schemes have an estimated lifetime of over 120 years. The scheme at La Rance has been operating for over 40 years, and on a recent routine inspection the 24 turbines showed hardly any signs of wear despite continuous use. In general, once the capital costs of such tidal range schemes have been recouped, the electricity is cheap to produce as the operation and maintenance costs are low and there are no ongoing fuel costs.

Intermittent but predictable power generation

Electricity generated from tidal range is intermittent but the generation is predictable as it follows the tides. This allows the system operator to balance the timing of the generation within the electricity transmission system, although the timing does not necessarily match peaks in demand, when electricity has the highest value. However in the future it should be possible to manage demand towards when the electricity is generated. As the electricity generated could come from a variety of sites around the UK coasts, it would be possible to have phased generation, which would help overcome issues with intermittency.

Other drivers

Tidal range schemes that cross estuaries can include road or rail transport links. Proponents believe that such creative use of the infrastructure could support economic growth and job creation in the area where a barrage is constructed. A scheme could also become a tourist attraction, and if it is built high enough the barrage could provide flood protection.

Enablers

Supply chain

There is no established installation rate for tidal range projects, given the limited number of projects in existence. There will be a need in future, especially for a large scheme, for significant quantities of materials (sand and gravel, concrete, rocks); manufacturing facilities (turbines, gates); construction yards (caissons, locks); vessels (jack-up barges, cranes, dredgers); skilled labour (marine engineers); and project managers. These requirements could cause significant constraints in the supply chain, having an impact on the costs and roll-out of any tidal range construction programme. Early planning and placing of orders will be essential.

Studies by the Severn Tidal Power Group in the 1980s and a supply chain study for the Government's Severn Tidal Power feasibility study state that an improvement in the existing international hydro turbine manufacturing facilities, including expansion of existing facilities or even a possible construction of a dedicated facility in the UK, would be required to support the delivery rate for turbines for a larger Severn Estuary scheme.[338,339] Turbines could be transported to the UK, but given capacity constraints at existing facilities and the size of the turbines (up to 9 metres in diameter), manufacturers may choose to open new facilities in the UK.

---

[338] Department of Energy (1989) *Severn Barrage Project (STPG) – Detailed Reports (Volumes I-V).*

[339] Department of Energy and Climate Change (2010 – not yet published) *Severn Tidal Power Supply Chain Report.*

Technology development

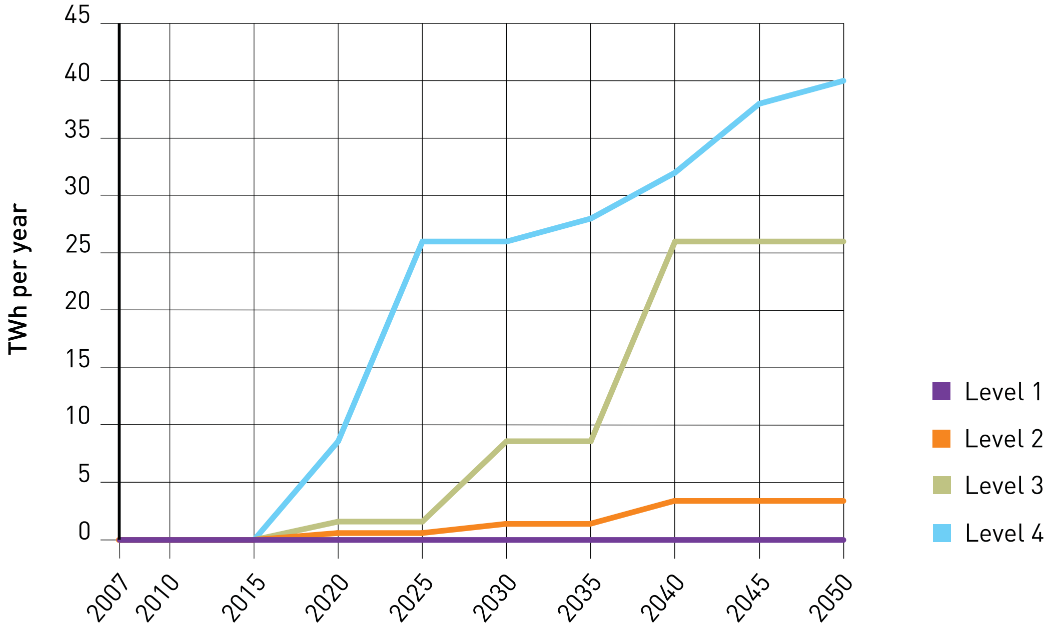
The Severn Tidal Power feasibility study gave rise to some innovative concepts being proposed, such as embryonic 'tidal fence' and 'tidal reef' designs, together with some novel designs for constructing embankments and walls. Some of these technologies, such as hybrids between tidal range and tidal stream technologies and very low head turbines, have been studied under the Severn Embryonic Technologies Scheme (SETS). New wall or embankment designs have also been looked at as part of the assessment of options in the feasibility study.

The design of turbines could be improved to make for more efficient two-way electricity generation and water pumping, and also to make them more friendly to migratory and estuarine fish. There is also a need to develop better modelling tools and methodologies to assess environmental impacts, such as sedimentation and erosion, and to improve energy yields via different operating modes.

The levels

Figure K2 below illustrates trajectories for tidal range schemes under four levels of deployment, which are described below.

Figure K2: Trajectories for electricity generation from tidal range schemes



Please note that these levels of deployment have been calculated prior to the conclusion of the Government's Severn Tidal Power feasibility study. The levels presented here are hypothetical and without prejudice to the conclusions of any of the studies underway in 2010 or of any planning and consenting decisions.

The assumptions common to all levels of deployment below are that tidal range has a load factor of 24% and an availability of 95%.[340]

---

[340] Department of Energy and Climate Change (2010–not yet published) *Severn Tidal Power: Options Definition Report*.

Level 1

This level of deployment assumes that the current situation continues, with no tidal range schemes being built in the UK.

Level 2

This level of deployment assumes that one of the three feasibility studies currently underway (Mersey, Solway, Severn) comes to fruition by 2020 with a further scheme built by 2030 and a third to follow by 2050. For example, one scenario with this level of ambition could see the construction of a scheme, on the Solway ranging between 250-300 MW; a scheme on the Mersey of around 400 MW; and one of the smaller schemes under consideration for the Severn Estuary, of between 600-1000 MW. The total capacity of 1.7 GW at 2050 is calculated to deliver 3.4 TWh of electricity per year.

Level 3

This level of deployment is high, with 13 GW of tidal range power being installed. By 2020, 800 MW is installed in line with the tidal range deployment scenario produced by Black and Veatch.[341] The total capacity of 13 GW at 2050 is calculated to deliver 26 TWh of electricity per year.

Such a high level of ambition could be met by schemes in the Solway and Mersey built by 2020; a medium Severn Estuary scheme (3.6 GW) built by 2030; and a large Severn Estuary scheme (8.6 GW) built by 2040. This would require expansion of the supply chain including caisson construction yards in the UK and expansion of worldwide turbine manufacturing and perhaps a turbine assembly plant in the UK.

Level 4

This very high level of deployment assumes that all of the UK's tidal range resource identified as being suitable is used to generate power. A potential timeline for this deployment could be schemes in the Solway, Mersey and medium and large Severn schemes built by 2025 and all practical tidal range resource (approximately 20 GW in total) developed by 2050. This would require significant expansion of the supply chain, large imports of materials and the construction of one or more turbine plants in the UK. The total capacity of 20 GW at 2050 is calculated to deliver 40 TWh of electricity per year.

---

[341] Department of Energy and Climate Change and Scottish Government (2010 – not yet published) *Cost of and financial support for wave, tidal stream and tidal range generation in the UK.*

Section L: Wave energy and tidal stream

Context

Wave and tidal stream technologies are currently emerging electricity generation technologies but they have significant potential to reach commercial deployment. As a result, the contribution that wave and tidal stream technologies can make to achieving the UK target of an 80% reduction in greenhouse gas emissions by 2050 could be significant.

Wave energy is created as winds pass over open bodies of water and transfer some of their energy to form waves, which can then be captured by wave conversion technologies to provide power. Tidal stream technologies harness the energy from the tides through the sheer velocity of the currents turning the blades of an underwater turbine (the majority of turbine designs are not dissimilar to a submerged wind turbine).

In early 2010 the Government announced a vision for the marine energy sector in the future, and set out the key steps both industry and the Government will need to take to achieve mainstream deployment of wave and tidal stream energy around the UK's coasts by 2020/2030.[342] Policies in this area will continue to be developed in collaboration with industry and other interested parties.

UK wave and tidal resource

The UK is considered to be the global leader in the development of both wave and tidal stream technologies and has a uniquely rich wave and tidal resource. Work carried out by RenewableUK and the Carbon Trust has suggested it may have the potential to meet 15-20% of the UK's current electricity demand once established.[343]

However, there are uncertainties about the wave and tidal resource because of the developing state of the industry, not least in terms of the methodologies and assumptions used to calculate the possible outputs out to 2050. This analysis seeks to improve the methodologies used in calculating tidal stream resource and indeed the assumptions used in the wave power calculations. However, the opportunities presented by this resource have led to the UK becoming a focus globally for the development and deployment of wave and tidal stream technologies.

Technology development

The UK is at the forefront of the wave and tidal stream renewable energy industry through its research and development programmes, test facilities and marine and offshore experience gained from the oil and gas industries. The UK has two dedicated operational test facilities, the National Renewable Energy Centre (NaREC) and the

---

[342] Department of Energy and Climate Change (2010) *Marine Energy Action Plan.*

[343] British Wind Energy Association (now RenewableUK) (2006) *Path to Power.*

European Marine Energy Centre (EMEC), in addition to 'WaveHub', a new demonstration facility in the South West that will be commissioned during 2010.[344]

There is a high volume of different device types currently in development, reflecting the large engineering challenges in harnessing wave and tidal power. The high financial cost of development makes it complex to determine and support the most effective emerging devices.

In recent years there has been significant progress in the marine industry with the testing of full-scale prototype devices at sea and the installation of the first grid-connected deep water wave energy device and tidal stream devices. The Crown Estate has announced the first commercial leases of the seabed and anticipates the deployment of commercial wave and tidal stream technologies to begin in the period up to 2015. At the end of April 2009 the UK had one 0.5 MW wave energy machine installed, and 1.45 MW of tidal stream capacity installed in two devices.[345] Since this time, at least one further wave device has been deployed for testing increasing the wave energy installed capacity to approximately 0.8 MW. In addition to this, several other wave and tidal stream devices are either about to begin testing or are currently being tested.

Drivers

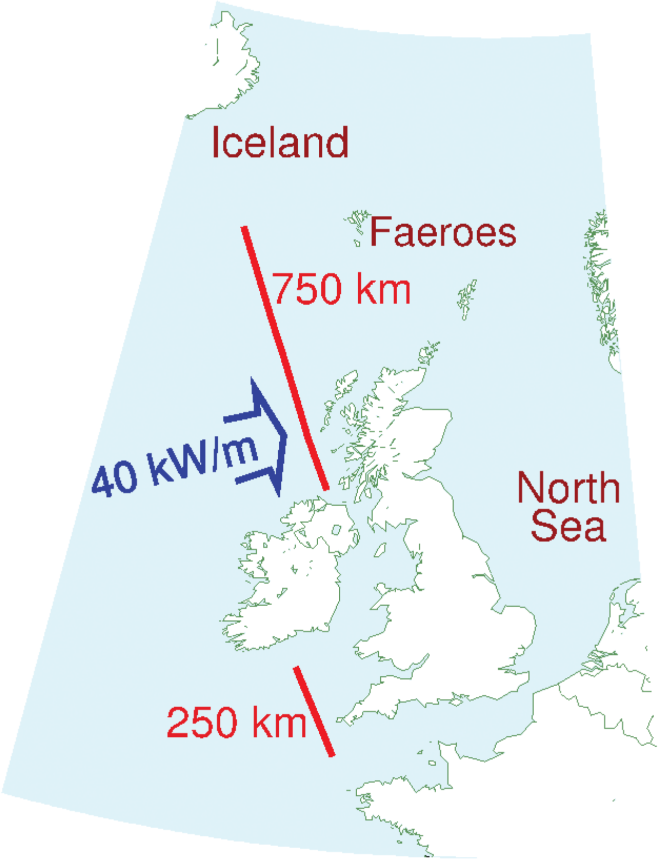
The plausible build rate for wave and tidal energy deployment can be estimated from a number of factors, including an understanding of the maximum levels of resource, the level of industry expertise and the rate at which the establishment of commercial-scale technology takes place. The build rate is also affected by the availability of the electricity grid connection and the ability of the supply chain to provide raw materials, components and manufacturing, deployment and other services. In addition to this, the opportunities for repowering and redeployment would also need to be considered within the build rate.

---

[344] Carbon Trust (2009) *Focus on Success.*

[345] British Wind Energy Association (2009) *State of the Marine Industry in the UK.*

Figure L1: Schematic showing 1000km of potential UK wave farm locations. 900km of wave farms would be required under level 4[346]



Resource

Wave

Due to the immature nature of the wave industry it is difficult to make resource predictions far into the future with any accuracy. However, there is a general consensus that the net on-coming wave power is 40 MW/km. This is illustrated in Figure L1.

Estimates indicate that the practical resource level for wave energy in the UK waters is in the order of 50 TWh/year, but estimates of the technical potential extend up to 157 TWh/year.[347,348]

There are two important assumptions relating to the feasible length of a wave farm and the extent to which devices can extract power from the on-coming waves. Technically, there is approximately 1000km of wave front in the UK Atlantic waters that can provide a wave energy resource (as shown in Figure L1). However a significant portion of this is a large distance offshore which may make it prohibitively expensive or impractical to develop.

The efficiency of a wave power device is highly dependent on the frequency of the oncoming waves, and this is important to consider when estimating the available resource. Long time period, low frequency waves are harder to extract energy from.

---

346 Mackay, David JC (2009) *Sustainable Energy – without the hot air.*
347 Carbon Trust (2006) *Future Marine Energy.*
348 LEK-Carbon Trust (2008) *Low Carbon Technology Commercialisation Review.*

In this report, the fraction of on-coming wave power which is captured is estimated to be between 20% and 25%, which is considered optimistic.[349]

Geographically, the largest wave resource is located off the west coast of Scotland and south west England/Wales, where the fetch (the distance travelled by waves without an obstruction) is across the Atlantic.

Tidal stream

The development of devices to capture the energy from tidal streams is still a very immature industry and again estimates of resource remain highly uncertain. It has been widely quoted that the total UK tidal stream potential is of the order of 17 TWh/year.[350] This is derived from a method that provides the most conservative estimate.[351] The tidal stream resource is largest off the north eastern coast of Scotland (the Pentland Firth), Strangford Lough in Northern Ireland, The Skerries off the coast of Anglesey, Wales, and the Channel Islands, where constrictions of tidal channels funnel water creating increases in flow velocity.

However, academic research has highlighted uncertainties surrounding the calculation of practical resource and other methods of estimating the tidal stream resource have resulted in higher technical potentials of up to 197 TWh/year.[352,353] A number of different methods have so far been used to determine the theoretical resource, as outlined below. The kinetic flux method has historically been the preferred method, although recent papers have questioned its applicability in all but very specific situations.

- The kinetic energy flux method, as used by the widely-referenced Black and Veatch study, calculates the kinetic energy in the water moving through a perpendicular plane within a channel.[354]
- The bottom friction model considers the amount of tidal energy being dissipated by friction on the sea bed since some of this energy could also potentially be captured by the devices. This technique was originally used by Taylor and subsequently by Salter.[355,356] The method suggests that the available resource could be an order of magnitude larger than that of the kinetic energy flux method.[357]
- MacKay conducts an analysis of the energy contained in the tide modelled as a wave assuming there is no bottom friction.[358] This method also suggests that the tidal resource is larger than that of the kinetic energy flux method by an order of magnitude.

In addition to this, Houlsby et al performed analysis suggesting that the theory that there is a maximum limit to the possible energy obtainable from devices has been

---

[349] Mollison (1986) *Wave climate and the wave power resource.*

[350] Sinclair Knight Merz (2008) *Quantification of Constraints on the Growth of UK Renewable Generating Capacity.*

[351] Blunden, L S and Bahaj, AS (2006) *Tidal energy resource assessment for tidal stream generators.*

[352] Houlsby, GT, Oldfield, MLG and Draper, S (2008) *The Betz Limit and Tidal Turbines.*

[353] MacKay, David JC (2009) *Sustainable Energy – Without the hot air.*

[354] Black and Veatch Consulting, Carbon Trust (2004) *UK, Europe and global tidal stream energy resource assessment.*

[355] Taylor, GI (1918) *Tidal Friction in the Irish Sea.*

[356] Salter, SH and Taylor, JRMT (2007) *Vertical-Axis Tidal-Current Generators and the Pentland Firth.*

[357] Taylor, GI (1918) *Tidal Friction in the Irish Sea.*

[358] MacKay, David JC (2009) *Sustainable Energy – Without the hot air.*

inappropriately applied to turbines in tidal flows.[359] Their calculations show that the actual resource could be 1.5–4 times greater when tidal turbines block a large fraction of the tidal channel.

Industry and academics across a range of disciplines, including oceanography, turbulence, marine energy and physics, need to collaborate to come to a consensus on the appropriate methods for estimating resource and the subsequent predictions that result.

A second area of uncertainty relates to the impact of energy extraction on the remaining resource, for example the extent to which resource is available within a formation of devices or a tidal stream farm. There is limited practical experience from which to draw any clear conclusion and until further arrays and tidal stream farms are constructed there will remain considerable uncertainty regarding the degree to which the deployment of an array of tidal stream devices alters the available resource. Furthermore these considerations are likely to be highly site specific.

As indicated there are a number of uncertainties but the potential resource they suggest is sufficiently large to justify further research. The tidal stream industry currently has a slight advantage over the wave industry in that devices are not only beginning to be deployed but they are also seeing some consensus in their design. Data and experience from all the installations will help to improve future resource estimations.

Finally, the full extent of both wave and tidal stream resource which can be exploited for generation is also dependent on many other assumptions including device capacity, interactions between devices, their spacing and formation in wave and tidal stream farms, cumulative impact and the other constraints on deployment such as shipping, defence and environmental considerations. Overall, the more wave and tidal stream devices that get deployed, the greater our level of understanding and exploitation of the available resource will be.

Expertise

The UK has a unique opportunity to capture the benefits of this new sector through the entire supply chain, from research and development through to engineering, manufacturing, installation and maintenance. Many of the leading device developers are located in the UK and they enjoy a comparative advantage due to their extensive domestic knowledge and experience. The UK has engineering and manufacturing expertise in the complex systems required for power conversion, which are high value and can be exported globally. The UK also has the historical advantage of manufacturing success in industries relevant to the wave industry, including oil, gas and shipping. In discussions with the marine industry, it has been commented that the UK's offshore experience in the North Sea has developed strong UK skills and expertise which could prove valuable for the emerging wave and tidal stream sectors.

Supporting the most effective devices

Currently a large number of devices for wave and tidal stream are in development, and determining and supporting the most effective devices has been found to be difficult. In the wave industry there are varying designs due to different deployment locations

---

[359] Houlsby, GT, Oldfield, MLG and Draper, S (2008) *The Betz Limit and Tidal Turbines.*

(onshore, nearshore and offshore) and fundamentally different approaches to extracting energy from waves, while tidal stream devices are showing more convergence towards a submerged horizontal axis turbine. The wish to establish a 'lead' technology approach from the plethora of devices forms a strong driver for those inside the wave and tidal stream industry and those looking to invest in this 'lead' technology.

Grid availability

As with other renewable energy technologies, the timely construction of grid connections is seen as essential by the sector (this is referred to in greater detail in Section P: Electricity balancing).

Lifetime and planning

Due to the harsh conditions in which the wave and tidal stream technologies operate, the overall plant life is assumed in this assessment to be 20 years.[360] The supply chain required to decommission and replace the plant is likely to develop further, however at this stage of assessment the impact of the replacement activities is unclear. The design of future wave and tidal stream technologies may extend plant life or components of the technology and reduce the rate at which they need to be replaced.

Enablers

In order for wave and tidal stream technologies to become commercially viable and to contribute to achieving the 2050 target the sector will require improvements to enable the technology to move forward. These are outlined below.

Innovation and cost reduction

The development of wave and tidal stream devices to commercial viability requires cost reduction and further step changes in technology development to reduce the cost of energy thereafter. Cost reductions may be found through:

- fundamental change in the engineering design of devices;
- more efficient use of materials;
- new and innovative ways of conducting installation, operation and maintenance; and
- increased efficiency of components.

Financing

The development of wave and tidal stream devices is currently expensive. Many developers are small to medium sized companies formed with the sole purpose of developing a specific device. Not only are these developers faced with trying to secure funding for the development of the device but also the funds to support the day-to-day operations of the company. This sector requires a mixture of both public and private funding to enable commercial viability of the technologies, and funding will need to be applied in different forms, including grant funding, equity investment and market

---

[360] Redpoint / Trilemma (2009) *Implementation of the EU 2020 renewables target in the UK electricity sector: RO Reform.*

incentives. The opening up of private finance into wave and tidal stream development is necessary for the continued development of the sector.

Regulatory framework

To ensure continued progression in this sector, the regulatory frameworks for leasing, planning and consenting need to be aligned to allow for commercial deployment of wave and tidal stream devices.

A Strategic Environmental Assessment (SEA) report for the development of wave and tidal stream energy around the Scottish Coastline was completed in 2007.[361] As a result The Crown Estate carried out a competitive application process for commercial seabed lease options for marine energy devices in the Pentland Firth, off north eastern Scotland. In March 2010 the Government also commissioned a full SEA for wave and tidal technologies in English and Welsh waters. The Crown Estate will look at opportunities for commercial leasing opportunities in England and Wales. The Crown Estate is initiating a programme of activities relating to commercial offshore renewable energy leasing in Northern Ireland and Scotland following the completion of relevant SEAs in these countries.

The Marine and Coastal Access Bill received Royal Assent in November 2009 and saw the creation of a strategic marine planning system.[362] This has led to changes in the marine licensing system which should result in more consistent licensing decisions and, through the Marine Management Organisation which will make decisions on offshore energy installations of less than 100 MW generating capacity, will enable the sector to kick start deployment.

However, to enable the longer term development of the sector, projects of more than 100 MW generating capacity will fall to the regime for nationally significant infrastructure projects established by the 2008 Planning Act. Although the Government intends to return decision making under this regime to Ministers, it will retain the streamlined consenting process for these projects. This would enable the sector to work towards achieving the scalability potential of the technologies when they are ready in the future.

Supply chain

The development of wave and tidal stream technologies will lead not only to a substantial generation industry in the UK, but more importantly to a substantial supply chain, a large part of which will be based in the UK provided the UK's technological lead is maintained and there is an attractive environment for domestic or inward investment in manufacturing facilities. In the longer term the potential for jobs arising from the wave industry is expected to continue to increase, peaking at 16,000 in the 2040s of whom about 25% will support UK exports.[363] Similar numbers are also expected to arise from the tidal stream industry.

---

[361] Scottish Executive (2007) *Scottish Marine Renewables Strategic Environmental Assessment Report.*

[362] UK Parliament (2009) *Marine and Coastal Access Bill.*

[363] Carbon Trust (2009) *Focus on Success.*

International competition

The UK is the current lead in wave and tidal stream technology development, due to the level of resource, its highly skilled expertise and the world-class testing facilities that are available. As a result the UK could become the 'natural owner' of this technology and continue to lead the commercialisation process for the rest of the world. Many of the leading devices are British innovations being developed by companies located in the UK. Therefore the level of domestic knowledge and experience places the UK in a strong position to design and develop these technologies.

The levels

Figures L2 and L3 below illustrates the trajectories for wave and tidal stream power under four levels of deployment, which are described below.

Figure L2: Trajectories for electricity generation from wave power

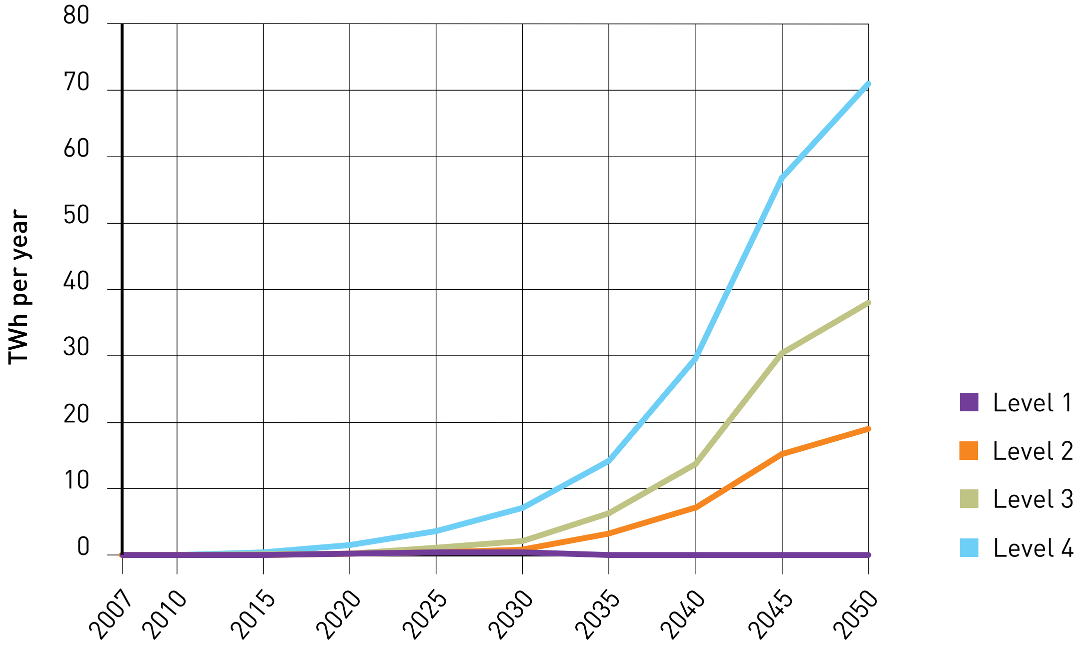
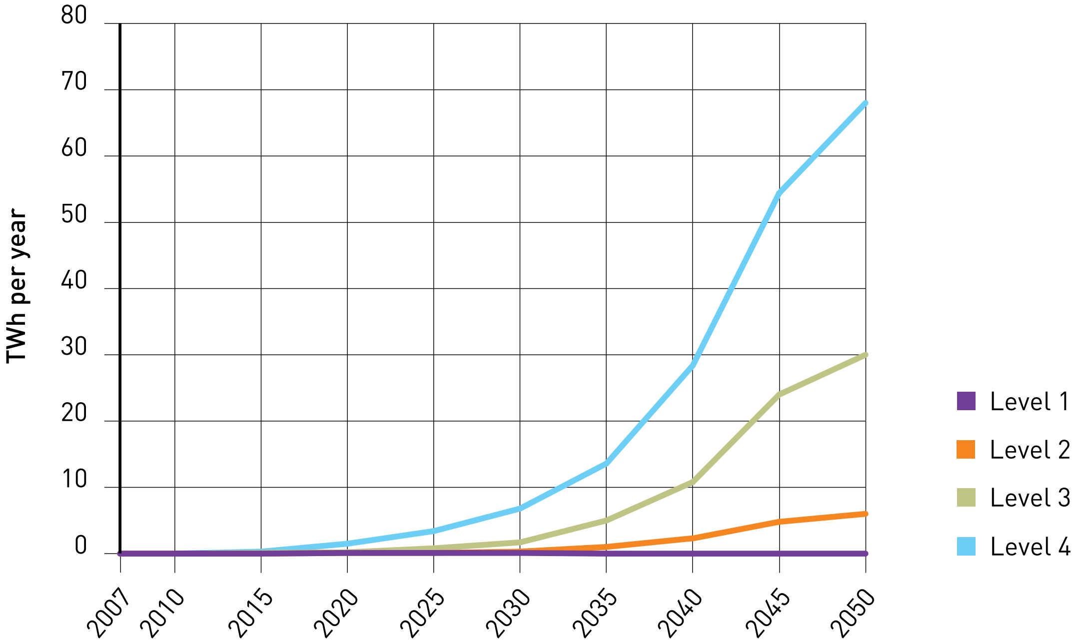


Figure L3: Trajectories for electricity generation from tidal stream power



The common assumptions for wave deployment include that, when calculating the installed wave capacity from annual energy yield, we always assume a load factor of 25% and allow for a device availability of 90%.

Tidal stream estimates have been based on the three deployment scenarios in a report recently published by the Offshore Valuation Group but also allowing for a device availability of 90%.[364] These estimates fall in between the highest and lowest published resource estimations.[365] The load factor in this calculator is always assumed to be 40%, which is consistent with the report.

Level 1

This level of deployment assumes that for both wave and tidal stream technologies there will be a very gradual increase in the number of projects being deployed out to 2040 based on current levels of financial support, and no further developments or increases in the level of financial support available to the sector. Deployment after 2040 is affected by the termination of the current Renewables Obligation policy in 2037, and without this level of support it assumes a fall-out of deployment to 2050 for both technologies.[366] Overall, the potential of the sector is not achieved.

Level 2

Level 2 assumes that for both wave and tidal stream technologies there will also be slow growth initially. However, an increase in learning rates during the early 2020s speeds up growth of the sector, particularly for wave energy. This level benefits from sufficient increases in the level of financial support for both wave and tidal stream, which leads to investor confidence in the sector. The supply chain at this level is more active in its cost reductions through the standardisation of components and volume of

---

[364] The Offshore Valuation Group (2010) *Valuing the UK Offshore Renewable Energy Resource.*
[365] Ibid.
[366] UK Parliament (2010) *The Renewables Obligation (Amendment) Order 2010.*

production. Grid connections have also been enabled and development of an enhanced distribution network has occurred.

The wave deployment assumptions are 300km of wave farms in the Atlantic delivering 8 MW per km (20% of raw power) with a device availability of 90%. The tidal stream deployment assumptions are 2 GW of installed capacity (1000 2 MW machines) with a load factor of 40% operating with 90% availability. The total capacity of 11.5 GW at 2050 is calculated to deliver 25 TWh of electricity per year.

Level 3

This highly ambitious level of deployment for both wave and tidal stream shows significant acceleration in proving and commercialising the technologies between 2015 and 2020. It has been assumed that there are much greater increases in the level of financial support for the sector from both Government and private investment, leading to the accelerated development of technologies and more rapid deployment. The supply chain is assumed to be very active, promoting cost reductions and drawing on expertise that has already been gained during the expansion of offshore wind, including in manufacturing, ports and deployment vessels. It is also assumed that for both wave and tidal stream, grid connections will be developed and that significant upgrades to the distribution network are carried out in more remote sites where the resource is high.

The wave deployment assumptions are 600km of wave farms in the Atlantic delivering 8 MW per km (20% of raw power) with a device availability of 90%. The tidal stream deployment assumptions are 9.4 GW of installed capacity (4700 2 MW machines) with a load factor of 40% operating with 90% availability. The total capacity of 29 GW at 2050 is calculated to deliver 68 TWh of electricity per year.

Level 4

This extremely ambitious level of deployment for wave and tidal stream shows an exceptional speed of development and deployment of technology. Although there is very little demonstrable capacity in 2010, by 2020 there is 0.8 GW and 0.5 GW capacity for wave and tidal stream technologies respectively, which equates to many hundreds of devices. This is a challenging timeline but it assumes much greater increases in the level of financial support for the sector to drive innovation in order for significant step changes to occur as soon as possible. This funding is assumed to be both through significantly increased government support mechanisms and through larger private investment in technology development and project finance. In this level, the supply chain is engaged and proactive in continually realising potential cost reductions, succeeding in driving down cost through step changes.

For both technologies, it is likely that there will be some element of repowering (the reinstallation and replacement of devices at utilised sites) that will increase the output per km of wave front intercepted and the output per area of sea occupied by tidal turbines. In this level, no grid constraints will be present and all development of the onshore grid distribution network would have occurred to enable the resource of wave and tidal stream to be harnessed.

The wave deployment assumptions are 900km of wave farms in the Atlantic delivering 10 MW per km (25% of raw power) with a device availability of 90%. An alternative level 4 would be to assume 750km of wave farm extracting 30% of the raw power (a greater technology improvement) with a device availability of 90%. The tidal stream deployment assumptions are 21.3 GW of installed capacity (10,600 2 MW machines) with a load factor of 40% operating with 90% availability. The total capacity of 58 GW at 2050 is calculated to deliver 139 TWh of electricity per year.

Section M: Microgeneration of electricity

Context

Microgeneration of electricity is currently a costly mitigation measure relative to others, although relative cost-effectiveness could significantly change between now and 2050. And small scale wind in particular can only make a very small contribution towards overall national targets for renewable energy. However, small scale generation can empower individuals by enabling them to contribute towards a common goal, or even to benefit personally or within a community. It is also an important tool in engaging the public and can often be used as a lever for behavioural change. Anecdotal examples of consumers reducing their overall energy use in response to generating their own energy are often quoted. Microgeneration is also considered by many to be crucial in order to garner public acceptance and support for the level of change needed to deliver the overall targets.

In April 2010 a system of feed-in-tariffs to incentivise small scale, low carbon electricity generation was introducted using powers in the Energy Act 2008. The 'clean energy cashback' will allow many people to invest in small scale, low carbon electricity, in return for a guaranteed payment for the electricity they generate. Small scale wind and solar PV generation up to 5 MW are eligible for the feed-in-tariff.

This section considers the potential supply from (1) small scale wind and (2) solar photovoltaic (PV).

Small scale wind

So far, there has been minimal deployment of small scale wind in the UK. However the UK has a growing domestic small scale wind industry. In a recent report by the Carbon Trust, the total resource for small scale wind energy was estimated to be 41.3 TWh/year of electricity. However, for many reasons it was considered practical to achieve only a small proportion of these figures.[367] In the recent Encraft Warwick Wind Trials Project Report, the industry and technology was described as still at the development stage and that it was likely to make a tangible contribution to energy and carbon saving but only on the most exposed sites and tallest buildings.[368]

Drivers and enablers

The energy generated by small scale wind farms will depend upon the number of suitable sites; the take-up and installation rates; and the size, efficiency and load factor of the wind turbines.

---

[367] Carbon Trust (2008) *Small-scale wind energy – Policy insights and practical guidance*.
[368] Encraft (2009) *Warwick Wind Trials Project, Final Report*.

Number of installation sites

A practical approach to assessing the resource for small scale wind was conducted by the Energy Saving Trust, which found that there is potential to generate 3.5 TWh/year of electricity from domestic small scale wind turbines in the UK.[369] The greatest potential for successful small scale domestic wind installations was in Scotland, and the best performing free standing sites in the field trials were always remote rural locations, usually individual dwellings near the coast or on exposed land such as moors. The Energy Saving Trust assumed in its analysis that installations should only be installed at locations where the average wind speed is greater than 5m/s.

Take up and installation rates

The Energy Saving Trust's scenario assumed a 50% uptake for agricultural farms; 30% uptake for pole mounted sites for buildings with significant land; and 10% for building mounted sites. The trajectories outlined below also look at higher and lower uptake rates. These would depend on a range of factors including the costs of the wind turbines in comparison to other energy sources, supply chain constraints, public attitudes and government policy.

Size, efficiency and load factor

The Energy Saving Trust reported average load factors for pole mounted installations to be 19%, with some sites in Scotland achieving in excess of 30%. The analysis also assumed that one 6kW wind turbine was installed at each suitable site and achieved an average load factor of 24%. However, higher generation rates could be achieved by installing more than one turbine at each site, or using larger 15kW turbines.

In the case of farms, the most likely limitation on higher uptake levels is the size of the grid connection. Upgrades to the grid infrastructure are likely to be expensive. Maximum installation sizes without grid upgrades are likely to be between 25-150kW depending upon the size of the farm and the size of the grid connection to the farm.

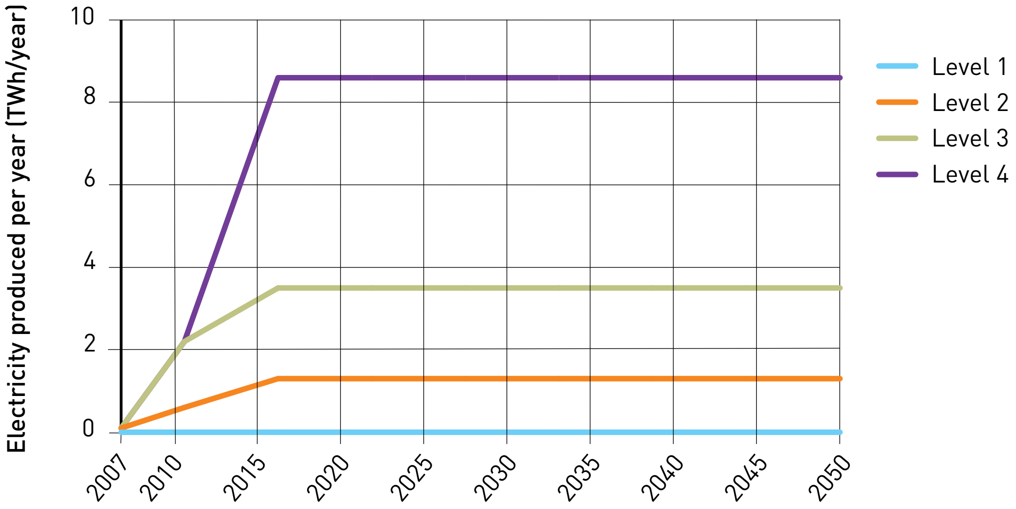
The trajectories

Figure M1 below illustrates four trajectories for small scale wind schemes, which are described below.

---

[369] Energy Saving Trust (2009) *Location, location, location. Domestic small-scale wind field trial report*.

Figure M1: Trajectories for electricity generation from small scale wind



Level 1

This level of ambition is based upon the pessimistic assumption that significant numbers of micro-wind turbines are not installed in the UK.

Level 2

This level of ambition is based upon the estimate for the realistic uptake of domestic small scale wind turbines in the report by the Energy Saving Trust.[370] This was based upon field trial results and assessed the potential number of domestic small scale wind turbine (400W to 6kW) installations at domestic sites with a suitable wind speed of at least 5m/s. The analysis indicated that there are likely to be approximately 450,000 domestic properties in the UK that would have a suitable wind resource, adequate land area and/or building profiles. The analysis assumes that a 50% uptake for agricultural farms, 30% uptake for pole mounted sites and 10% for building mounted sites would deliver 1.34 TWh/year. In order to construct a suitable build rate, a maximum annual growth rate of 25% per annum is assumed, with a one-off jump in installations to 25 MW a year. For example, 25 MW of installed capacity would be almost 4,500 6kW installations. By 2015 the rate of installations would have reached over 12,000 and by 2020 the roll-out of small scale wind turbines would peak at about 40,000 a year, reaching saturation shortly after that. Maintenance and replacement would mean an ongoing role for the small scale wind industry for this level and higher ones.

Level 3

The ambition for this level is based upon the Energy Saving Trust's estimate of the number of suitable domestic properties[371] but assumes a 100% uptake. Gross annual generation from these turbines (maximum size 6kW) would be approximately 3.5 TWh/year. In order to construct a suitable build rate on an ambitious scale, a maximum annual growth rate of 50% per annum is assumed, with a one-off jump in installations

---

[370] Ibid.

[371] Ibid.

to 50 MW a year.[372] For example, 50 MW of installed capacity would be almost 9,000 6kW installations. By 2015 the rate of installations would have reached over 60,000, reaching a peak shortly after and by 2020 the roll-out of small scale wind turbines would effectively be complete.

Level 4

This level is based upon the maximum feasible resource and would require significant investment in infrastructure and the roll-out of small scale wind turbines on non-domestic sites as well, rather than limiting installations to domestic sites as in the previous levels. This level of ambition is based on the Element Energy / Poyry estimates for the total UK potential for sub-5 MW wind turbines.[373]. The report estimates that the total resource for sub-5 MW turbines is over 17 TWh/year, although 8.4 TWh/year of this was for turbines larger than 500kW which would be accounted for elsewhere within the onshore wind section. Therefore the maximum resource for small scale wind in level 4 is assumed to be 8.6 TWh/year. This is also commensurate with the Energy Saving Trust report which was based upon the assumption that a single turbine of maximum 6kW would be installed at each site. A significant number of sites from the Energy Saving Trust report are farms or dwellings with large land areas where it would be feasible to install more than one turbine, and so installing larger 15kW turbines or increasing the number of turbines per site would achieve a similar upper estimate.

In order to construct a suitable build rate, the ambitious maximum annual growth rate of 50% per annum is assumed with a one-off jump in installations to 50 MW a year. Growth would therefore be identical to level 3, but installation rates would continue to grow and peak around 2020 with installation rates of around 200,000, when the roll-out of small scale wind turbines would effectively be complete.

Solar PV

So far, there has been little deployment of solar PV (photovoltaic) in the UK (see Table M1). However, the installation rates presented here have been demonstrated in a number of other countries around the world (see Table M2).

---

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

[373] Ibid.

Table M1: The status of solar PV in the UK[374]

Year	Installed capacity (Megawatt peak [MWp])	Annual growth rate	Installation rate (MWp)
2004	8.2	–	–
2005	10.9	33%	2.7
2006	14.3	31%	3.4
2007	18.1	26%	3.8
2008	22.5	24%	4.4

Table M2: The status of solar PV in the world[375]

Year	Installed capacity (MWp)	Annual growth rate	Installation rate (MWp)
2004	3,847	38%	1,052
2005	5,167	34%	1,320
2006	6,770	31%	1,603
2007	9,162	35%	2,392
2008	14,730	61%	5,568

The solar PV industry's plans to develop photovoltaic energy in the UK over the next decade are ambitious. The UK photovoltaic manufacturers association (UK-PV) consider that solar PV could contribute more than 21 TWh/year of electricity by 2020, which would represent about 26 GWp (Gigawatt Peak) of installed capacity.[376] For comparison this would be equal to roughly 8.7 million domestic 3kWp (roughly 15-20 m^2) installations by 2020. Build rates would have to be very ambitious in order to achieve this, and average growth in installed capacity would have to exceed 75% per year between 2010 and 2020.

To put this in context with wider industry expectations, the European Photovoltaic Industry Association has similarly ambitious targets and believes that solar PV could generate 12% of electricity in Europe by 2020.[377] This is based upon upper estimates of industry growth rates and would require approximately 340 GWp of installed capacity in Europe. The UK, with 26 GW, would represent a 7.6% market share.

Delivering this amount of solar PV in just under a decade would be an immense challenge and represents the upper estimate of the PV industries' projections for growth. It would require relatively large solar PV installations to be installed on roughly 25% of the country's domestic building stock. This would be an unprecedented challenge and require major effort at all levels of society.

---

374 DUKES 2009

375 European Photovoltaic Industry Association (2009) *Solar Photovoltaic Electricity: A mainstream power source in Europe by* 2020.

376 UK Photovoltaic Manufacturers Association (2009) *Feed-in-Tariff Consulation Response.*

377 European Photovoltaic Industry Association (2009) *Solar Photovoltaic Electricity: A mainstream power source in Europe by* 2020.

Drivers and enablers

The energy generated by solar PV will depend upon the number of suitable sites; the take-up and installation rates; and the size, efficiency and load factor of the solar panels.

Number of installation sites

In theory it would be possible to generate all of the UK's electricity from solar PV. If 5% of the UK's surface area (5,800km^2) was covered in solar PV with an average load factor of 9.7%, almost 1,150 TWh/year of electricity could be generated.

However, this would require over 1,350 GWp to be installed by 2050, equivalent to about 100m^2 per person. Additional problems would also be encountered around the time of day and year that the electricity would be generated, with obvious supply problems at night time and during winter months. The amount of energy storage capacity required to smooth supply in order to meet demand would also be considerable.

Practical estimates exist such as those produced by UK-PV who have calculated that there is a total of 4,000km^2 of available roof space and facades on UK buildings and that the resource potential for south facing roofs and facades is about 140 TWh/year.[378]

Take up and installation rates

The plausible installation rate for solar PV can be estimated by comparing the UK with worldwide build rates, in particular in countries such as Japan, Germany, the US and Spain, which account for much of the installation. In 2007, the UK had a market share of 0.16%. Clearly it could multiply its installation rates dramatically for a number of years without imposing a noticeable burden upon the supply chain. Spain did this in 2007, starting from a low base and increasing its capacity by 480% in one year.[379]

The UK Energy Research Centre (UKERC) in 2007 estimated that the UK could realistically achieve 16 GWp of installed capacity by 2030, assuming that 75% of installations in 2030 would be domestic (implying four million domestic installations) with the balance installed on public and commercial buildings.[380]

The energy used in manufacture is normally paid back within 1-4 years, warranties are normally given for 25 years, and life expectancy is normally assumed to be 30 years or more.[381]

Size, efficiency and load factor

The UKERC report assumed that future domestic solar PV systems will average around 3kWp in capacity and roughly 15-20m^2 in size, which will fit on most roofs.[382]

---

[378] UK-PV (2009) *2020 A vision for UK PV.*

[379] Stafford, Anne and Irvine, Stuart (2009) *UK Photovoltaic Solar Energy Road Map*. OpTIC Technium/ Glyndwr University,

[380] Infield, David (2007) *A Road Map for Photovoltaics Research in the UK.* UK Energy Research Centre.

[381] US National Renewable Energy Laboratory (January 2004) PV FAQs: What is the energy payback for PV?

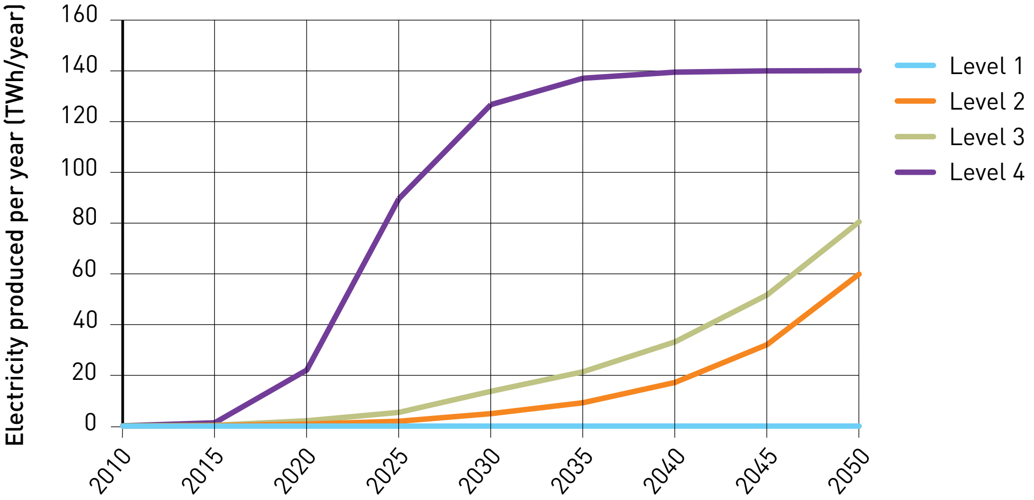
[382] Infield, David (2007) *A Road Map for Photovoltaics Research in the UK.* UK Energy Research Centre.

An average load factor of 9.7% (850kWh/kWp per year) is typically assumed for well orientated (ie, south facing and free of obstructions) UK solar PV installations.[383] The average load factor is a function of solar panel efficiency and the average incident solar radiation of the UK which is also a function of UK weather conditions.

The trajectories

Figure M2 illustrates four trajectories for small scale solar PV, which are described below.

Figure M2: Trajectories for electricity generation from small scale solar PV



Level 1

This level of ambition is based upon the pessimistic assumption that significant installations of solar PV in the UK do not occur and existing installations are not maintained.

Level 2

This level assumes that by 2050 there would be the equivalent of 4m^2 of photovoltaic panels per person in the UK. In the report by POYRY and Element Energy on the design of feed-in tariffs, the technical potential for solar PV was estimated to be 60 TWh/year,[384] which would require roughly 70 GWp of installed capacity by 2050.

This is a level of ambition greater than existing trends would predict: an increase in average growth in installed capacity (to match that seen worldwide in the last five years) to 34% per year is projected out to 2020. This would result in an installed capacity of almost 0.9 GWp by 2020. Beyond 2020, increases in average growth in installed capacity are assumed to be about 20% between 2020 and 2030 and about 13% beyond 2030, delivering 70 GWp of installed capacity by 2050.

---

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

[384] Ibid.

Level 3

This level assumes that by 2050 there would be the equivalent of 5.4m^2 of solar PV per person, generating roughly 80 TWh/year of electricity. This level of ambition is based upon a report written by the UK Energy Research Centre (UKERC) in 2007, which estimates that the UK could realistically achieve 16 GWp of installed capacity by 2030.[385] The report also assumes that future domestic solar PV systems will average around 3 kWp in capacity and roughly 15-20m^2 in size, which will fit on most roofs. It assumes that 75% of installations in 2030 will be domestic, implying four million domestic installations, and the balance will be installed on public and commercial buildings. A total of 16 GWp of installed capacity would generate roughly 13.6 TWh/year of electricity by 2030. In order to achieve a realistic projection of growth commensurate with a significant effort, a 'catch-up' average growth in installed capacity of 45% is assumed for ten years up to 2020 delivering 2.5 GWp of installed capacity, followed by an average growth in installed capacity of 20% between 2020 and 2030.

By 2050 UKERC estimates that there could be 20 million domestic installations delivering 60 GWp of installed capacity. If it is assumed that non-domestic buildings have a similar coverage in terms of surface area, then they could contribute an additional 35 GWp of installed capacity. A total of 95 GWp of installed capacity would generate about 80 TWh/year of electricity and be equivalent to roughly 5.4m^2 per person.

Level 4

The amount of installed solar PV capacity in level 4 needs to be even more ambitious than level 3, yet still physically possible. Typical approaches for such calculations normally assume that south facing roofs present the most logical sites for installations, and use this assumption to calculate the potential for solar PV in the UK. This is not strictly true, as ground based installations are likely to be suitable in many locations. UK-PV has estimated that there is a total of 4,000km^2 of available roof space and facades on UK buildings.[386] It calculates that the resource potential for this total area is 460 TWh/year or 140 TWh/year for south facing roofs and facades. This latter figure is roughly in line with estimates by Mackay of 111 TWh/year,[387] and the IEA of 105 TWh/year, both based upon south facing roofs only.[388]

The ambition of level 4 is based upon 140 TWh/year in 2050, which would come from a mixture of optimally sited roofs and facades and ground-based installations and would be equivalent to roughly 9.5m^2 per person.

A build rate of 75% per year is used for this level to achieve the UK-PV target of 26 GWp by 2020. Beyond 2020 a reduction in the average annual growth in installed capacity of roughly 26% each year is assumed. This would represent a peak installation rate of 17.6 GWp in 2023, with saturation of all optimum sites between 2030 and 2040. This peak installation rate is highly challenging but plausible considering the European Photovoltaic Industry Association projection that the PV supply chain is expected to

---

[385] Infield, David (2007) *A Road Map for Photovoltaics Research in the UK*. UK Energy Research Centre.
[386] UK-PV (2009) *2020 A vision for UK PV*.
[387] MacKay, David JC (2009) *Sustainable Energy – Without the hot air*, UIT, Cambridge.
[388] IEA (2002) *PVPS Annual Report*.

deliver and sustain production to support a market between 80 GW and 160 GW worldwide.[389]

The replacement rate necessary for normal wear and tear has been assumed to be relatively low compared to overall installation rates.[390] Adequate levels of maintenance are implicitly assumed as it is necessary to keep panels clean and free of debris in order to maximize efficiency.

---

[389] European Photovoltaic Industry Association (2009) *Solar Photovoltaic Electricity: A mainstream power source in Europe by 2020.*

[390] Stafford, Anne and Irvine, Stuart (2009) *UK Photovoltaic Solar Energy Road Map*. OpTIC Technium/ Glyndwr University.

Section N: Geothermal electricity generation

Context

Rocks buried deep underground can hold a considerable amount of heat. The deeper they are, the more heat they tend to store. Moreover, specific geological features such as granite generate considerable amounts of heat due to natural radioactive decay. Through the use of geothermal technologies, this heat deep in the earth can be mined and used to generate electricity. The emissions from this form of electricity generation will be close to zero.

In the UK, Cornwall is considered to be the region with the most potential for developing geothermal power plants. There is a wealth of information available about the geology of Cornwall, and geothermal resources specifically, as a result of mining operations going back to Roman times; and the work done at the UK Engineered Geothermal Systems project at Rosemanowes in the 1980s. Cornwall has an underlying basement of granite, and estimates from the project at the time were that this resource could potentially supply the UK with 3% of today's electricity consumption, for the next 50 to 200 years.

There are other granite basements in the north of England and in North East Scotland, which could also supply geothermal energy for electricity generation. It is estimated that in the UK as a whole, there is the geothermal resource to produce the equivalent of up to 35 TWh of electricity per year for around 50 years down to a depth of 6km[391] (approximately 5 GW with an average load factor of 80%).

Via the Deep Geothermal Challenge Fund, DECC has awarded grants to help explore the potential for deep geothermal power in the UK, assisting companies to carry out exploratory work necessary to identify viable sites.

Drivers and enablers

Technological advances

To date, the UK has not fully harnessed its geothermal potential, largely due to the depth of drilling required to reach a suitable temperature. However, in recent years interest in geothermal electricity generation in the UK has been triggered by the development of technologies which can harness heat from dry rocks buried at depths of around 3–5km (often called 'Enhanced Geothermal Systems' or EGS). High-pressure water is pumped through a specially drilled well into these rocks, causing them to fracture. The water permeates through these artificial fractures, extracting heat from the surrounding rock, which acts as a natural reservoir. This 'reservoir' is later penetrated by a second well, which is used to extract the heated water.

---

[391] MacDonald P, Steadman A and Symons G (1992) The UK Geothermal Hot Dry Rock R&D Programme, Energy Technology Support Unit, Harwell. Reported in PROCEEDINGS, Seventeenth Workshop on Geothermal Reservoir Engineering (January 29-31, 1992) Stanford University, Stanford, California, SGP-TR-141.

Much of the technology that has been developed has its roots in the Rosemanowes project. This trial in the 1980s was a success but the technology to drill the necessary depths was not commercially viable at the time. However, subsequent developments in drilling technology and the introduction of carbon pricing policy instruments have renewed interest in the results of the Rosemanowes projects and in geothermal electricity generation in the UK as a whole.

Demonstration projects

There are currently two demonstration projects being planned in the UK, partly supported by the Department of Energy and Climate Change under the 'Challenge Fund for Deep Geothermal Energy'.

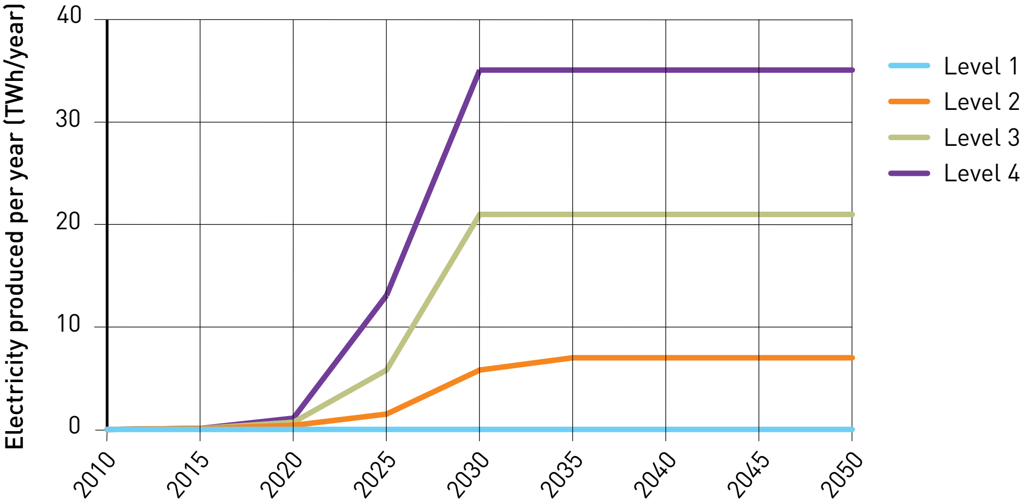
EGS Energy in partnership with the Eden project is developing a 3 MWe plant which is expected to come on stream in late 2012. The waste heat will also be used by the Eden Project to heat greenhouses in a combined heat and power operation. It is anticipated that the demonstration plant could be scaled up so that it eventually generates between 25–50 MWe.

Geothermal Engineering Ltd is developing a 10 MWe and 55 MWt power plant at Redruth in Cornwall. It hopes that the plant will be operational by 2013.

The trajectories

Figure N1 illustrates trajectories for geothermal electricity generation in the UK under four levels of ambition, which are described below.

Figure N1: Trajectories for geothermal electricity generation under four levels of deployment



An average load factor of 80% is used in all of the trajectories. And it is assumed that 5.5 times the amount of thermal energy compared to electrical energy will be available for other uses if suitable demands are available, based upon the ratio of heat to electricity for the Redruth demonstration plant.

Level 1

This level of ambition is based upon no additional interest or investment in geothermal electricity generation.

Level 2

This level of ambition is based upon successful demonstrations of geothermal electricity generation in the UK with currently planned schemes in operation by 2015. Investment and interest in geothermal electricity generation is then focused on the optimum resources and sites, mostly in Cornwall, and installed capacity grows at roughly 32% per year. Total installed capacity levels reach about 1 GW by 2035 mostly representing the practical resource in Cornwall.

Level 3

This level of ambition is also based upon successful demonstrations of geothermal electricity generation in the UK with currently planned schemes in operation by 2015. Investment and interest in geothermal electricity generation is expanded to include areas other than Cornwall where granite is predominant and of the right age such as in the Midlands near Chesterfield, and in Cumbria. Installed capacity grows at roughly 52% per year to reflect the larger number of sites being developed, and reaches a total installed capacity of 3 GW by 2030.

Level 4

This level of ambition is based upon exploiting the maximum technically feasible resource. Most industry reports estimate that the UK could generate up to 35 TWh/year from geothermal electricity generation. This would equate to an installed capacity of roughly 5 GW. It has been estimated that the total available resource in the UK is around 1880 TWh, so this rate of extraction would last for approximately 50 years. Higher rates of extraction are considered unfeasible and even this level is only possible in an aggressive scenario 4.[392] Installed capacity grows at roughly 64% per year and reaches a total installed capacity of 5 GW by 2030.

---

[392] Ibid.

Section O: Hydropower

Context

Current installed hydropower capacity in the UK is 1.6 GW, which generates about 5 TWh/year, approximately 1.4% of the UK's electricity demand.[393] The majority (90%) of this comes from large-scale hydro, which was installed during the first renewable energy revolution in the 1940s and 50s, with the remaining 10% from hundreds of micro and small scale schemes. As well as generating electricity, some large hydropower plants combined with pumped storage facilities have the additional function of being able to store energy. This becomes increasingly important as the level of intermittent sources of electricity grows.

Using the powers in the Energy Act 2008 the Government has introduced a system of feed-in-tariffs to incentivise small scale, low carbon electricity generation. Feed-in tariffs will offer financial support for a) the generation and b) the export of renewable electricity from hydropower over a number of years which should encourage businesses, local authorities, householders and communities to invest in small scale low carbon electricity generation, in return for a guaranteed payment for the electricity they produce. Hydropower generation of up to 5 MW is eligible for feed-in-tariffs. The support will work alongside the Renewables Obligation for installations larger than 5MW. Feed-in-tariffs are expected to stimulate a rate of installations up to 2020 commensurate with level 3.

Drivers and enablers

It is considered unlikely that many more large scale schemes will be developed, since most of the economically attractive sites have already been exploited and there are considerable environmental concerns with developing new ones. However, there is still significant potential for developing the small hydro resource on existing weirs and disused mills, as well as for developing more pumped storage facilities.[394]

The average load factor for hydro schemes is estimated at 35-40% across the year, with 38% being the figure used in this analysis. The load factor at any given point in time can vary from 80% in winter down to 10-20% in summer, depending on the amount of rainfall.

The trajectories

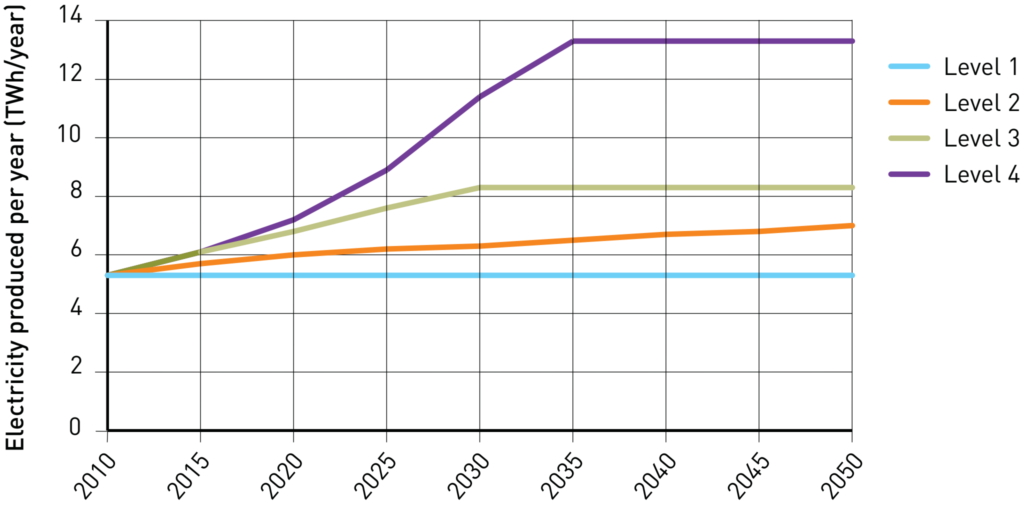
Figure O1 illustrates trajectories for hydroelectricity generation in the UK under four levels of ambition, which are described below.

---

[393] Department of Energy and Climate Change, *Digest of UK Energy Statistics (2009).*

[394] MacKay, David JC (2009) *Sustainable Energy – Without the hot air,* UIT, Cambridge.

Figure O1: Trajectories for hydroelectricity generation under four levels of deployment



Level 1

The normal lifetime for hydro turbines is 40 to 50 years, although they can last longer if well maintained. Many of the schemes installed in the mid 20th century now need major refurbishment, so there is a challenge to maintain the current level of generating capacity at around 1.6 GW. There are, however, possibilities for small increments to the total from small and micro hydro schemes. This level of ambition assumes that current installed capacity is maintained but no new capacity is installed.

Level 2

This level of ambition assumes that the refurbishment of existing capacity is coupled with a programme of upgrades of existing installations, for example replacing turbines with more efficient ones, and optimising maximum operating height. Coupled with this, the roll out of a number of micro-hydro sites progressively increases the total installed capacity from 1.6 GW to 2.1 GW by 2050.

Level 3

In the last few years, studies of the remaining hydro resource have been carried out for Scotland, England and Wales. The Scottish Hydropower Resource Study,[395] published in August 2008, estimates the remaining practical resource at 657 MW (base case). The Department of Energy and Climate Change and Welsh Assembly Government funded the 'England and Wales Hydropower Resource Assessment'[396] which estimates the current viable hydropower resource at between 156 and 248 MW. Taking the most optimistic figures would give a total remaining viable resource of 900 MW which, when added to the existing 1.6 GW would give 2.5 GW of generating capacity in 2050.

---

[395] Nick Forrest Associates Ltd, SISTech, Black & Veatch Ltd (August 2008) *Scottish Hydropower Resource Study – Final Report*.

[396] Department of Energy and Climate Change/Welsh Assembly Government (2010 – yet to be published) England and Wales Hydropower Resource Assessment.

This level of ambition assumes that the additional 900 MW of capacity is installed progressively at a rate of 45 MW per year until 2030 and maintained beyond this.

Level 4

A more recent study on the employment potential of Scotland's hydro resource[397] includes an up-rating of the remaining resource from 657 MW to 1.2 GW, which would generate up to 4 TWh/year. The Environment Agency's recent report on hydropower opportunities in England and Wales[398] looks at the maximum theoretical potential from a strategic point of view, while taking account of fish protection legislation. It came up with a Maximum potential capacity for England and Wales of 1.2 GW. Thus the total remaining UK maximum potential would equate to around 2.4 GW, which would make 4 GW in total in 2050. However, realising this potential is dependent on overcoming a number of environmental, technical and financial constraints.

This level of ambition assumes that an additional 2.4 GW of capacity is installed starting at a rate of 45 MW per year from 2010, with the installation rate growing by approximately 8% until installed capacity reaches 4 GW in 2035 and is maintained beyond this.

---

[397] Forrest, N & Wallace, J (September 2009) *The Employment Potential of Scotland's Hydro Resource*.
[398] Environment Agency (February 2010) *Opportunity and environmental sensitivity mapping for hydropower in England and Wales- Non-technical project report.*