HM Government

Ipsos MORI

2050 Pathways Analysis

1-page summaries of 2050 Calculator sectors

Domestic transport behaviour

On average, each of us currently travels about 14 000 km per year, excluding trips abroad. 83% of this distance is by car, van or motorcycle, 7% by rail, 6% by bus, 2% on foot, 1% by air and 0.5% by bike.

Level 1

Level 1 assumes that by 2050 each of us travels 1300 km per year more than in 2007, with a slight shift from road and rail to bus and air: 82% road, 6% rail, 7% bus, 2% foot, 2% air and 0.7% bike.

Level 2

Level 2 assumes that by 2050, each of us travels 900 km per year more than in 2007. Slightly less travel is by road and slightly more by bus: 80% road, 6% rail, 9% bus, 2% foot, 2% air and 0.7% bike. Buses are on average 50% more occupied than today.

Level 3

Level 3 assumes that by 2050, each of us travels an extra 900 km per year more than in 2007 and with a substantial shift away from cars towards buses, rail and bikes: 74% road, 8% rail, 13% bus, 2% foot, 2% air and 5% bike. 1 in 20 car trips are shared with one extra person.

Level 4

Level 4 assumes that in 2050 each of us travels the same distance per year as today. There is a big shift away from the car: 62% road, 10% rail, 19% bus, 2% foot, 2% air and 5% bike. There is an increase in alternatives to travel such as teleconferencing or more flexible working arrangements. 1 in 10 car trips are shared with one extra person, with on average twice as many people on board each bus, and with trains a third fuller than today.

Interaction with other choices

We can power the UK's cars, buses and trains by biofuel rather than diesel or petrol, or rely on electricity or hydrogen fuel cells. In the 2050 Calculator, the technology used and hence the emissions created are influenced by how much transport is electrified, how much electricity is decarbonised, and how much bioenergy is available for transport.

Figure 1. In 2007, 0.5% of distance travelled was by bicycle. Level 4 assumes that this increases to 4.7% by 2050.

	2007	2050 Level 1	2050 Level 2	2050 Level 3	2050 Level 4
km travelled/person/y	14 104	15 363	15 023	15 023	14 076
% of km by:					
Car, van or motorcycle	83%	82%	80%	74%	62%
Rail	7%	6%	6%	8%	10%
Bus	6%	7%	9%	13%	19%
Foot	2%	2%	2%	2%	2%
Domestic air	1%	2%	2%	2%	2%
Bicycle	1%	1%	1%	1%	5%

Table 1. The assumptions about km travelled and the split of how that distance is travelled.

Domestic transport electrification

In 2007, almost all the UK's domestic passenger transport was powered by diesel or petrol. Only 1% of transport fuel was electricity, and that was almost entirely for electrified railways.

Level 1

Level 1 assumes that by 2050, 20% of passenger kilometres are in cars that have both petrol engines and electric motors (known as plug-in hybrid electric vehicles), with batteries that can be charged from the mains, and 2.5% are in fully electric vehicles. Buses and trains are largely unchanged.

Level 2

Level 2 assumes that by 2050, only 35% of passenger-km are travelled in conventional petrol or diesel engine cars. 54% are plug-in hybrid vehicles and 11% are fully electric or fuel cell vehicles. All buses are hybrids with electric motors as well as diesel engines. The fraction of passenger railway travel that is electrified increases from 64% to 73%.

Level 3

Level 3 assumes that by 2050, 20% of passenger-km are travelled in conventional combustion engine cars, with 32% in plug-in hybrid vehicles and 48% in fully electric or fuel cell electric vehicles. 22% of bus travel takes place in fully electric or fuel cell electric buses, with all other buses powered by hybrid diesel-electric engines. 87% of passenger railway travel is electrified.

Level 4

Level 4 assumes that by 2050 100% of car travel is powered by an electric motor, with 80% from batteries and 20% from hydrogen fuel cells. All passenger trains are electrified and 50% of bus travel is fully electrified (25% from batteries and 25% from fuel cells), with the remainder being hybrid diesel-electric.

Interaction with other choices

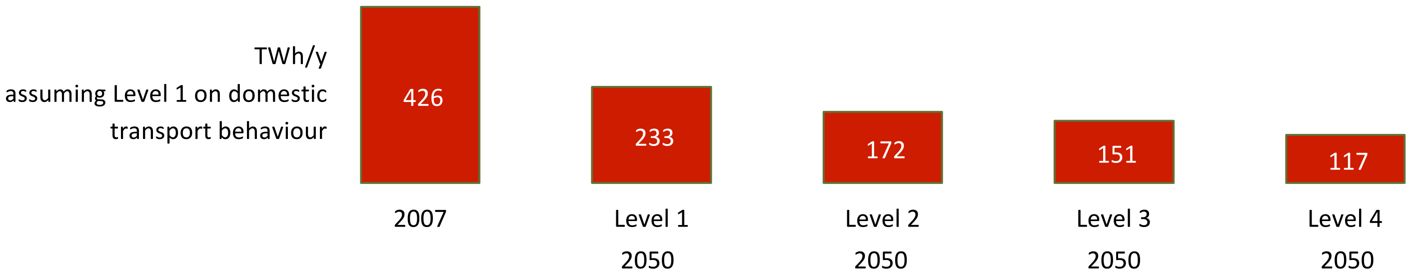
How individuals choose to travel, and how far, influences the types of vehicle on the road as well as overall demand for different fuel types, including electricity.

Where vehicles are not electrified (and even in level 4, buses are expected to be at least partially powered by liquid fuel) they can run on biofuel rather than diesel or petrol. This option can be selected in the 2050 Calculator by choosing bioenergy imports, or choosing to dedicate land to biomass and to turn that biomass into liquid biofuel.

Figure 1. The Vauxhall Ampera is scheduled to enter the UK market in 2012. Its battery can store 16 kWh which gives it a pure electric range of 80 km. It also contains a petrol-electric generator to extend its range. Photo © Vauxhall.

		2050			
% of car travel by:	2007	Level 1	Level 2	Level 3	Level 4
Conventional car	100%	78%	35%	20%	
Hybrid petrol-electric		20%	54%	32%	
Fully electric car		3%	10%	28%	80%
Fuel cell car			1%	20%	20%

Table 1. The assumptions about the types of passenger car used.



Domestic freight

In 2007, 68% of all UK freight tonne-kilometres were by road, 20% by water, 8% by rail and 4% by pipe. Almost all freight transport was powered by diesel or petrol engine. In 2007, the total amount of goods-movement was 255 billion tonnes-kilometres – that equates to 4183 tonne-kilometres per person.

Level 1

Level 1 assumes that by 2050 the proportion of freight by road increases to 73%, and the proportion by water declines to 13%. This level assumes overall goods-movement increase by 33% from 2007 to 2050.

Level 2

Level 2 assumes that by 2050, the proportion of freight by road decreases to 66%, and the proportion by rail increases to 11%. Lorries are about a third more efficient and trains are about a fifth more efficient. This level assumes overall goods moved in 2050 increase by 33% from 2007.

Level 3

Level 3 assumes that by 2050, the volume of freight grows but less quickly than GDP. The shift from road to rail is stronger: 58% of tonne-kilometres are moved by road and 19% by rail. Half of rail freight is electric and it is 30-40% more efficient than in 2007. Lorries are twice as efficient. This level assumes overall goods-movements increase by 14% from 2007 to 2050. Taking account of population increase, there is a drop of 10% in goods-movements per person.

Level 4

Level 4 assumes that the volume of freight grows less quickly than GDP. There is a significant increase in rail freight and, by 2050, only 50% of tonne-kilometres are by road; rail increases to 23%; and water increases to 23%. All freight trains are electric. This level assumes overall goods moved in 2050 increase by 14% from 2007. There is a drop of 10% in goods-movements per person.

Interaction with other choices

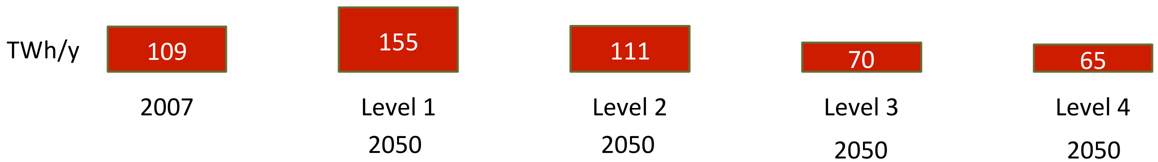
Choices about building different sorts of infrastructure, about the different volumes of fuels, and shifts in the size of UK industry will all influence freight transport demand. The 2050 Calculator does not model the impact on freight of these choices; you have to make sure your choices are consistent.

We can power the UK's lorries, boats and trains by biofuel rather than diesel or petrol. To bring this about in the Calculator, choose either (i) to import bioenergy or (ii) to dedicate land to biocrops; and then turn those biocrops into liquid fuel.

Figure 1. A diesel freight train running on an electrified track. Photo: © railway-technology.com.

		2050			
	2007	Level 1	Level 2	Level 3	Level 4
freight (t-km/person/y)	4183	4417	4417	3786	3786
% of freight t-km by					
Road	68%	73%	66%	58%	50%
Waterway	20%	13%	19%	19%	23%
Rail	8%	9%	11%	19%	23%
Pipeline	4%	4%	4%	4%	4%

Table 1. The assumptions about freight volume and mode.



International aviation

In 2005 there were 238 million passenger-flights to or from UK airports - a 130% increase on 1990 levels. The Committee on Climate Change (CCC) has further projected that, if unconstrained, there is likely to be an increase in international aviation passenger demand of over 200% by 2050.

The UK's 2050 target currently does not include international aviation emissions, but the 2050 Calculator does. We have used CCC scenarios for reducing emissions from international aviation to illustrate alternative pathways for emissions from this sector out to 2050.

Level 1

Level 1 assumes that the efficiency of the aircraft fleet improves by 0.8% per year. By 2050 passenger demand increases to about 115% above 2005 levels, and the sector uses 35% more fuel than in 2007.

Levels 2 and 3 (identical)

Level 2 assumes a 1% improvement in efficiency each year up to 2050. There are increases in the level of investment in new aircraft technologies and the pace of fleet renewal, as well as improvements in air traffic management and operations. In 2050 videoconferencing results in a 10% reduction in business aviation demand, international aviation passenger demand increases to about 105% above 2005 levels, and the sector uses 22% more fuel than in 2007.

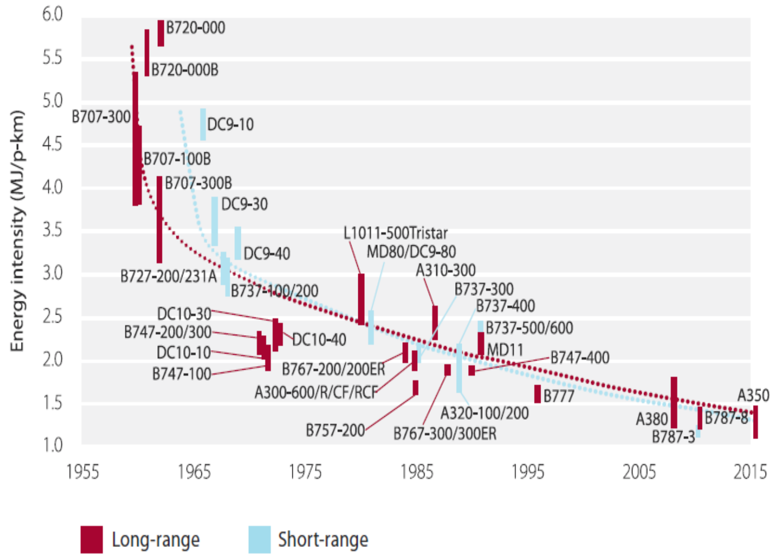
Level 4

Level 4 assumes that there are technological breakthroughs and a significant increase in the pace of aircraft fuel efficiency improvements to achieve an increase in fleet fuel efficiency of 1.5% a year up to 2050. Videoconferencing results in a 30% reduction in business demand, international aviation passenger demand increases to about 90% above 2005 levels, and international aviation uses 1% less fuel than in 2007.

Interaction with other choices

Test flights have demonstrated the technical feasibility of using biofuels in aviation. However biofuel is limited in quantity and there are competing demands for it. In the future, aircraft may be able to use biofuels in significant quantities. To choose a 2050 Calculator pathway where biofuels are used in aviation, either select a pathway that has bioenergy imports, or select a pathway that has both UK bioenergy production and conversion to mainly liquid bioenergy.

Figure 1. A Boeing 787 Dreamliner designed to use 20% less fuel than comparable aircraft of the previous generation.
Photo © Dave Sizer.



Source: IEA (2009).
Note: The range of points for each aircraft reflects varying configurations; connected dots show estimated trends for short and long-range aircrafts.

Figure 2. Historic trends in aircraft efficiency. From the Committee on Climate Change report *'Meeting the UK aviation target – options for reducing emissions to 2050'*.

International shipping

In 2007, 4 tonnes of goods per person were imported through UK ports and 3 tonnes per person exported to other countries. Historically, shipping levels are closely tied to economic growth, and shipping has played a key role in supporting trade and the UK's quality of life.

International shipping is a large and complex industry, and there is currently no agreed way of allocating international shipping emissions to different countries.[1] International shipping emissions are not currently included in the UK's 2050 emissions target, largely for this reason. Further research is needed to understand the UK's share of global international shipping emissions. In the meantime, the 2050 Calculator includes four illustrative scenarios. These illustrative scenarios are only place-holders, and the aim is to refine them as more evidence becomes available.

The four scenarios are based on the International Maritime Organization's (IMO) activity-based scenarios of global international shipping emissions. It is assumed that the UK's share of the IMO's global estimates is around 1.2%, which was the UK's share of global international shipping emissions based on IEA fuel statistics for 2007. In reality, these shares will differ, and the UK's share would be expected to change over time.

The IMO scenarios do not show the full potential to reduce emissions from international shipping, but reflect business-as-usual efficiency improvements. All four scenarios include an efficiency improvement of 39% between 2007 and 2050. This is assumed to be achieved through a 10% reduction in average fleet speed, the use of larger ships and improvements in ship design, technology and operation. Emissions could be reduced further if additional efficiency improvements are made or other measures are adopted.

The key difference between the four illustrative scenarios is the level of international shipping activity, which depends on the size and character of the world economy and on population growth. The scenarios do not differ in the extent to which emissions abatement measures are implemented.

Trajectory A

Trajectory A assumes that total global shipping activity grows by a factor of 3.1 between 2007 and 2050. Ships travel more globally, reflecting a world of rapid global growth and cultural convergence.

Trajectory B

Trajectory B assumes that total global shipping activity grows by a factor of 2.5 between 2007 and 2050. Global economic growth is still fast but trade is more regionally-orientated.

Trajectory C

Trajectory C assumes that total global shipping activity grows by a factor of 2.4 between 2007 and 2050. This reflects a world where a shift towards IT and service economies slows the growth of shipping.

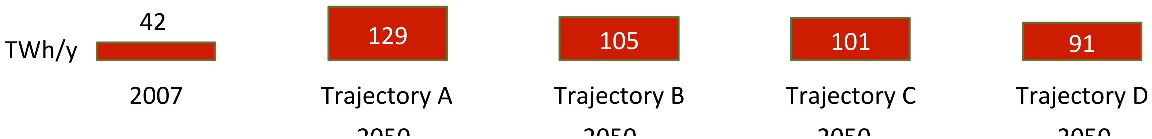
Trajectory D

Trajectory D assumes that total global shipping activity grows by a factor of 2.2 between 2007 and 2050. This reflects a world with slower economic development and an emphasis on local trade.

Interaction with other choices

Global shipping activity is influenced by the amount and type of fuel we import, the extent of recycling of raw materials, the quantities of imports and exports, and the size and shape of UK industry. The 2050 Calculator does not consider any of these factors in relation to shipping. Some international shipping could be powered by biofuels; however biofuel is very limited in quantity and there are many other competing uses for biofuels across the transport, heating and electricity generation sectors.

Figure 1. The Kohyohsan, a ship built with an 'axe bow' that reduces the energy lost in waves, reducing fuel consumption by up to 6%. Source: IMO.



[1] The UK reports international shipping emissions based on international shipping fuels sold in the UK.

Average temperature of homes

The mean internal temperature of UK homes during the winter months was 17.5˚C in 2007, compared to 16˚C in 1990. Almost no homes had air conditioning. Historically, the temperature people choose to heat their homes to has increased over the years.

Level 1

Level 1 assumes that the mean internal temperature of UK homes during the winter months continues to increase to 20˚C in 2030, then stabilises. Use of air conditioning grows to 50 TWh/y in 2050.

Level 2

Level 2 assumes that the mean temperature increases slightly to 18˚C in 2050. Use of air conditioning grows to 31 TWh/y in 2050.

Level 3

Level 3 assumes that the mean temperature decreases slightly to 17˚C in 2050. Use of air conditioning grows to 14 TWh/y in 2050.

Level 4

Level 4 assumes that the mean temperature decreases to 16˚C in 2050 , which is equivalent to the mean internal house temperature in 1990. There is no use of air conditioning in the summer.

Householders can experience today's levels of thermal comfort while also reducing energy demand by wearing warmer clothing or by heating the house in a smarter way. Using a 13 TOG winter duvet rather than a 12 TOG one offers the same level of thermal comfort in a house with a 1.5˚C lower internal temperature. Similarly, wearing one extra layer of clothing can compensate for a 1.5˚C drop in temperature. For an older home that is otherwise maintained at 17.5˚C, an alternative to reducing the temperature by 1.5°C is to leave it unheated for two or three additional hours per day, which is likely to result in the same energy savings.

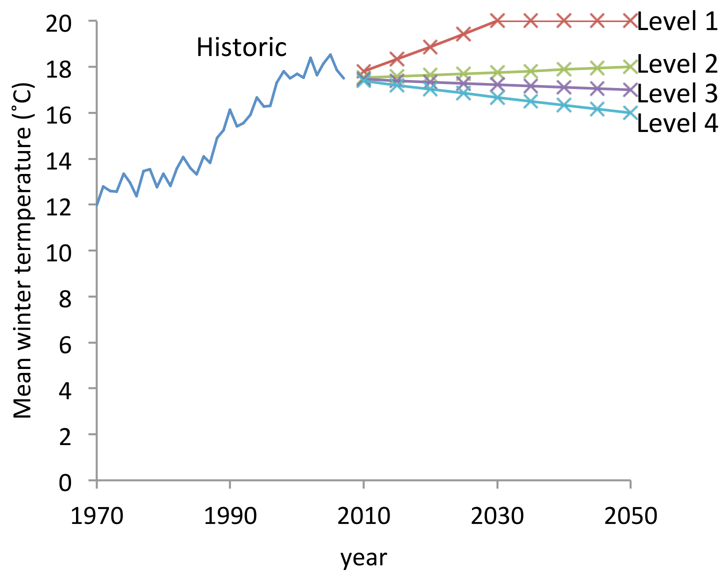
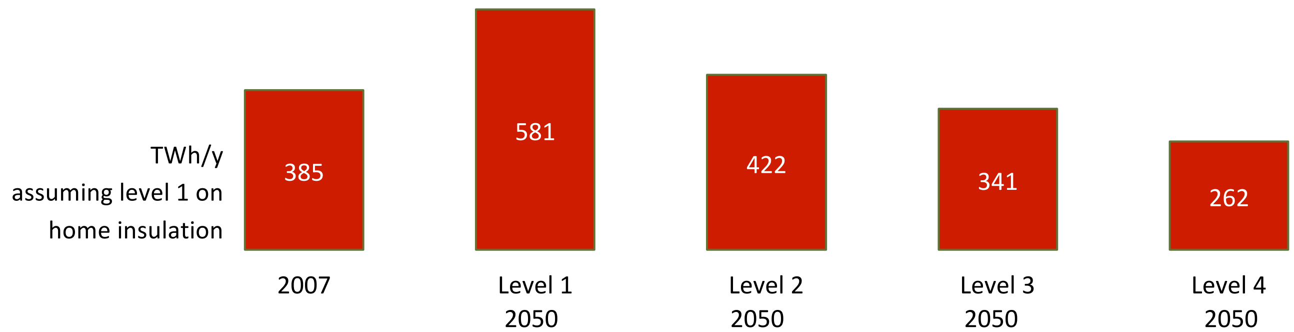


Figure 1. Historic average UK home temperatures during winter (up to 2008) and assumptions about possible futures (2010 onwards).



Home insulation

In 2007, the average 'leakiness' of all UK homes, which measures how much power is required to maintain each degree of temperature difference, was 247 W/˚C. It is assumed that 25 million of 2007's homes will still be with us in 2050, with 15 million more new homes constructed between 2007 and 2050.

Level 1

Level 1 assumes that the average leakiness falls by about 25%, from 247 W/˚C in 2007 to 190 W/˚C in 2050. New homes are built to 2006 insulation standards. 6 million existing homes receive extra loft insulation, 3.5 million receive floor insulation and 3 million receive cavity wall insulation.

Level 2

Level 2 assumes that the average heat loss parameter falls by around 33%. New homes are built to the Energy Saving Trust's advanced practice energy standard. 8 million existing homes receive triple glazing, 7 million receive extra loft insulation and draught proofing, 5 million receive floor insulation, 4.5 million receive cavity wall insulation and 2.5 million receive extra insulation on their walls (solid wall insulation).

Level 3

Level 3 assumes that the average leakiness falls by 40%. New homes are built to the Energy Saving Trust's advanced practice energy standard. 18 million existing homes receive extra loft insulation, 14 million receive triple glazing, 13.5 million receive extra draught proofing, 7 million receive floor insulation, 7 million receive cavity wall insulation and 6 million receive extra insulation on their walls.

Level 4

Level 4 assumes the average leakiness is reduced by 50%. New homes are built close to the PassivHaus standard. 24 million existing homes receive extra draught proofing, 22 million receive triple glazing, 21 million receive extra loft insulation, 11 million receive floor insulation, 9 million receive cavity wall insulation and 8 million receive extra insulation on their walls.

Interaction with other choices

Note that, although level 4 insulation halves the power required for a typical home to maintain a given temperature, this will be at least partially offset by the increase in the number of homes and the expectation that we will choose to have warmer homes, with internal temperatures increasing from 17.5°C at 2007 to 20°C by 2030-2050.

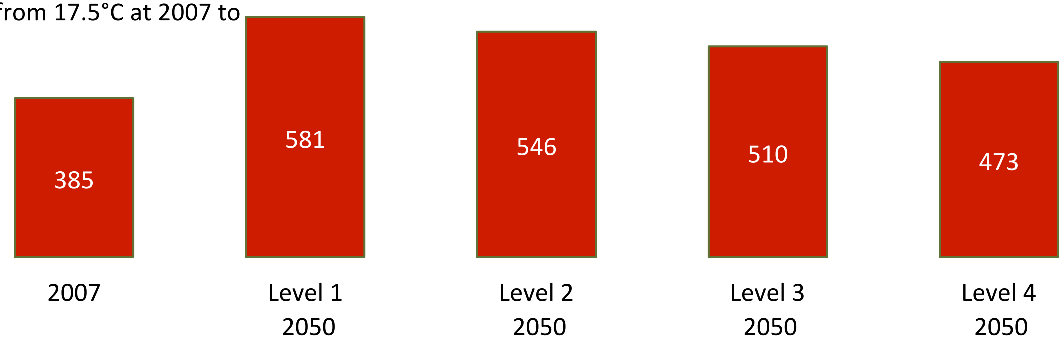


Figure 1. Internal solid wall insulation in a London home being enhanced as part of Retrofit for the Future.

Domestic and commercial heating choices

In 2007, 82% of homes were heated with gas boilers, 10% with electric heaters, and the remainder used oil, coal or biomass, heat pumps or community heating schemes. It is expected that the 26 million heating systems in existing homes and the systems in 14 million new homes will need to be replaced by 2050, so the options below outline the technologies they could be replaced with.

In 2007, 70% of commercial heating was from gas boilers, 20% from electric heaters and 10% from oil boilers with less than 1% from coal, biomass, heat pumps or community heating schemes. It is also expected that all commercial heating systems will need to be replaced by 2050, so these choices outline the technologies they could be replaced with.

The 2050 Calculator considers eleven technologies for heating buildings. Combinations of these can be chosen through two choices, one that mainly influences the level of electric heating and the other that influences what is used when electric heating is not used. The table to the right indicates which technologies are covered by each choice.

Types of technology which could be used to supply the UK's building heat in 2050 include:

- **Conventional gas boilers**, assumed to be capable of using either biogas or natural gas. (Their use is maximised by choosing A for electrification and A for the other heating choice).
- **Solid fuel boilers**, assumed to be capable of using either coal or biomass. (Maximised by choosing A for electrification and A for the other heating choice).
- Electrification via the installation of **resistive heating technologies, ground-source and air-source heat pumps**. (Maximised by choosing D for electrification and D for the other heating choice).
- Home heating technologies, designed to produce electricity while they are producing heat, e.g. **micro-Combined Heat and Power** (μCHP). (Maximised by choosing B for electrification and A for the other heating choice).
- Piped-in heat, for example **district heating** that takes steam or hot water from large power stations (Maximised by choosing A for electrification and C for the other heating choice), or from community scale gas or solid-fuel CHP systems (Maximised by choosing B for electrification and C for the other heating choice).

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

Table 1. There is a large existing stock of heating systems dominated by gas. Every year heating systems are replaced, and the table above shows the split by technology of those new heating systems.

Domestic and commercial heating choices

In 2007, 82% of homes were heated with gas boilers, 10% with electric heaters, and the remainder used oil, coal or biomass, heat pumps or community heating schemes. It is expected that the 26 million heating systems in existing homes and the systems in 14 million new homes will need to be replaced by 2050, so the options below outline the technologies they could be replaced with.

In 2007, 70% of commercial heating was from gas boilers, 20% from electric heaters and 10% from oil boilers with less than 1% from coal, biomass, heat pumps or community heating schemes. It is also expected that all commercial heating systems will need to be replaced by 2050, so these choices outline the technologies they could be replaced with.

The 2050 Calculator considers eleven technologies for heating buildings. Combinations of these can be chosen through two choices, one that mainly influences the level of electric heating and the other that influences what is used when electric heating is not used. The table to the right indicates which technologies are covered by each choice.

Types of technology which could be used to supply the UK's building heat in 2050 include:

- **Conventional gas boilers**, assumed to be capable of using either biogas or natural gas. (Their use is maximised by choosing A for electrification and A for the other heating choice).
- **Solid fuel boilers**, assumed to be capable of using either coal or biomass. (Maximised by choosing A for electrification and A for the other heating choice).
- Electrification via the installation of **resistive heating technologies, ground-source and air-source heat pumps**. (Maximised by choosing D for electrification and D for the other heating choice).
- Home heating technologies, designed to produce electricity while they are producing heat, e.g. **micro-Combined Heat and Power** (μCHP). (Maximised by choosing B for electrification and A for the other heating choice).
- Piped-in heat, for example **district heating** that takes steam or hot water from large power stations (Maximised by choosing A for electrification and C for the other heating choice), or from community scale gas or solid-fuel CHP systems (Maximised by choosing B for electrification and C for the other heating choice).

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

Table 1. There is a large existing stock of heating systems dominated by gas. Every year heating systems are replaced, and the table above shows the split by technology of those new heating systems.

Lighting and appliances

Domestic and commercial ownership of lighting and appliances such as refrigerators, ovens, televisions and computers is steadily increasing. Many such devices are more energy efficient than in the past. Around half of all light bulbs are now more efficient than incandescent models, and the average energy consumed per appliance is falling.

In the 2050 Calculator the lighting and appliance sector's future energy use is determined by two factors: demand and efficiency (described here) and technology change (described in a separate note).

Level 1

Level 1 assumes that energy demand per household declines 20% between 2007 and 2050. There is a general trend towards more energy-efficient equipment, but this is partially counteracted by extra electronics and computers in each home. This level also assumes that overall energy demand from commercial lighting and appliances increases by 25% between 2007 and 2050.

Level 2

Level 2 assumes that demand per household declines 34% by 2050. This involves replacing all appliances with efficient alternatives and using energy displays to monitor and manage home energy consumption. This level also assumes that by 2050 overall demand from commercial lighting and appliances increases by 10%.

Level 3

Level 3 assumes that demand per household declines by 61% by 2050. This involves replacing all lighting with very efficient light emitting diodes (LEDs); appliance manufacturers taking substantial extra steps to improve the energy efficiency of their equipment; and consumers being smarter about how and when they use equipment. This level also assumes that overall demand from commercial lighting and appliances decreases by 10% by 2050.

Level 4

Level 4 assumes that demand per household declines by 73% by 2050. This involves both technological breakthroughs in the efficiency of equipment and substantial care and attention by householders in how they use energy. Equipment manufacturers take widescale action to reduce power consumption by their products. This level also assumes that overall demand from commercial lighting and appliances decreases by 30% by 2050; that 90% of lights are high-efficiency LEDs; that commercial fridges are much more efficient designs; and that computing systems are designed to be low energy.

Figure 1. Under level 4 assumptions our fridges would use one-fifth of the energy that they do today. Photo © Lara Love.

Figure 2. Under level 4 assumptions, all household lights and 90% of commercial lights would use high efficiency LEDs. Photo © Geoffrey Landis.

Electrification of cooking

Currently all lighting and most appliances are powered by electricity; for cooking there is a choice between gas and electricity. In 2007, 40% of commercial cooking and 37% of domestic cooking were gas-powered, with the rest being electrified.

In the 2050 Calculator the lighting and appliance sector's future energy use is determined by two factors: electrification (described here) and demand and efficiency (described on another page). The changes here represent different choices rather than an increasing scale of effort. They cannot be compared with the Levels 1-4 in other sectors and have therefore been labelled as Trajectories A and B instead.

Trajectory A

Trajectory A assumes that in 2050 the cooking technology mix remains the same as in 2007; 40% of commercial cooking and 37% of domestic cooking is by gas and the rest is by electricity.

Trajectory B

Trajectory B assumes that in 2050 all commercial and domestic cooking is electrified. Gas hobs and ovens have been replaced with traditional electric, induction or microwave alternatives.

Interaction with other choices

The 2050 Calculator allows biogas to be used to replace natural gas in cooking. This option can be chosen by dedicating land to biocrops and then choosing to turn those biocrops into gaseous fuel. However biogas is very limited in quantity and there are many other competing uses for biofuels across the transport, heating and electricity generation sectors.

Figure 1. Trajectory A assumes that the current mix of electric and gas cooking continues. This picture is of a 1934 gas oven. Photo © Arnington

Figure 2. An electric induction hob. Photo © Eric1980

The choice around the electrification of cooking is assumed not to influence cooking energy demand.

Growth in industry

The industry sector includes the manufacture of metals, minerals, and other chemicals. In 2007 industry was responsible for about 25% of total UK energy demand. In addition to emissions from the energy used, the sector also emitted 28 $MtCO_2e$ directly from its processes. 36% of industrial energy demand was supplied by gas, 28% by electricity, and the rest by oil, coal, and combined heat and power.

In the 2050 Calculator the industrial sector's future energy use is determined by two factors: industry growth (described here) and industry energy intensity (described on another page). The changes here represent different choices rather than an increasing scale of effort. They cannot be compared with the Levels 1-4 in other sectors and have therefore been labelled as Trajectories A-C instead.

Trajectory A

Trajectory A assumes that UK industry will expand, because of the need to manufacture new low-carbon technologies, and low-carbon replacements for existing goods and machinery. Assuming a growth rate of 1.5% growth rate (similar to the UK's historical rate in the 1980s and 1990s) industrial output will double between 2007 and 2050.

Trajectory B

Trajectory B assumes that the growth trend of 1970 to 2008 continues, leading to industrial output increasing by 30% to 2050.

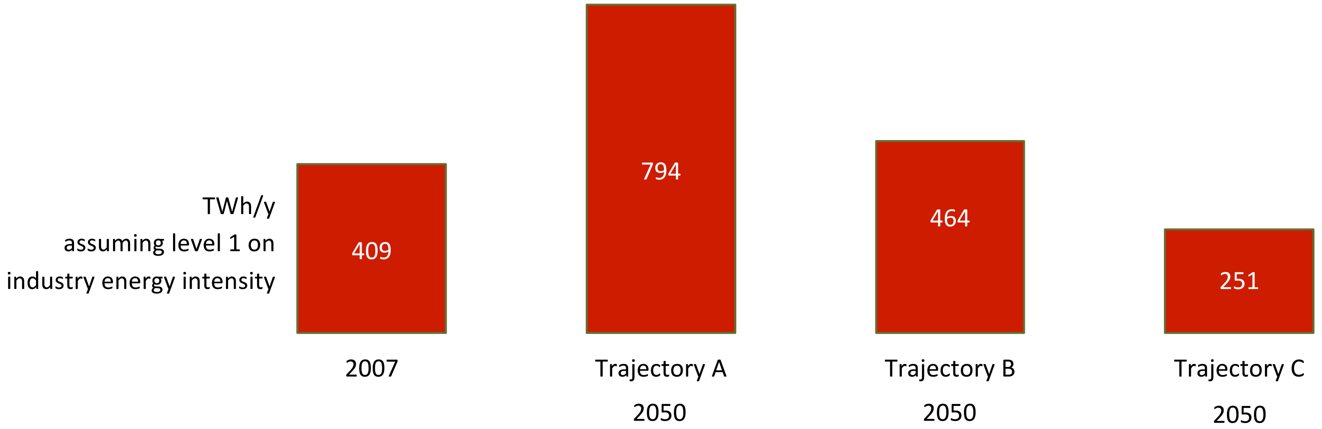
Trajectory C

Trajectory C assumes the UK's economy shifts from industry into other sectors, leading to industrial output declining by 30-40% between 2007 and 2050.

Interaction with other choices

The size of the industrial sector affects the need for freight, but this is not handled automatically by the Calculator – you have to choose the setting for each independently.

Figure 1. A UK cement processing plant. Currently about 30% of all industrial process emissions come from cement making. This makes cement this the largest emitting industrial sector, followed by steel making. Photo © agg-net.com



Energy intensity of industry

The industry sector includes the manufacture of metals, minerals, and other chemicals. In 2007 industry was responsible for about 25% of total UK energy demand. In addition to emissions from the energy used, the sector also emitted 28 $MtCO_2e$ directly from its processes. 36% of industrial energy demand was for gas, 28% was for electricity, with the rest from oil, coal and district heating.

In the 2050 Calculator the industrial sector's future energy use is determined by two factors: industry energy intensity (described here) and industry growth (described on another page).

Level 1

Level 1 assumes that there is no widespread deployment of carbon capture and storage (CCS) or fuel switching; that process emissions remain constant; and that there is a 10% reduction in energy intensity between 2007 and 2050.

Level 2

Level 2 assumes a 20% improvement in energy intensity; that 40% of industrial energy demand is for electricity; a 30% reduction in process emissions per unit of output; and that 10% of emissions are captured through CCS.

Level 3

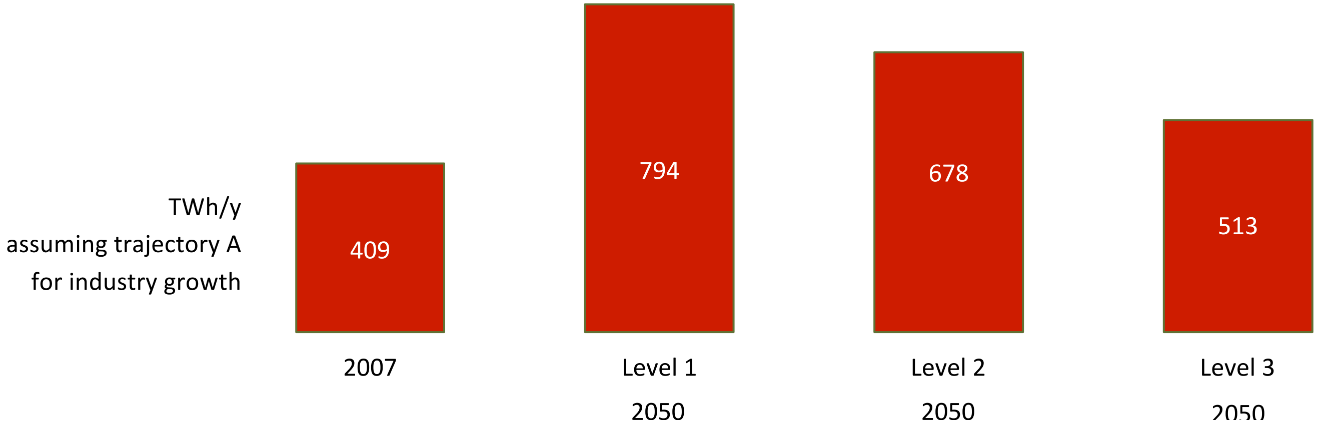
Level 3 assumes there is a 40% improvement in energy efficiency and at least a 25% average reduction in process emission intensity. 66% of energy demanded is for electricity. CCS is rolled out quickly after 2025 and by 2050 about half of industrial emissions are captured (including 80% of emissions from steel, ammonia and cement plants).

Interaction with other choices

The coal, gas and oil used by industry could be replaced with bioenergy. To do this in the 2050 Calculator, select bioenergy imports, or choose to dedicate land to biomass and to turn that biomass into solid, liquid or gaseous biofuel.

There is significant demand for carbon dioxide (CO_2) transport infrastructure and storage capacity in three sectors: industry, carbon capture and storage, and geosequestration. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

Figure 1. A blast furnace at Ijmuiden, in The Netherlands.
It uses coke to reduce iron ore into iron. The parent company is part of ULCOS, a group investigating how to capture the emissions from the blast furnace and how the entire process might be electrified through the use of electrolysis rather than chemical reduction.
Photo © Svdolen.



Commercial demand for heating and cooling

This sector considers the amount of heating, cooling and hot water used within commercial buildings such as shops, hotels, offices, and schools; it doesn't include industrial buildings which are covered under the industry sector. In 2007, commercial premises used 75 TWh/y of energy for heating, 14 TWh/y for hot water, and 27 TWh/y for cooling.

The 2050 Calculator assumes that the number of commercial properties increases by 1% per year, from 1.8 million in 2007 to 2.7 million in 2050.

Level 1

Level 1 assumes that in 2050, heating and hot water demand are both higher than 2007 levels, reaching 121 TWh/y for heating and 22 TWh/y for hot water. This means in 2050 each building is demanding about the same heat and hot water as in 2007. All commercial buildings are air-conditioned in 2050, increasing energy demand for cooling to 103 TWh/y. The total energy demand for commercial heating and cooling in 2050 is 246 TWh/y.

Level 2

Level 2 assumes that in 2050, heating demand grows to 97 TWh/y, while hot water demand grows by 47% to 19 TWh/y. This means each building is demanding 20% less heat and 10% less hot water in 2050. All offices and retail units and half of the other commercial buildings are air-conditioned in 2050, increasing energy demand for cooling by 75% to 48 TWh/y. The total energy demand for commercial heating and cooling in 2050 is 165 TWh/y.

Level 3

Level 3 assumes that in 2050, total heating demand and cooling demand remain close to 2007 levels, at 78 TWh/y for heating and 28 TWh/y for cooling. This means each building is demanding 30% less heat and air-conditioning in 2050. Demand for hot water grows to 17 TWh/y in 2050, a drop in demand of 20% per building. The total energy demand for commercial heating and cooling in 2050 is 123 TWh/y.

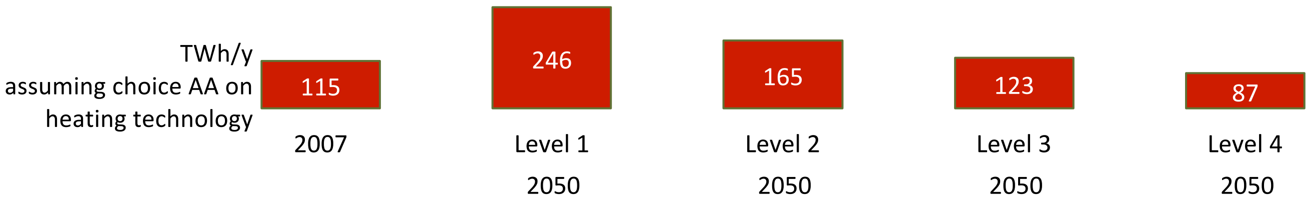
Level 4

Level 4 assumes that in 2050, total heating and cooling demand is lower than in 2007. Heating demand falls to 59 TWh/y, hot water demand grows to 15 TWh/y, and cooling demand falls to 14 TWh/y. This means each building is demanding 40% less heat, 30% less hot water and 50% less air-conditioning in 2050. The total energy demand for commercial heating and cooling in 2050 is 87 TWh/y.

Interaction with other choices

2050 Calculator users should choose the technologies for heating and air-conditioning in the 'Domestic and commercial heating choices' sector.

Figure 1. A Fujitsu heating and air conditioning system. Level 4 assumes that fewer commercial buildings than today are air conditioned, while level 1 assumes that all of them are air conditioned.



Domestic and commercial heating choices

In 2007, 82% of homes were heated with gas boilers, 10% with electric heaters, and the remainder used oil, coal or biomass, heat pumps or community heating schemes. It is expected that the 26 million heating systems in existing homes and the systems in 14 million new homes will need to be replaced by 2050, so the options below outline the technologies they could be replaced with.

In 2007, 70% of commercial heating was from gas boilers, 20% from electric heaters and 10% from oil boilers with less than 1% from coal, biomass, heat pumps or community heating schemes. It is also expected that all commercial heating systems will need to be replaced by 2050, so these choices outline the technologies they could be replaced with.

The 2050 Calculator considers eleven technologies for heating buildings. Combinations of these can be chosen through two choices, one that mainly influences the level of electric heating and the other that influences what is used when electric heating is not used. The table to the right indicates which technologies are covered by each choice.

Types of technology which could be used to supply the UK's building heat in 2050 include:

- **Conventional gas boilers**, assumed to be capable of using either biogas or natural gas. (Their use is maximised by choosing A for electrification and A for the other heating choice).
- **Solid fuel boilers**, assumed to be capable of using either coal or biomass. (Maximised by choosing A for electrification and A for the other heating choice).
- Electrification via the installation of **resistive heating technologies, ground-source and air-source heat pumps**. (Maximised by choosing D for electrification and D for the other heating choice).
- Home heating technologies, designed to produce electricity while they are producing heat, e.g. **micro-Combined Heat and Power** (µCHP). (Maximised by choosing B for electrification and A for the other heating choice).
- Piped-in heat, for example **district heating** that takes steam or hot water from large power stations (Maximised by choosing A for electrification and C for the other heating choice), or from community scale gas or solid-fuel CHP systems (Maximised by choosing B for electrification and C for the other heating choice).

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

Table 1. There is a large existing stock of heating systems dominated by gas. Every year heating systems are replaced, and the table above shows the split by technology of those new heating systems.

Domestic and commercial heating choices

In 2007, 82% of homes were heated with gas boilers, 10% with electric heaters, and the remainder used oil, coal or biomass, heat pumps or community heating schemes. It is expected that the 26 million heating systems in existing homes and the systems in 14 million new homes will need to be replaced by 2050, so the options below outline the technologies they could be replaced with.

In 2007, 70% of commercial heating was from gas boilers, 20% from electric heaters and 10% from oil boilers with less than 1% from coal, biomass, heat pumps or community heating schemes. It is also expected that all commercial heating systems will need to be replaced by 2050, so these choices outline the technologies they could be replaced with.

The 2050 Calculator considers eleven technologies for heating buildings. Combinations of these can be chosen through two choices, one that mainly influences the level of electric heating and the other that influences what is used when electric heating is not used. The table to the right indicates which technologies are covered by each choice.

Types of technology which could be used to supply the UK's building heat in 2050 include:

- **Conventional gas boilers**, assumed to be capable of using either biogas or natural gas. (Their use is maximised by choosing A for electrification and A for the other heating choice).
- **Solid fuel boilers**, assumed to be capable of using either coal or biomass. (Maximised by choosing A for electrification and A for the other heating choice).
- Electrification via the installation of **resistive heating technologies, ground-source and air-source heat pumps**. (Maximised by choosing D for electrification and D for the other heating choice).
- Home heating technologies, designed to produce electricity while they are producing heat, e.g. **micro-Combined Heat and Power** (µCHP). (Maximised by choosing B for electrification and A for the other heating choice).
- Piped-in heat, for example **district heating** that takes steam or hot water from large power stations (Maximised by choosing A for electrification and C for the other heating choice), or from community scale gas or solid-fuel CHP systems (Maximised by choosing B for electrification and C for the other heating choice).

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

Table 1. There is a large existing stock of heating systems dominated by gas. Every year heating systems are replaced, and the table above shows the split by technology of those new heating systems.

Lighting and appliances

Domestic and commercial ownership of lighting and appliances such as refrigerators, ovens, televisions and computers is steadily increasing. Many such devices are more energy efficient than in the past. Around half of all light bulbs are now more efficient than incandescent models, and the average energy consumed per appliance is falling.

In the 2050 Calculator the lighting and appliance sector's future energy use is determined by two factors: demand and efficiency (described here) and technology change (described in a separate note).

Level 1

Level 1 assumes that energy demand per household declines 20% between 2007 and 2050. There is a general trend towards more energy-efficient equipment, but this is partially counteracted by extra electronics and computers in each home. This level also assumes that overall energy demand from commercial lighting and appliances increases by 25% between 2007 and 2050.

Level 2

Level 2 assumes that demand per household declines 34% by 2050. This involves replacing all appliances with efficient alternatives and using energy displays to monitor and manage home energy consumption. This level also assumes that by 2050 overall demand from commercial lighting and appliances increases by 10%.

Level 3

Level 3 assumes that demand per household declines by 61% by 2050. This involves replacing all lighting with very efficient light emitting diodes (LEDs); appliance manufacturers taking substantial extra steps to improve the energy efficiency of their equipment; and consumers being smarter about how and when they use equipment. This level also assumes that overall demand from commercial lighting and appliances decreases by 10% by 2050.

Level 4

Level 4 assumes that demand per household declines by 73% by 2050. This involves both technological breakthroughs in the efficiency of equipment and substantial care and attention by householders in how they use energy. Equipment manufacturers take widescale action to reduce power consumption by their products. This level also assumes that overall demand from commercial lighting and appliances decreases by 30% by 2050; that 90% of lights are high-efficiency LEDs; that commercial fridges are much more efficient designs; and that computing systems are designed to be low energy.

Figure 1. Under level 4 assumptions our fridges would use one-fifth of the energy that they do today. Photo © Lara Love.

Figure 2. Under level 4 assumptions, all household lights and 90% of commercial lights would use high efficiency LEDs. Photo © Geoffrey Landis.

Electrification of cooking

Currently all lighting and most appliances are powered by electricity; for cooking there is a choice between gas and electricity. In 2007, 40% of commercial cooking and 37% of domestic cooking were gas-powered, with the rest being electrified.

In the 2050 Calculator the lighting and appliance sector's future energy use is determined by two factors: electrification (described here) and demand and efficiency (described on another page). The changes here represent different choices rather than an increasing scale of effort. They cannot be compared with the Levels 1-4 in other sectors and have therefore been labelled as Trajectories A and B instead.

Trajectory A

Trajectory A assumes that in 2050 the cooking technology mix remains the same as in 2007; 40% of commercial cooking and 37% of domestic cooking is by gas and the rest is by electricity.

Trajectory B

Trajectory B assumes that in 2050 all commercial and domestic cooking is electrified. Gas hobs and ovens have been replaced with traditional electric, induction or microwave alternatives.

Interaction with other choices

The 2050 Calculator allows biogas to be used to replace natural gas in cooking. This option can be chosen by dedicating land to biocrops and then choosing to turn those biocrops into gaseous fuel. However biogas is very limited in quantity and there are many other competing uses for biofuels across the transport, heating and electricity generation sectors.

Figure 1. Trajectory A assumes that the current mix of electric and gas cooking continues. This picture is of a 1934 gas oven. Photo © Arnington

Figure 2. An electric induction hob. Photo © Eric1980

The choice around the electrification of cooking is assumed not to influence cooking energy demand.

Nuclear power stations

In 2007, UK nuclear power stations produced 164 TWh/y of high-grade heat that was converted to 63 TWh/y of electricity. 57 TWh/y of this was delivered to the grid, and 6 TWh/y was used on-site to run the power stations.

There are two possible ways of measuring the energy produced by a nuclear power station, modelled in the chart below. Most of the figures in this document show the electrical energy delivered (the green bars), but sometimes it is conventional to display the primary energy (the blue bars), which is the heat generated by the nuclear processes. The electrical energy is smaller than the primary energy due to the inherent conversion losses and the energy requirements of the power station itself. If the nuclear power stations were located near to buildings with heat demand they could generate combined heat and power: in return for a modest loss in electrical output much of the 'waste' heat can be delivered to the heat-users.

Level 1

Level 1 assumes that no new nuclear power stations are built. By 2050, the UK's existing fleet has all been retired.

Level 2

Level 2 assumes a 4-fold increase in capacity over 2010 levels, reaching 39 GW by 2050, equivalent to building 13 3- GW power stations.

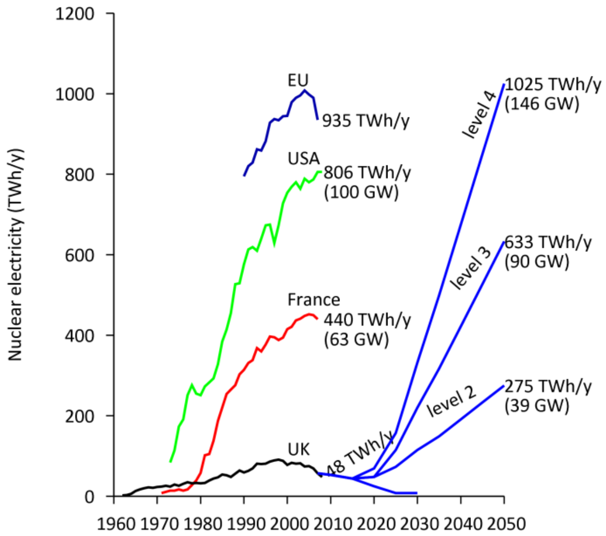


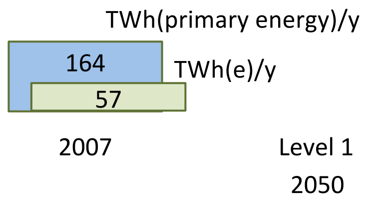
Figure 1. UK nuclear electricity production versus time, historic (to 2010) and possible-future (from 2010 onwards) compared with France, USA and the EU.

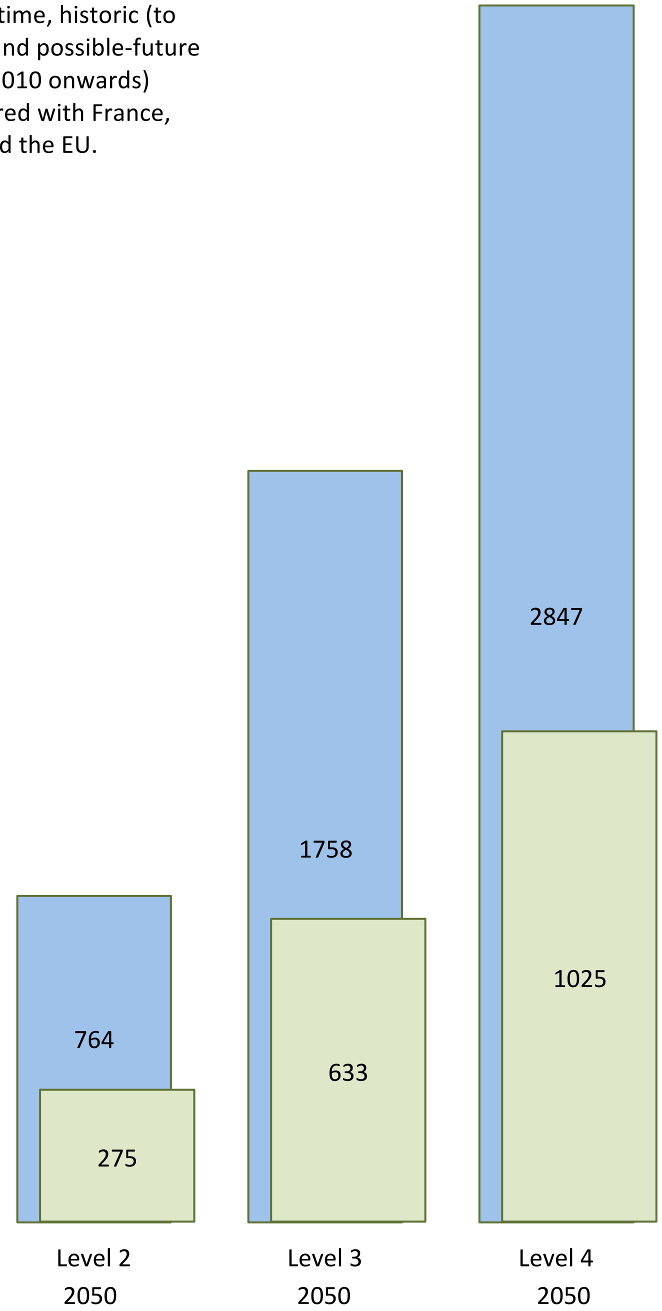
Level 3

Level 3 assumes a 9-fold increase in capacity over 2010 levels by 2050, building the equivalent of 30 3-GW power stations. The build-rate would be similar to France's in the 1980s and would be maintained for longer (Figure 1).

Level 4

Level 4 assumes a 13-fold increase in capacity over 2010 levels to 146 GW by 2050, roughly equivalent to 50 3-GW power stations. These stations produce just over 1000 TWh/y of electrical output, which is 40% of the total output of all the nuclear power stations operating in the world in 2009.





Carbon capture and storage power stations

Carbon capture and storage (CCS) technology captures carbon dioxide (CO_2) from fossil fuel power stations, which is then transported via pipelines and stored in deep underground structures such as depleted oil and gas reservoirs. Up to 90% of the carbon dioxide from a fossil fuel power station could be captured using CCS technology. CCS is unproven on a large scale, as yet.

In the 2050 Calculator the future shape of the CCS sector is determined by two choices: the CCS power station build rate (described here) and the CCS power station fuel mix' (described on another page).

Level 1

Level 1 assumes that, aside from the coal and gas demonstration projects currently planned, there is no further construction of new CCS plants or retrofitting of CCS technology.

Level 2

Level 2 assumes that CCS technology is developed successfully and that by 2050 the UK buries between 79 and 164 million tonnes of CO_2 per year (depending on whether the fuel is gas or coal). This is similar to the amount of oil that was handled each year at the peak of the UK's North Sea oil industry. 40 GW of CCS-fitted power plants effectively replace the UK's existing fleet of fossil fuel power stations, providing around 260 TWh/y of output. That means building about 30 1.2-GW power stations.

Level 3

Level 3 assumes that the UK builds 53 GW of CCS power station capacity by 2050, which is about 45 1.2-GW power stations, producing around 370 TWh/y of electricity.

Level 4

Level 4 assumes that the UK builds 87 GW of CCS power stations by 2050, equivalent to around 70 1.2-GW power stations, producing around 560 TWh/y of output. Such a build rate is similar to the rate at which gas power stations were built during the 1990s but sustaining this level of construction for the period of time needed has never been done before. This amount of CCS plant also requires the construction of infrastructure for transporting and storing the captured CO_2 on a large scale.

Interaction with other choices

There is significant demand for CO_2 transport infrastructure and storage capacity in three sectors: industry, carbon capture and storage power stations, and geosequestration. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

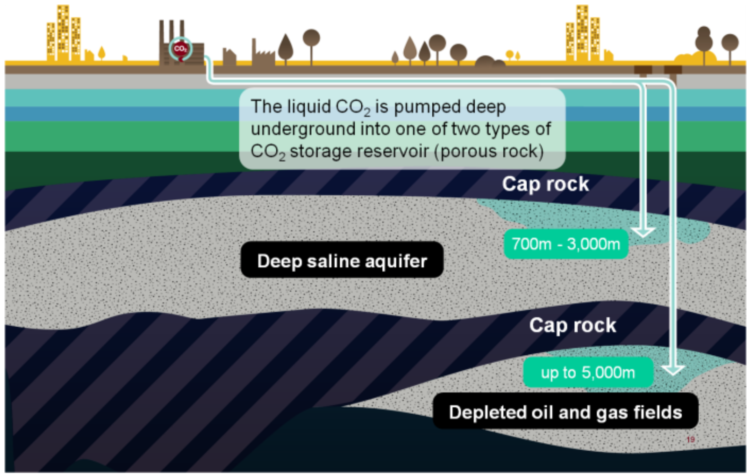
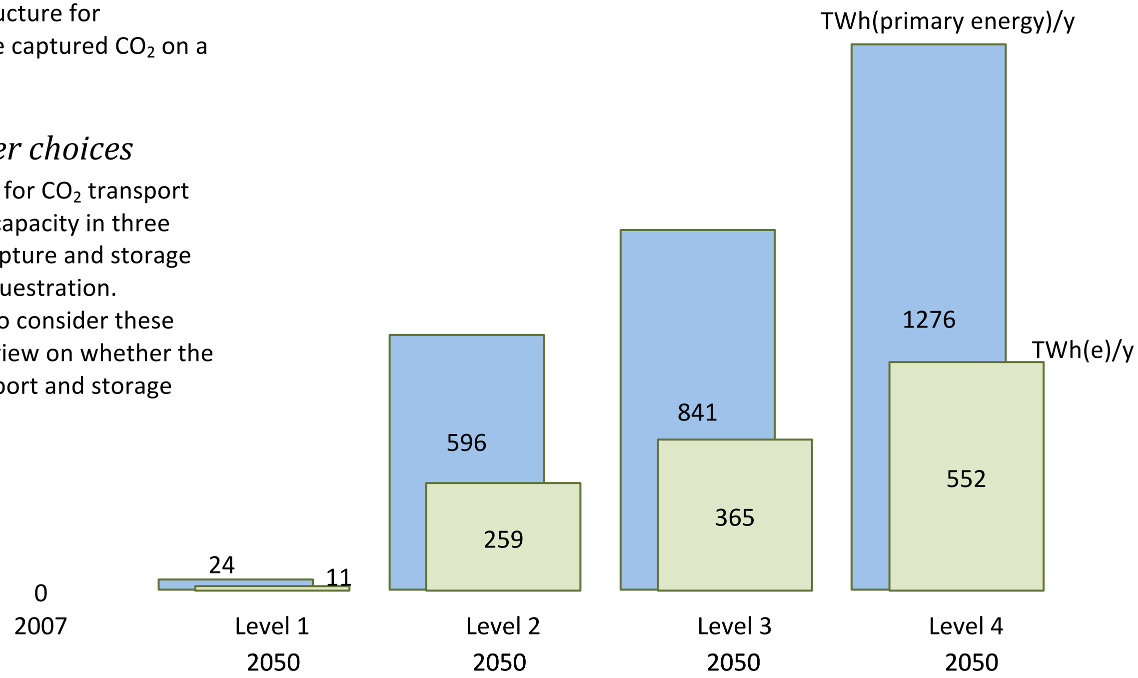


Figure 1. CO_2 can be stored within two types of geological formations; deep saline aquifers and depleted oil and gas fields. Picture © Zero Emissions Platform



Carbon capture and storage power station fuel mix

The 2050 Calculator allows CCS power stations to be fueled by a solid fuel (coal or biomass if it is available) or a gaseous fuel (natural gas or a biogas if it is available). Any available biofuel is used in preference to the equivalent fossil fuel.

In the 2050 Calculator the future shape of the CCS sector is determined by two choices: the CCS power station fuel mix (described here) and the CCS power station build rate (described on another page).

All of the trajectories below assume that the four CCS demonstration projects built in level 1 of the 'CCS power stations' lever consist of three coal plants and one gas plant. The different fuel trajectories only apply to any commercial-scale CCS plants built in addition to these four demonstration plants (in levels 2-4).

Trajectory A

Trajectory A assumes that all CCS power stations use solid fuel (coal or biomass).

Trajectory B

Trajectory B assumes that two-thirds of CCS power stations use solid fuel (coal or biomass), and the rest use gas (natural gas or biogas).

Trajectory C

Trajectory C assumes that two-thirds of CCS power stations use gas (natural gas or biogas), and the rest use solid fuel (coal or biomass).

Trajectory D

Trajectory D assumes that all CCS power stations use gas (natural gas or biogas).

Interaction with other choices

Plants capture CO_2 from the atmosphere as they grow, which they store in the form of biomass. The UK can take advantage of this by harvesting the biomass and burning it in electricity generation plants which are fitted with CCS infrastructure. This would ensure that up to 90% of the CO_2 sequestered from the atmosphere by plants is stored underground in designated CCS facilities. This process is called bioenergy plus carbon capture and storage (BECCS).

A 2050 Calculator user can select BECCS by:

- Assuming that CCS is in commercial operation, by selecting levels 2-4 for CCS.
- Selecting options for biomass to be grown in the UK and/or imported.
- Ensuring that the biomass is in the same form as the fuel demanded by the CCS power plants. For example, gas CCS power plants require biogas.

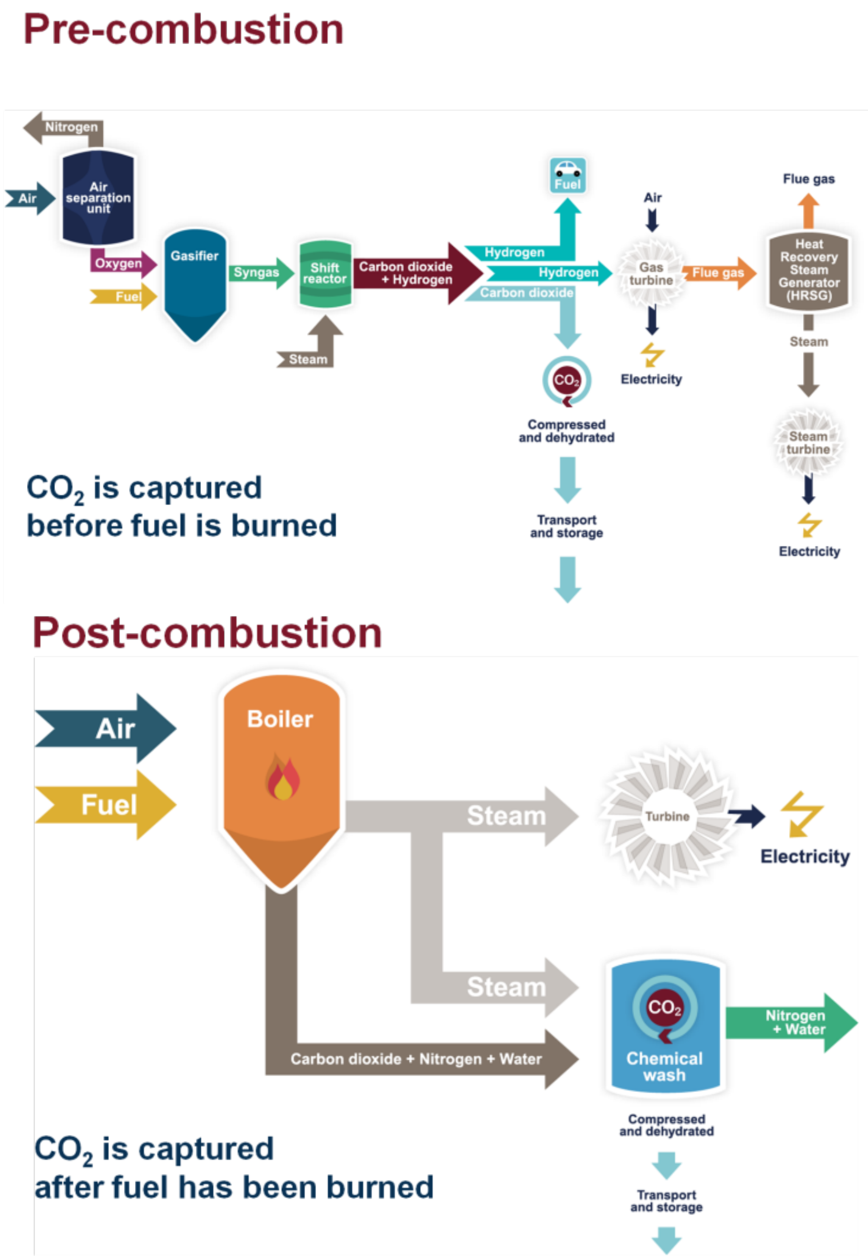


Figure 1. An illustration of two broad approaches to carbon capture. Pictures © Zero Emissions Platform.

Offshore Wind

In 2007 the UK had around 0.4 GW of offshore wind capacity, and at the end of 2010, 1.3 GW. All of these were fixed to the seabed by solid foundations, with no floating offshore turbines yet present in the UK.

Level 1

Level 1 assumes that only the current turbines and those already advanced in the planning process are built. Offshore wind capacity initially rises from 1 GW to 8 GW in 2025 then reduces to zero by 2045 as decommissioned sites are not replanted. 8 GW is equivalent to around 1400-5.8 MW turbines (although in reality turbines would have different capacities) and generates around 29 TWh/y at 2025.

Level 2

Level 2 assumes that capacity increases to 60 GW by 2040 and is then maintained. This means building and maintaining about 10 000 of the 5.8-MW turbines in total. In this scenario the sea area occupied by wind farms is about 10 800 km^2, about half the area of Wales. It requires maintaining the same build rate that Germany achieved for onshore turbines from 2000 to 2010 over a 20-year period in the UK and in an offshore environment. 60 GW of offshore wind turbines generates around 237 TWh/y in 2050.

Level 3

Level 3 assumes that capacity rises to 45 GW by 2025, and to 100 GW by 2050, which is equivalent to around 17 000 5.8-MW turbines. The sustained installation rate is 5 GW per year. Installing 5 GW per year might require roughly 30 jack-up barges and means building offshore wind turbines at a rate never before achieved in any country. The sea area occupied by wind farms is 18 000 km^2, close to the area of Wales. The combined weight of steel and concrete in these turbines is roughly 0.4 tonnes for every Briton. 60 GW of offshore wind turbines generates around 395 TWh/y in 2050.

Level 4

Level 4 assumes that capacity rises to 68 GW by 2025, and to 236 GW by 2050 – a 180-fold increase from 2010. The sustained installation rate required is 6 GW per year of fixed turbines (which requires roughly 30 jack-up barges) plus 6 GW/y of floating turbines. In total, this is equivalent to about 40 000 5.8-MW turbines being built by 2050. The costs of offshore wind installation and maintenance increase with the distance from shore and water depth. For level 4, the sea area occupied by wind farms is over 42 000 km^2, roughly twice the area of Wales, including both fixed and floating turbines. If 236 GW of the 5.8 MW turbines were arranged uniformly along 3400 km of coastline, there would be 12 of them per kilometre, generating around 929 TWh/y in 2050. The combined weight of steel and concrete in these turbines is 0.9 tonnes for every Briton.

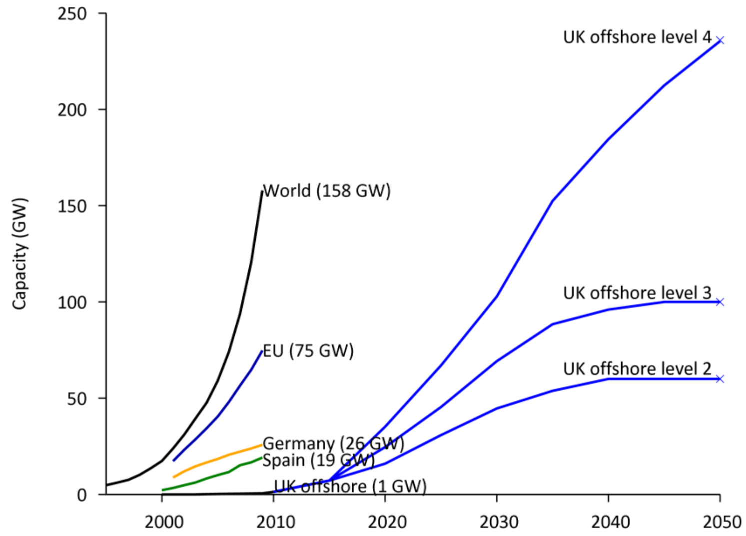
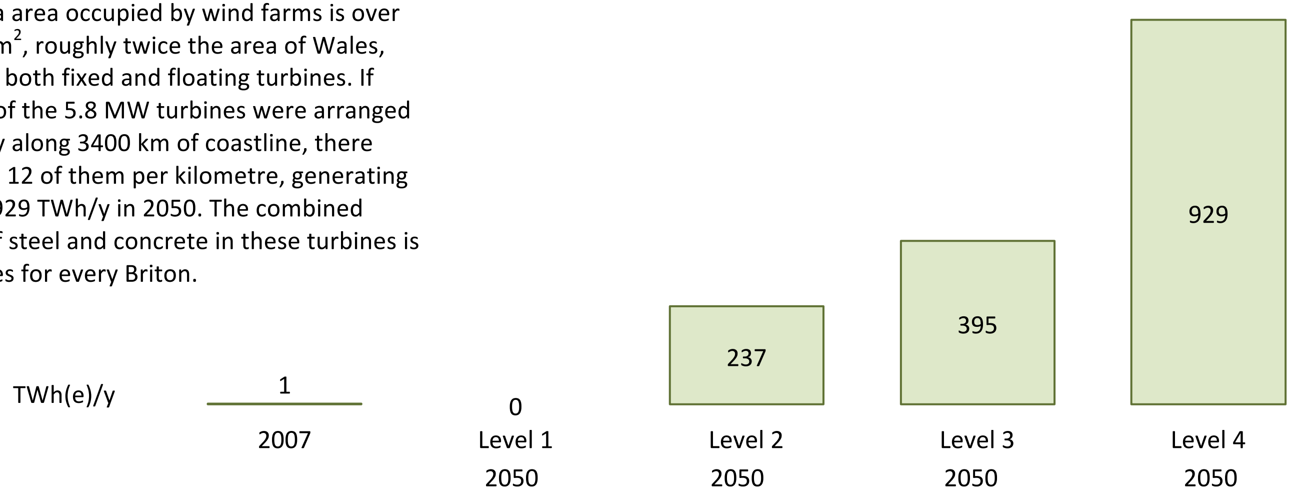


Figure 1. UK offshore wind capacity versus time, historic (to 2010) and assumptions (from 2010 onwards), compared with onshore wind in Spain, Germany, EU, and world totals.



Onshore Wind

In 2007 the UK had around 2 GW of installed onshore wind capacity. This figure excludes small wind turbines (micro and mini turbines), which are considered separately.

Level 1

Level 1 assumes that only turbines that are advanced in the planning process today are built. Onshore wind capacity therefore rises from 3.9 GW in 2010 to a peak of 11 GW at 2025, before falling back to zero in 2050 as the turbines reach the end of their useful life. 11 GW is equivalent to 4400 2.5-MW turbines (slightly bigger than those shown in Figure 1), and generates around 29 TWh/y in 2025.

Level 2

Level 2 assumes that capacity rises to 20 GW in 2030 and is maintained at that level by replacing retired turbines. Level 2 represents a 1 GW/y build rate from 2010 onwards, producing around 8000 2.5-MW turbines by 2030. This would be a five-fold increase in onshore wind compared to 2010.
20 GW of onshore wind turbines generates around 53 TWh/y in 2050.

Level 3

Level 3 assumes that capacity rises to 26 GW by 2025, then to 32 GW by 2050. As Figure 2 shows, level 3 roughly corresponds with the high levels of deployment in Germany and Spain over the last decade or so. Level 3 assumes that capacity is built at the rate of 1.6 GW/y from 2015 onwards. That means building about 13 000 2.5-MW turbines across the country. The total area of the wind farms would be about 4000 km^2, or 1.5% of the UK. If 13 000 turbines were spaced evenly alongside all of Britain's motorways, dual carriageways and trunk roads, you would find one every 920 metres. 32 GW of onshore wind turbines generates around 84 TWh/y in 2050.

Level 4

Level 4 assumes that capacity rises to 34 GW by 2025, then to 50 GW by 2050, with a sustained installation rate of about 1000 turbines per year. There are significant interconnection and storage requirements, as discussed in the section on 'Storage, demand shifting and interconnection'. The level 4 output of 132 TWh/y could be delivered by about 20 000 2.5-MW turbines in 2050, although in reality we would expect turbine capacities to increase over that time period. The total area of the wind farms would be about 6000 km^2, or 2.5% of the UK. If 20 000 turbines were spaced evenly alongside all of Britain's motorways, dual carriageways, and trunk roads, there would be one every 600 metres.

Figure 1. Red Tile wind farm, East Anglia. Each turbine has a capacity of 2 MW

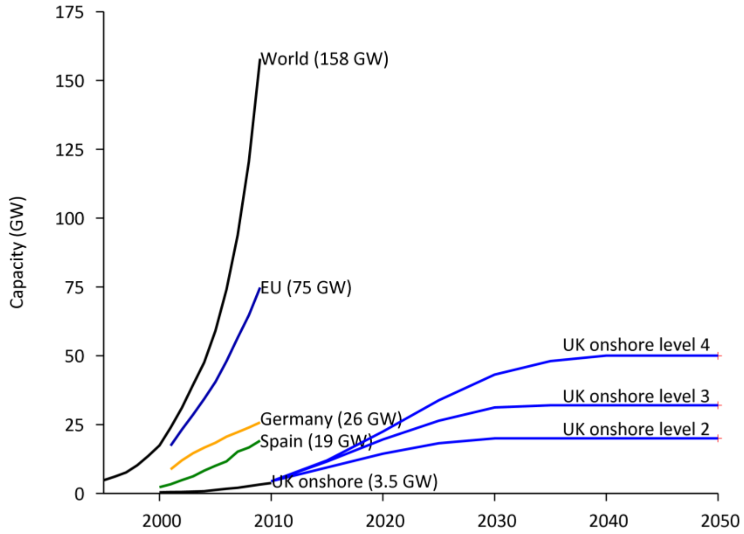
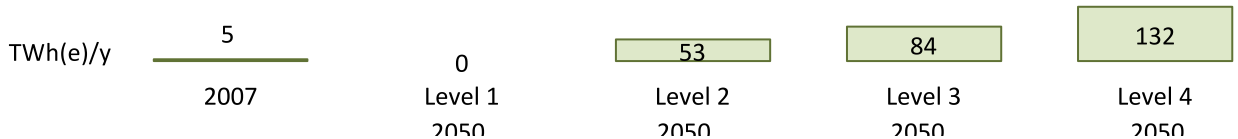


Figure 2. UK onshore wind capacity versus time, historic (to 2010) and assumptions (from 2010 onwards), compared with Spain, Germany, the EU, and world totals.



Wave

Most of the wave power approaching Britain comes from the Atlantic. As the map shows, Britannia rules about 1 000 km of Atlantic coastline. The power of Atlantic waves is about 40 kW per metre of exposed coastline.

One of the leading offshore wave devices is the Pelamis (Figure 1), a ‘sea snake’ which floats in deep water and faces nose-on to the oncoming waves. The waves make the snake flex, and these motions are resisted by hydraulic generators. The peak power from one snake is 750 kW; in the best Atlantic location one snake would deliver 300 kW on average. One snake weighs 700 tons, including 350 tons of ballast. Other designs such as sea-bed-mounted wave machines are also in development.

Level 1

Level 1 assumes there is very little investment in wave power, with no wave machines deployed up to 2050.

Level 2

Level 2 assumes the UK deploys the equivalent of 300 km of Pelamis wave farms in the Atlantic by 2050. This requires a Pelamis every 40 metres over the 300 km stretch, totalling 8000 machines. The machines deliver 8 kW per metre of the wave farm (20% of the waves’ raw power) with an availability of 90% (allowing time for maintenance). The total output of these wave farms is 19 TWh/y.

Level 3

Level 3 assumes that the UK deploys the equivalent of 16 000 Pelamis machines over 600 km of the Atlantic coastline by 2050, delivering the same power per machine as in level 2. 600 km is a little further than the distance between London and Glasgow. The total output of these wave farms is 38 TWh/y.

Level 4

Level 4 assumes that the UK deploys the equivalent of around 27 000 Pelamis machines over a 900 km stretch, involving installing the full capacity north of Ireland as well as some off the south-west tip of Cornwall (see Figure 2).These machines are also assumed to be more efficient, delivering 10 kW per metre (25% of the waves’ raw power). With a 90% availability, the total output of such wave farms is 71 TWh/y.

Figure 1. A Pelamis wave energy converter is a ‘sea snake’ made of four sections, each the size of a railway locomotive. It faces nose-on towards the incoming waves. Photo © Pelamis wave power.

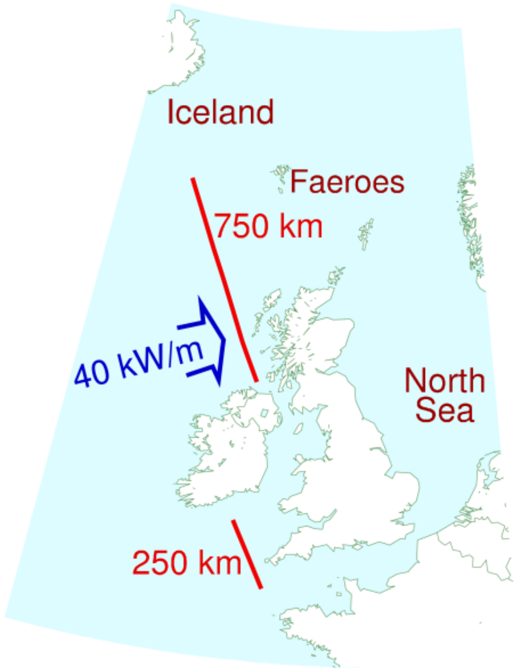
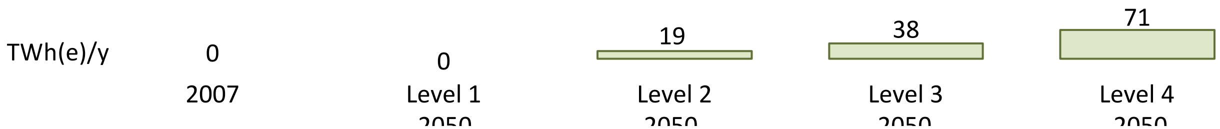


Figure 2. Map showing 1000 km of potential UK wave farm locations. Level 4 requires 900 km of wave farms.



Tidal range

In 2007 there were a few tidal range schemes in operation around the world, including the La Rance barrage in France, but there were none in the UK.

Level 1

Level 1 assumes that the UK does not exploit tidal range technology by 2050.

Level 2

Level 2 assumes the UK builds 1.7 GW of tidal range schemes by 2050, equivalent to seven schemes like La Rance in France (Figure 1) and requiring an enclosed water area of about 130 km^2. This is well within the scope of the potential sites available; the proposed Cardiff-Weston barrage on the Severn would be five times as big. The total electricity generated is 3 TWh/y in 2050.

Level 3

Level 3 assumes that the UK builds 13 GW of tidal range capacity by 2050 with an enclosed water area of around 900 km^2, about the size of 41 La Rance schemes. There are a number of possible options for achieving this level of ambition, including the proposed Cardiff-Weston barrage on the Severn which could generate 17 TWh/y. Other tidal range sites are also developed, for example at the Solway and Mersey. The total electricity generated is 26 TWh/y in 2050.

Level 4

Level 4 assumes that 20 GW of tidal range capacity is built by 2050 with an enclosed water area of around 1400 km^2, about the size of 64 La Rance schemes. This requires all of the UK's potential tidal range resource to be fully developed. The total electricity generated is 39 TWh/y in 2050.

Figure 1. The La Rance tidal barrage in Brittany, France, has been operating since 1966, with a peak generation of 240 MW.

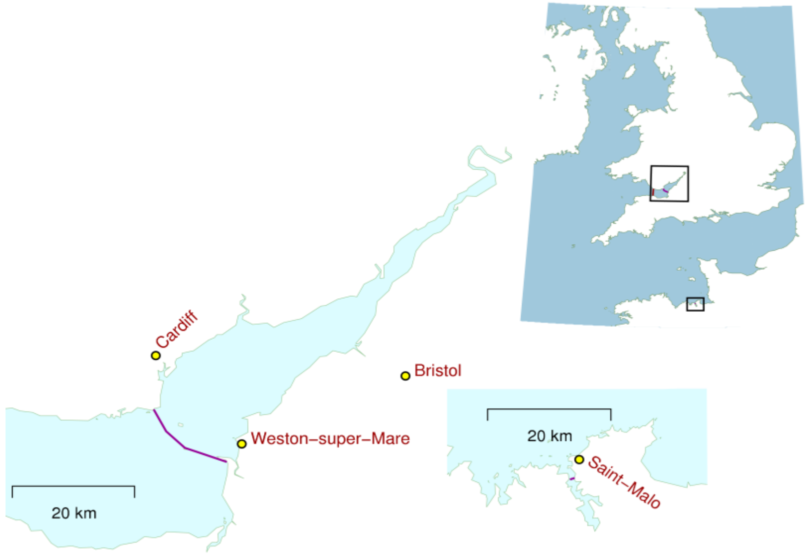
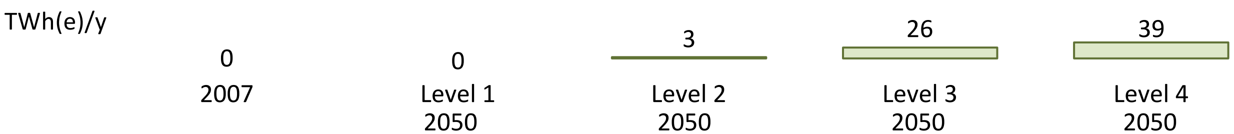


Figure 2. The La Rance Tidal Power Station (lowest map) plotted at the same scale as one of the options for a tidal range scheme in the Severn (on the left).



Tidal stream

Tidal stream technologies harness the energy from the tides using underwater turbines. In 2007 there were only experimental tidal stream machines in the UK. There remains considerable uncertainty about the tidal stream resource in British waters.

Level 1

Level 1 assumes that no tidal stream devices are installed by 2050.

Level 2

Level 2 assumes that tidal stream capacity grows to 1.9 GW by 2050, equivalent to roughly 000 2-MW tidal stream devices, larger than the 1.2-MW Seagen prototype shown in Figure 1. This capacity generates 6 TWh/y of electricity output.

Level 3

Level 3 assumes that tidal stream capacity grows to 9.5 GW by 2050, equivalent to 4700 2-MW devices. This generates 30 TWh/y of electricity output.

Level 4

Level 4 assumes that tidal stream capacity grows to 21.6 GW by 2050, equivalent to 10 600 2-MW devices. This generates 68 TWh/y of electricity output.

Figure 1. Seagen (Strangford Lough), the first grid-connected tidal stream device in the UK, with capacity of 1.2 MW. Photo by Dr. I.J. Stevenson.

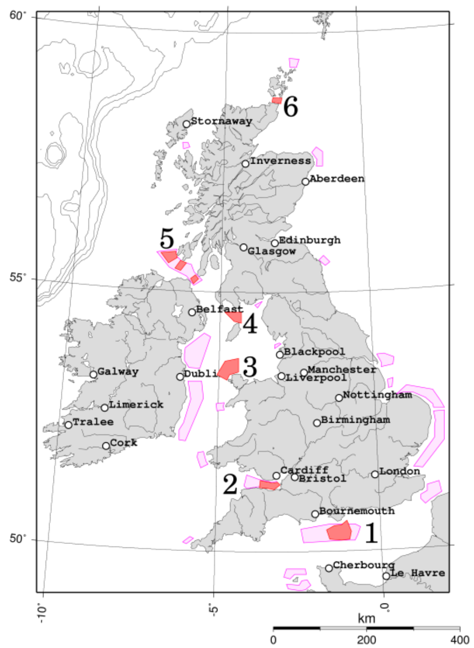
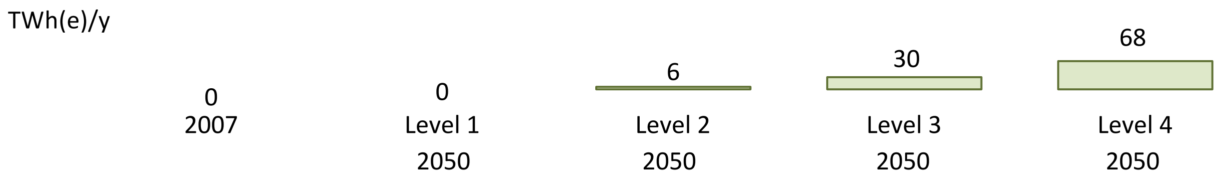


Figure 2. The six areas marked in red have peak tidal flows that exceed 1 m/s.



Biomass power stations

In 2009 the UK had 400 MW capacity of dedicated biomass plants, and 255 MW capacity of biomass co-firing plants, which can burn both coal and biomass. If these plants were running 90% of the time and using just energy crops, it would require around 1700 km^2 of land to grow the fuel on, if it all came from purpose-grown energy crops.

Level 1

Level 1 assumes dedicated biomass plants reach an installed capacity of 600 MW by 2010 and remain at that level until 2050, delivering 4.7 TWh/y of electricity.

Level 2

Level 2 assumes that 180 MW of biomass power plants are built or converted from coal plants every year, reaching 3 GW of installed capacity in 2025 and just under 8 GW by 2050. This is equivalent to a third of the current coal power station fleet and generates 62 TWh/y of electricity. The biomass power plants require solid biomass amounting to 16 times the UK's current use, and if this were all from purpose-grown energy crops they could cover an area the size of Wales.

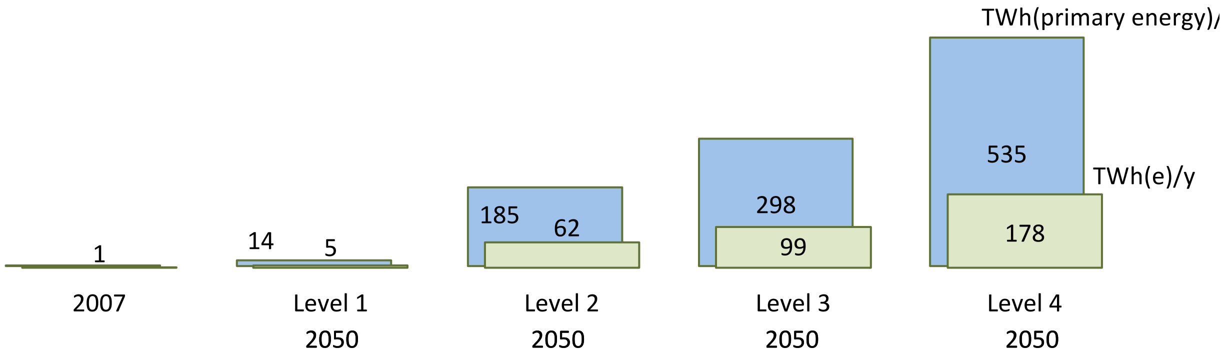
Level 3

Level 3 assumes there is a sustained build/conversion rate of biomass plants just above the historical maximum rates in Sweden and Italy for every year from 2010 to 2050. The installed capacity reaches 5 GW in 2025 and over 12 GW by 2050. This is roughly equivalent to half the UK's current fleet of coal power stations and generates about 100 TWh/y of electricity. These biomass power stations use up to 26 times more solid biomass than we do today, which could be sourced from 32 000 km^2 of land, or 1.5 times the area of Wales.

Level 4

Level 4 assumes that the UK constructs a fleet of biomass power stations roughly equivalent to the current coal power stations' installed capacity of 23 GW. Total capacity reaches 8 GW in 2025 and over 22 GW by 2050. Based on the size of today's average power stations, this requires over 500 dedicated biomass power stations or 11 coal-plant-sized equivalents. The power stations use just under the maximum available solid biomass of 535 TWh/y, representing 58 000 km^2 of energy crops, an area nearly 3 times the size of Wales. After efficiency and processing losses, these biomass power stations produce nearly 180 TWh/y of electricity output.

Figure 1. Drax power station, which burns both coal and solid biomass. Photo ©Ashley Lightfoot.



Solar panels for electricity

In 2007, the UK had about 8 MW of solar panels for electricity (also known as 'solar photovoltaic' or solar PV). By 2010, the capacity had increased to about 75 MW, generating less than 1 TWh.

Level 1

Level 1 assumes that solar PV's contribution remains much less than 1 TWh/y up to 2050.

Level 2

Level 2 assumes that solar PV capacity reaches 6 GW in 2030 (producing 5 TWh/y) and 70 GW by 2050 (producing 60 TWh/y). At this level there are 4 m^2 of solar panels for every person in the UK. This would be a 900-fold increase compared to 2010.

Level 3

Level 3 assumes that UK solar PV capacity reaches 16 GW in 2030 (producing 14 TWh/y) and 95 GW by 2050 (producing 80 TWh/y). This is the equivalent of 5.4 m^2 of roof space for every person by 2050. This is roughly half of all South-facing roofs of domestic homes.

Level 4

Level 4 assumes that solar PV capacity reaches 150 GW in 2030 (producing 127 TWh/y) and 165 GW by 2050 (producing 140 TWh/y). The area of panels required is about 10m^2 per person, roughly the same as the area of all South-facing roofs of domestic homes.

Level 4 can also be visualized in terms of land-based solar farms, where the land area required to deliver 140 TWh/y is 3 200 km^2 (assuming a power per unit land-area of 5 W/m^2). This is equivalent to 12 800 of the solar farms in Figure 2. It is also equivalent to 1.3% of the country and similar to the land area currently occupied by all buildings.

Figure 1. The peak power delivered by this 25 m^2 array is about 4 kW. The average is 0.5 kW, equivalent to 20 W/m^2.

Figure 2. The peak power delivered by this 25 000 m^2 solar photovoltaic farm in Muhlhausen, Bavaria is about 6.3 MW. The average is 0.7 MW, so the average power per unit area is 5 W/m^2.

	2007	Level 1 2050	Level 2 2050	Level 3 2050	Level 4 2050
TWh(e)/y	0	0	60	81	140

Solar panels for hot water

Solar water heating systems (also known as 'solar thermal') use solar panels to warm water which is stored in a hot water cylinder. In 2007 less than 1% of buildings had solar hot water systems.

Level 1

Level 1 assumes that in 2050, as today, only a very small proportion of buildings have a solar thermal system.

Level 2

Level 2 assumes that in 2050 about 30% of suitable buildings have 30% of their annual hot water demand met by solar thermal. The panels for a typical home would occupy about 3 m^2 of South-facing roof (Figure 1). In 2050 solar thermal delivers around 20 TWh/y of heat.

Level 3

Level 3 assumes that all suitable buildings have some level of solar thermal heating system in 2050, with around 30% of their annual hot water demand met by solar thermal. 1.6 m^2 of panels per person are installed to generate 58 TWh/y of heat.

Level 4

Level 4 assumes that in 2050 all suitable buildings have around 60% of their annual hot water demand met by solar thermal. This requires 3.1 m^2 of solar panels per person, delivering 116 TWh/y of heat energy. This is feasible given that all south-facing domestic roofs could accommodate 10 m^2 per person. It is possible that there will be competition for roof space between solar photovoltaic and solar thermal panels, in which case some of these solar panels may appear as ground-based solar farms instead. It is estimated that 1.5 m^2 of solar thermal panels per person are needed to supply all domestic summer hot water demand using today's technology. Level 4 assumes double this area of panels. To avoid wasting the excess heat delivered in the summer, seasonal heat storage systems are needed to store heat so that it can be used during the winter.

Figure 1. A house with a 3 m^2 Viridian Solar panel on its roof. Photo © Viridian Concepts Ltd.

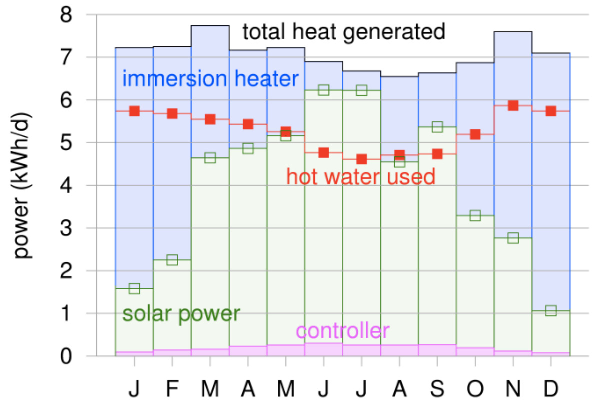


Figure 2. Solar power generated by the 3 m^2 hot-water panel in figure 1 (green), and supplementary heat required (blue) to make hot water in the test house of Viridian Solar. The average solar power from 3 m^2 was 3.8 kWh/d. The experiment simulated the hot-water consumption of an average European household – 100 litres of hot (60˚C) water per day. The 1.5–2 kWh/d gap between the total heat generated (black line, top) and the hot water used (red line) is caused by heat-loss. The magenta line shows the electrical power required to run the solar system. The average power per unit area of these solar panels is 53 W/m^2.

	2007	Level 1 2050	Level 2 2050	Level 3 2050	Level 4 2050
TWh(60˚C thermal)/y	0	0	19	58	116

Geothermal electricity

Using the heat from hot dry rocks deep underground (typically 4-5 kilometres deep) to generate electricity is a technology in its early stages: there are a handful of prototypes and small-scale commercial plants around the world which generate a few MW each.

The UK has only a few areas where rocks are confidently predicted to be hot enough to support electricity generation. This includes Cornwall, where some geothermal experiments were carried out in the 1980s.

It is possible to generate heat as well as electricity from geothermal resources but heat exploitation is constrained by the need to locate geothermal plants near to heat demand.

Level 1

Level 1 assumes that there is no commercial use of geothermal sources for power generation by 2050.

Level 2

Level 2 assumes that the geothermal demonstration projects currently being built in Cornwall today are successful, leading to steady building of geothermal plants in the best sites in Cornwall. These plants could typically have capacity of around 10 MW, greater than the 3-MW plant in Figure 1. The total capacity reaches about 1 GW by 2035 (equivalent to roughly 100 10-MW plants), and is maintained at this level, leading to an output of 7 TWh/y between 2035 and 2050.

Level 3

Level 3 assumes that geothermal extraction efforts are focused not only on Cornwall, but also other areas where granite is predominant, like Cumbria. Total capacity reaches about 3 GW by 2030 (equivalent to roughly 300 10-MW plants), and is maintained at this level, leading to an output of 21 TWh/y between 2030 and 2050.

Level 4

Level 4 assumes that the UK utilises all of its practically available hot rock resource. This requires drilling geothermal wells to a depth of 5 km not only across Cornwall, but also in the Eastern Highlands of Scotland, the Pennines and the Lake District. Total capacity reaches about 5 GW by 2030 (equivalent to roughly 500 10-MW plants), and is maintained at this level, leading to an output of 35 TWh/y between 2030 and 2050.

Figure 1. Landau 3-MW geothermal power station in der Pfalz, Germany. The blue pump brings the hot water up and the red one puts it back into the ground. Photo © Geox.

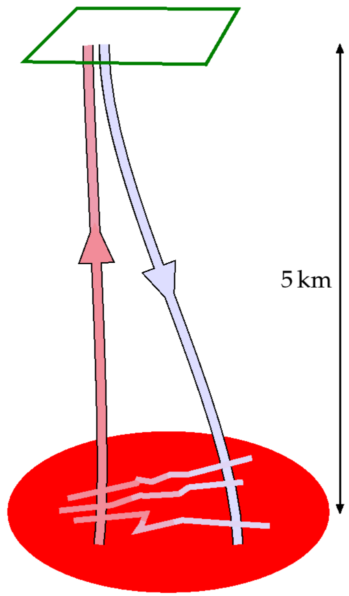


Figure 2. Enhanced geothermal extraction from hot dry rock. A well is drilled and pressurized to create fractures. A second well is drilled into the far side of the fracture zone. Cold water is pumped down one well, driving heated water or steam up the other.

Hydroelectric power stations

In 2007 the UK had 1.3 GW of large-scale hydropower capacity which generated about 4 TWh/y, approximately 1.4% of the UK's electricity demand, and a much smaller amount of small-scale hydropower capacity.

Level 1

Level 1 assumes that total hydropower capacity is maintained at the 2010 level of 1.6 GW up to 2050, typically producing around 5 TWh/y of electricity output.

Level 2

Level 2 assumes that capacity reaches 2.1 GW by 2050, through the refurbishment of existing schemes and some micro-hydro sites. This capacity generates around 7 TWh/y of electricity.

Level 3

Level 3 assumes that hydropower capacity reaches 2.5 GW by 2030 and then remains the same until 2050, generating around 8 TWh/y of electricity. This output represents a 60% increase on the current energy output of the UK's existing hydropower resource. To achieve this by 2030 requires dramatic action in terms of planning and constructing hydroelectric sites, leading to the creation of a total UK reservoir area of around 80 km^2 to be used for hydroelectric power (including existing reservoir sites).

Level 4

Level 4 assumes that capacity grows rapidly, reaching 4 GW by 2035 and then remaining the same until 2050, generating 13 TWh/y of electricity. The extra reservoir area required to deliver this additional output beyond the 2007 baseline is roughly 83 km^2, set in a rainfall catchment area of 4 600 km^2 (assuming a power per unit reservoir area of 11 W/m^2, and a power per unit catchment area of 0.2 W/m^2, typical of a Highland hydroelectric facility).

Glendoe, the first new large-scale hydroelectric project in the UK since 1957, added capacity of 100 MW and is expected (once working) to deliver 0.18 TWh/y. So level 4 involves building roughly 40 new Glendoes in the UK. This is technically feasible but would raise large environmental and planning concerns.

Figure 1. Nant-y-Moch dam, part of a 55 MW hydroelectric scheme in Wales. Photo © Dave Newbould, www.origins-photography.co.uk

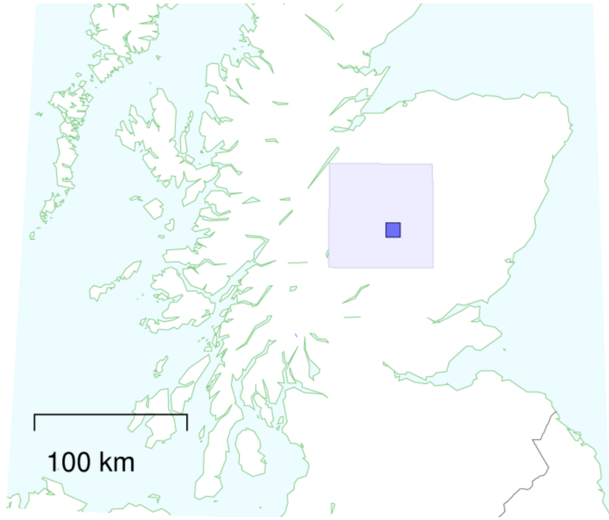


Figure 2. The total area of additional reservoirs assumed for level 4 is 83 km^2 (dark blue square), drawing on a rainfall catchment area of 4600 km^2 (light blue square).

TWh(e)/y	4	5	7	8	13
	2007	Level 1 2050	Level 2 2050	Level 3 2050	Level 4 2050

Small-scale wind

In 2007 the UK had almost no small-scale wind turbines.

Level 1

Level 1 assumes no significant increase, with small-scale wind turbines having negligible impact on the UK's energy system or the landscape.

Level 2

Level 2 assumes that capacity increases to 0.6 GW in 2020, delivering 1.3 TWh/y, and is sustained at that level to 2050. Today's roof-mounted micro-turbines (Figure 1) don't contribute significantly as they are simply too small. Let's therefore visualize levels 2, 3 and 4 in terms of mini-turbines (Figure 2). Each of these turbines produces an average output of 4000 kWh/y. Reaching level 2 requires the construction of about 325 000 turbines. That's roughly 1.5 mini-turbines per square kilometre of the UK.

Level 3

Level 3 assumes that capacity increases to 1.6 GW in 2020, delivering 3.5 TWh/y, and is sustained at that level to 2050. Roughly 875 000 mini-turbines are needed, 3.5 mini-turbines per square kilometre of the UK.

Level 4

Level 4 assumes that capacity increases to 4.1 GW in 2020, delivering 8.9 TWh/y, and is sustained at that level to 2050. This corresponds to 2.2 million mini-turbines, nine mini-turbines per square kilometre of the UK. If we assume that each of those mini-turbines 'occupies' an area of 30 m × 30 m, the area occupied at level 4 is 2000 km^2, or nearly 1% of the UK.

Figure 1. A 5.5 m diameter Iskra 5-kW mini-turbine having its annual check-up. This turbine, located in Hertfordshire (not the windiest of locations in Britain), mounted at a height of 12 m, has an average output of 11 kWh per day.

Figure 2. The average power generated by this Ampair 600-W micro-turbine in Leamington Spa is 0.037 kWh per day (1.5 W). For comparison, the average British person's share of electricity consumption is 17 kWh per day.

	2007	Level 1 2050	Level 2 2050	Level 3 2050	Level 4 2050
TWh(e)/y	0	0	1	4	9

Electricity imports

Low carbon electricity can be imported from abroad as well as being produced in the UK. This could come from sources such as geothermal energy from Iceland, wind energy from Norway's North Sea, or solar energy from southern Europe or northern Africa. These other countries could oversupply electricity and then export it to the UK, which might require improving the electricity connections to the UK.

Solar energy is collected by arrays of solar panels in sunny countries and the electricity generated is imported to the UK via cables. There are currently no dedicated solar farms supplying solar energy directly to the UK. The electricity connection from the UK to France has a capacity of 2 GW but this is currently used for non-solar electricity.

Level 1

Level 1 assumes that in 2050 the UK imports no electricity from solar plants abroad.

Level 2

Level 2 assumes that in 2050 the UK imports 30 TWh/y of electricity. This average energy production is the equivalent of every person in Britain having 2.5m^2 of solar photovoltaic panels in an overseas solar array.To deliver this energy, the capacity of the interconnector with France would be increased by 4 GW.

Level 3

Level 3 assumes that by 2050 the land area occupied by solar power stations in the countries exporting energy to the UK is 500 km^2, assuming a power per unit area of 15 W/m^2. This is one-third of the area of Greater London and generates 70 TWh/y. For this level of electricity imports the interconnector capacity between France and England needs to be boosted by 8 GW, giving a total of 10 GW. It also requires grid enhancements enabling an extra 8 GW to flow all the way from the Sahara to Surrey. This 70 TWh/y of output equates to every person in Britain having 6m^2 of solar photovoltaic panels in an overseas solar array, or 2.3 m^2 of mirrors in a concentrating solar power station like the one in Figure 1.

Level 4

Level 4 assumes that by 2050 the land area occupied by solar power stations in the countries exporting energy to the UK is 1000 km^2, assuming a power per unit area of 15 W/m^2. This is two-thirds of the area of Greater London and generates 140 TWh/y. The interconnector to France needs 20 GW of extra capacity. This level also requires grid enhancements in the UK enabling an extra 16 GW of electricity flow. This 140 TWh/y equates to every person in Britain having either 12 m^2 of overseas solar photovoltaic panels or 4.6 m^2 of mirrors in a concentrating solar power station.

Figure 1. The Andasol solar power station, occupying 2 km^2 of land in Andalusia, Spain. It produces a peak output of 100 MW of electricity, and 42 MW of electricity on average, equivalent to 20 W/m^2. Photo © BSMPS

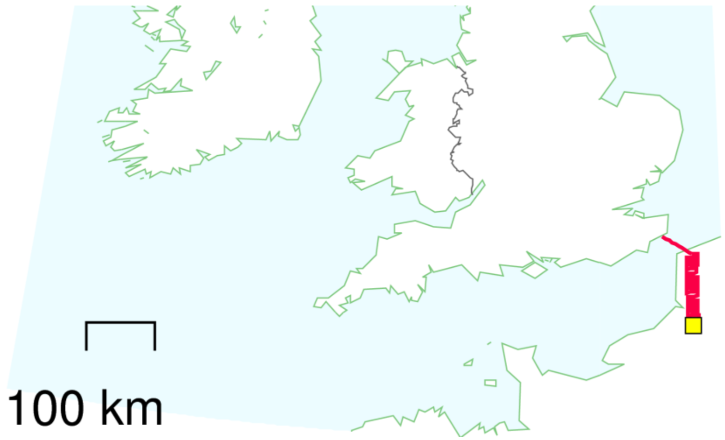
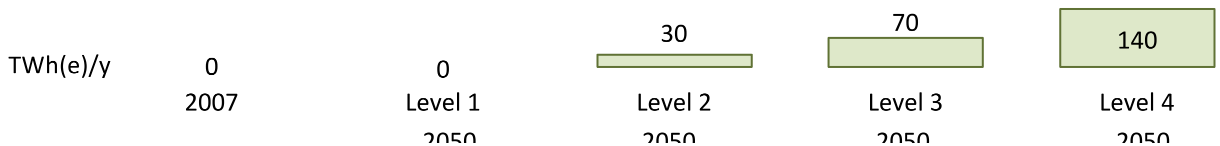


Figure 2. The yellow box shows an area of 500 km^2, as envisaged at level 3 for a solar power station.



Land dedicated to bioenergy

In 2007, the UK used 4000 km^2 of land to grow energy crops, which is less than 2% of the country. For comparison, 174 000 km^2 of land was used for arable crops, livestock, and fallow land. The 2050 Calculator contains two options relating to agricultural biomass and land use: land use management (described here) and livestock management (described on another page).

Level 1

Level 1 assumes that in long-term land management decisions until 2050, food production has priority over bioenergy. Land is split between activities in a way similar to today, although we are able to get more food from the land thanks to increased crop yields. The resulting energy available in 2050 is 55 TWh/y.

Level 2

Level 2 assumes that current trends and drivers in land management continue from now to 2050, with an increasing area of land covered by housing. However the area planted with bioenergy crops also increases, so that five times more energy crops are produced in 2050 than today. The resulting energy available in 2050 is 117 TWh/y.

Level 3

Level 3 assumes that bioenergy begins to break through as a significant part of domestic agricultural output, with 10% of UK land used by 2050 for growing energy crops, an area the size of Wales. There is an appreciable improvement in soil and crop management technologies, with some land currently used for food crops being reassigned to bioenergy production and forestry. The resulting energy available in 2050 is 324 TWh/y.

Level 4

Level 4 assumes that the UK has a strong domestic bioenergy production focus, with 17% of the country planted with energy crops. There is extensive carbon capture through forestry, and highly effective management and collection of waste materials for bioenergy use. The resulting energy available in 2050 is 545 TWh/y.

For comparison, Denmark's production of straw, woodchips, firewood, woodpellets, woodwaste, biogas, biooil, and biodiesel for energy in 2008 was 18 TWh/y. Scaled by the population ratio of UK to Denmark, this energy production is equivalent to 200 TWh/y in the UK.

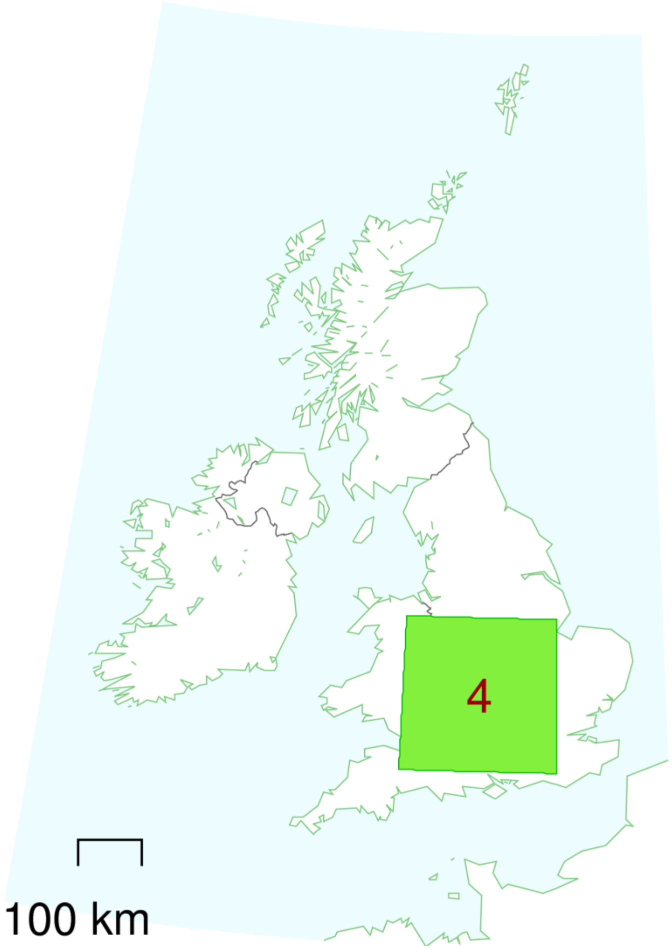
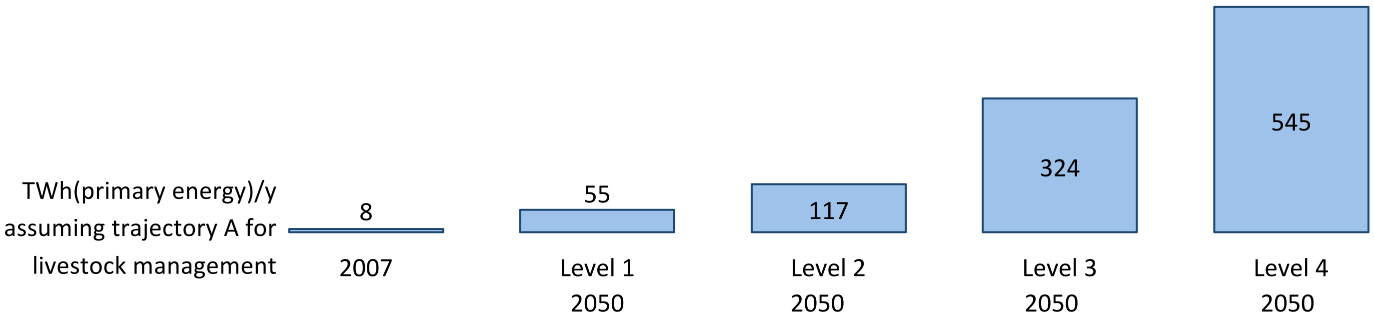


Figure 1. The 42 000 km^2 taken up by domestically produced bioenergy crops in level 4.



Livestock and their management

In 2007, there were over 220 million livestock animals, including nearly 2 million dairy cows. The 2050 Calculator contains two options relating to agricultural biomass and land use: livestock management (described here) and land use management (described on another page).

Level 1

Level 1 assumes that, by 2050, domestic food production takes priority imports, with livestock numbers increased by 10% over 2010 levels. This means approximately 200 000 more cows grazing on UK grass in 2050.

Level 2

Level 2 assumes that livestock numbers remain constant through to 2050. However due to manure yields increasing by 0.2% per year, more energy from waste is generated from agricultural by-products.

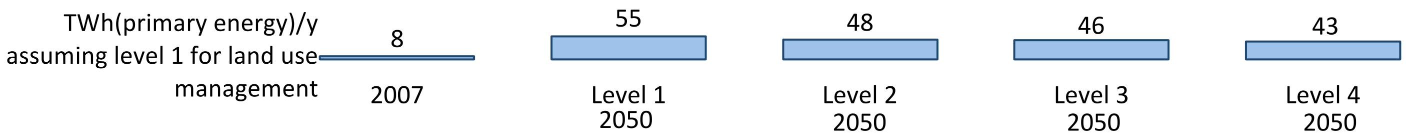
Level 3

Level 3 assumes that livestock numbers reduce by 10% by 2050. This is effectively the converse of level 1, and means there are approximately 200 000 fewer cows in the UK by 2050.

Level 4

Level 4 assumes a significant shift away from livestock production in the UK, potentially caused by us eating less meat, by switching from beef to less land-intensive meats such as chicken, or increasing the agricultural focus on bioenergy. Livestock numbers decline by 25% on 2010 levels, equivalent to 390 000 fewer cows by 2050.

Figure 1. A Hereford Bull. The 2050 Calculator assumes that every cow produces 400 oven dried kg of manure each year. Photo © US Department of Agriculture.



Volume of waste and recycling

In 2007 the UK produced around 119 Mt of non-agricultural wastes, including industrial waste, wood waste, sewage sludge and other sources. In the same year, around 58 TWh/y of energy was generated from waste facilities, landfill gas, sewage gas and non-biodegradable waste.

The best use of waste is not necessarily energy recovery. Agricultural materials such as manure and slurry and loose wood from forests are useful for land management and livestock management choices.

The changes here represent different choices rather than an increasing scale of effort. They cannot be compared with the Levels 1-4 in other sectors and have therefore been labelled as Trajectories A-C instead.

Trajectory A

Trajectory A assumes that between 2007 and 2050 the quantity of non-agricultural waste increases nearly 60%. The levels of waste going to landfill increase but the waste contains less biodegradable material. 196 TWh/y of primary energy is generated in 2050.

Trajectory B

Trajectory B assumes that the quantity of waste increases by 30% between 2007 and 2050. Recycling and energy recovery levels increase and the waste going to landfill is significantly reduced. This trajectory maximises energy from waste. It is assumed that around 1000 towns in the UK have their own waste-to-energy facility, each receiving on average 300 tonnes of waste per day. A large improvement in collection and processing of waste is assumed by 2050: 41% of residential, commercial, industrial and construction waste is used for energy (compared with 9% today) and 68% of methane from landfill sites is used for energy (compared with 30% today). 85% of sewage gases are used for energy in 2050 (compared with 75% today). Overall 212 TWh/y is generated in 2050.

Trajectory C

Trajectory C assumes that the quantity of waste remains the same as in 2007. Biodegradable waste going to landfill is eliminated, with most waste recycled. This maximises the level of waste that is avoided, reused and recycled. 134 TWh/y is generated in 2050.

For comparison, Denmark's use of waste for energy in 2008 was 11 TWh/y, including both agricultural and non-agricultural waste, but not straw or wood. Scaled to the UK population, that level of waste-to-energy is equivalent to 122 TWh/y in the UK.

Figure 1. The South East London Combined Heat and Power plant, SELCHP, takes about 1100 tonnes of black-bag waste per day and delivers about 31 MW of electricity. Photo © Bill Bertram

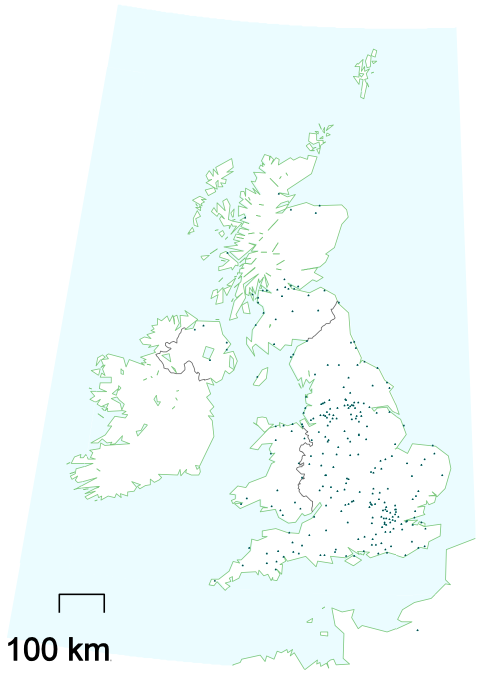
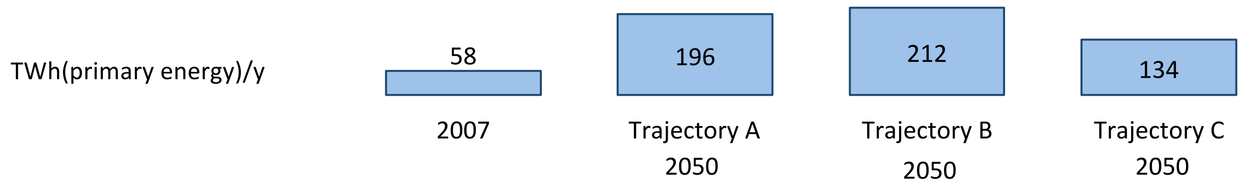


Figure 2. The 262 blue dots each represent a waste facility capable of taking as much waste as the SELCHP plant above and either recycling it or converting it into energy. This is the scale required to process UK waste in trajectory C, although the locations are



Marine algae

This section looks at macro-algae such as seaweed. To turn macro-algae into usable fuel, most of the water should be removed by filters and centrifuging before the oil contained in the algae is extracted. In 2007 most of the macro-algae in the UK grew naturally off the north-west coast of Scotland but no significant quantities of this were harvested.

The levels below are compared to the amount of macro-algae growing naturally in Scotland but the intention would be to harvest purpose-grown commercial stocks, not natural ones. These need not necessarily all be grown in Scotland as there are suitable sites elsewhere in the UK, such as off the coast of East Anglia.

Level 1

Level 1 assumes that macro-algae cultivation is not a significant source of liquid biofuel.

Level 2

Level 2 assumes that 560 km^2 of sea, equivalent to half of Scotland's current natural macro-algae stocks, is used for the commercial growth and collection of macro-algae by 2050. While feasible, this still represents an unprecedented offshore agricultural proposition. The algae grown on this area of sea produces 4 TWh/y of energy output.

Level 3

Level 3 assumes that by 2050 marine algae is commercially grown in an area of 1125 km^2, the same size as the current natural macro-algae stocks in Scotland. The area occupied would be about three Isles of Wight. This amount of algae produces 9 TWh/y of energy output.

Level 4

Level 4 assumes that by 2050 an area of 4700 km^2 is used to cultivate algae, over four times larger than existing natural stocks in Scotland and equivalent in area to over 12 Isles of Wight.

The algae grown on this area of sea generates about 46 TWh/y of usable energy per year. It is possible that cultivation at such large levels requires the addition of nutrients to help the algae grow. Water movements mean that such nutrient additions cannot be contained, so there is a risk of causing uncontrolled algal blooms. These might increase greenhouse gas emissions through ammonia and nitrous oxide production.

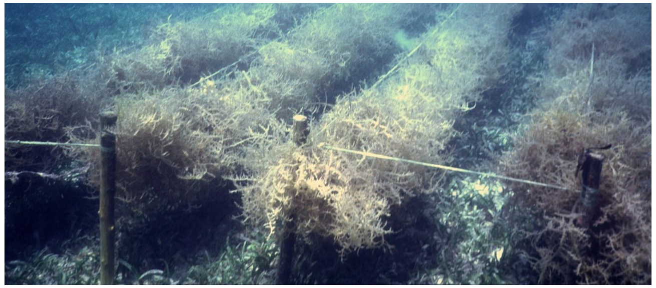


Figure 1. An algae farm in the Philippines, where the yield from a one-hectare farm can be as much as 48 tonnes in two months. In 2008 the Philippines harvested about 75 000 tonnes of seaweed. Photo © derekkeats.

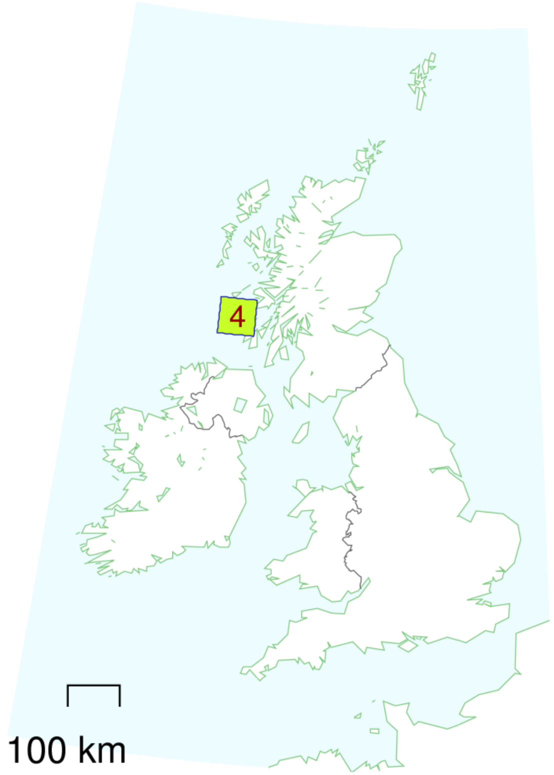
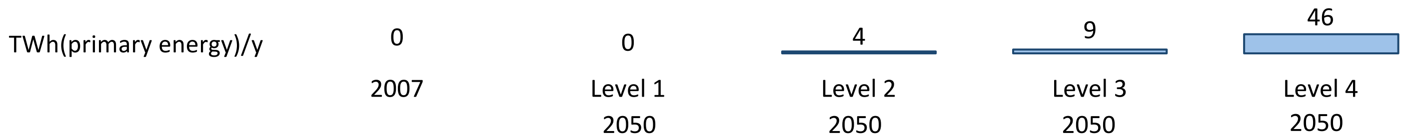


Figure 2. The 4700 km^2 taken up by macro-algae production in level 4.



Types of fuel from bioenergy

In the 2050 Calculator, the amount of bioenergy available for use is determined by the 'Land dedicated to bioenergy', 'Marine algae', 'Volume of waste and recycling' and 'Bioenergy imported' options (described on other pages). Biomass created through the first three of these levers is turned into bioenergy according to the options described here. Bioenergy imports are already usable as fuels.

Some types of biomass can only become particular fuels. For example landfill gas and manure are always turned into biogas, and first generation energy crops (crops usually used as fuel or animal feeds sources) are always turned into liquid bioenergy.

Other types of biomass can be turned into several different biofuels, and the Calculator allows the user to choose which fuel. By chosing between Trajectories A, B, C or D you choose whether second generation energy crops (derived from non-food crops), wood, algae and waste are turned into either solid, liquid or gas bioenergy. Table 1 shows the conversion efficiencies for 2020-2050, with lower efficiencies assumed before 2020.

The Calculator assumes that solid bioenergy can be used in any situation that uses coal (such as a coal power station), liquid bioenergy can be used in any situation that uses oil (such as a car engine), and gaseous bioenergy can be used in any situation that uses natural gas (such as heating).

When the user selects options which need coal in the 2050 Calculator, the fuels available are used up in a particular order. This order of fuel preference is:

1. Domestic biomass
2. Imported biomass
3. Domestic coal
4. Imported coal

If there is not enough of one fuel type available then the Calculator uses the next category until enough fuel has been found. The same order of preference is assumed for oil and liquid bioenergy, and also for natural gas and gaseous bioenergy, where bioenergy is used ahead of fossil fuel sources when it is available.

Trajectory A – Mixed fuels

Wood from forests, straw, and dry waste from residential, commercial and industrial waste are turned into solid bioenergy. Sewage, algae and the wet waste from residential, commercial and industrial waste are turned into gaseous bioenergy. Second generation energy crops are turned into liquid bioenergy.

Trajectory B – Solid fuels

Wood from forests, straw, dry waste and second generation energy crops are turned into solid bioenergy. Sewage, algae and wet waste are turned into gaseous bioenergy.

Trajectory C – Liquid fuels

All biomass apart from manure and landfill gas is turned into liquid bioenergy.

Trajectory D – Gaseous fuels

All biomass apart from first generation biocrops is turned into gaseous bioenergy.

Raw biomass input	**Final biofuel output**		
	Solid biomass	**Liquid biofuel**	**Biogas**
Algae and wet waste	x	38%	85%
Straw, forests and dry waste	95%	45%	66%
2nd generation energy crops	95%	45%	66%
1st generation energy crops	x	32%	x
Gaseous waste	x	x	100%

Table 1. The conversion efficiencies when different types of biomass are turned into solid, liquid or gaseous biofuel, showing the percentage of the energy that is retained. x indicates that a particular conversion route is not possible. The assumptions above apply for the period 2020-2050, with lower efficiencies assumed up to 2020.

Bioenergy imports

In 2007 the UK imported 4.8 TWh/y of liquid and solid biofuels from overseas producers.

The International Energy Agency (IEA) estimates that 4–8 million km^2 of land could be used globally for growing energy crops by 2050. That area would produce around 42 000 TWh/y of bioenergy. The IEA assumes that 40% of this bioenergy would be exported from the producer countries, with potential global supply of 17 000 TWh/y. If exports were split equally across the global population then the maximum 'fair market share' for the UK would be about 140 TWh/y. The 2050 Calculator assumes that the bioenergy imported is already processed ready to use, and is half in solid and half in liquid state, as replacements for coal and oil respectively.

Considerable uncertainty remains about these estimates (including uncertainty about the potential for plant breeding and technology enhancements to improve yields), and there are important questions about the sustainability and impacts of bioenergy imports.

Level 1

Level 1 assumes the UK does not import any bioenergy by 2050, with the amounts of bioenergy imported gradually declining from 2007 levels to zero.

Level 2

Level 2 assumes a 10-fold increase of bioenergy imports from current levels by 2050, equating to roughly 13 000 km^2 of production land in other countries. A total of up to 70 TWh/y may be imported, corresponding to half of what we have assumed to be the UK's fair market share.

Level 3

Level 3 assumes that by 2050 the UK is importing its fair market share under the assumptions outlined above. This means a 20-fold increase of imports, using about 26 000 km^2 of land in other countries, providing up to 140 TWh/y of bioenergy.

Level 4

Level 4 assumes that by 2050 the UK is importing bioenergy from a land area almost the size of the Republic of Ireland (52 000 km^2), assuming an average power per unit area of 0.6 W/m^2 (Figure 1). This represents a 40-fold increase of imports (or twice the UK's projected fair market share), providing up to 280 TWh/y of biofuel. Importing this much biofuel presents a sizeable infrastructure challenge for ports and supply chains.

Interaction with other choices

In the 2050 Calculator bioenergy is only imported if there is demand for it, up to the maximum limit allowed under the chosen level of imports and after all domestic bioenergy has been used up. For example, if level 2 imports is selected (maxiumum 70 TWh/y) but only 30 TWh/y is demanded, then only 30 TWh/y will be imported.

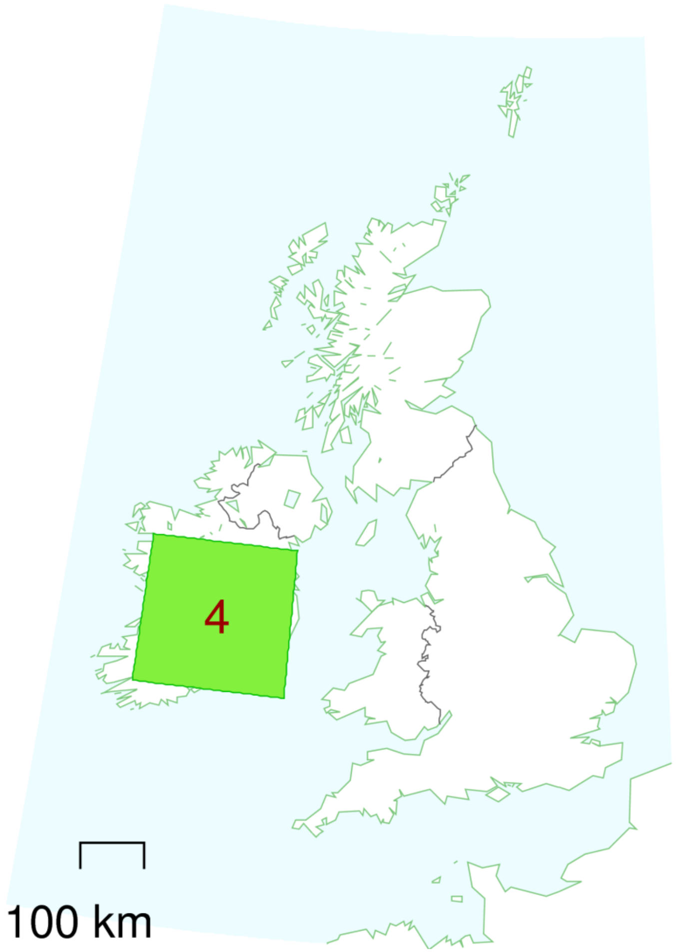
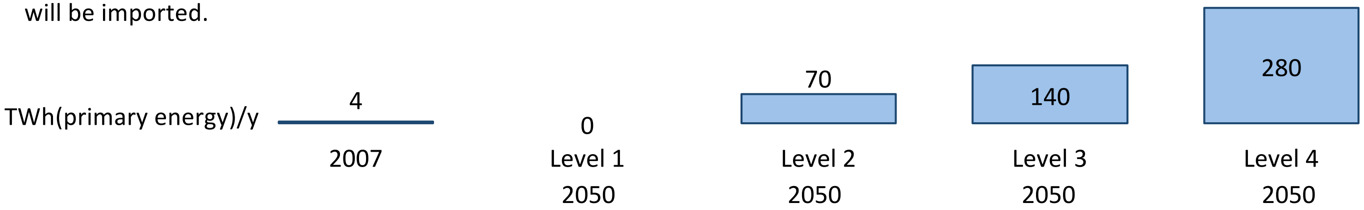


Figure 1. The area needed to grow the bioenergy imports assumed at level 4 is 52 000 km^2, if they were to be grown close to the UK. This is equivalent to an area almost the size of the Republic of Ireland.



Geosequestration

Geosequestration technologies can remove carbon dioxide (CO_2) directly from the atmosphere and store it in soils, building materials, rocks or other parts of the geochemical system. In 2007 these were new and emerging techniques which did not exist at commercial scale.

Technologies that capture carbon dioxide in power stations and industrial facilities, rather than from the atmosphere are described separately in the Carbon Capture and Storage (CCS) and industry sections.

Level 1

Level 1 assumes that the UK does not implement any geosequestration by 2050.

Level 2

Level 2 assumes that by 2050 about 1 $MtCO_2$ a year is removed from the atmosphere by optimising some processes such as chalk and cement production, to maximise their capture of CO_2; and by burying biochar in soils.

Level 3

Level 3 assumes that by 2050, carbon sequestration machines remove about 30 $MtCO_2$ a year (roughly 4% of the UK's CO_2 emissions in 1990).This might require roughly 60 000 carbon sequestration devices each the size of an upended shipping container and requires a flow of CO_2 into storage equal to half the mass of oil that the UK is currently extracting from the North Sea. The machines might need about 100 TWh/y of energy to power them. This is the amount of electricity produced by 10 nuclear power plants the size of Sizewell B.

Level 4

Level 4 assumes that by 2050, carbon sequestration machines remove 31 $MtCO_2$ a year. Britain also funds large-scale carbon capture in other countries; this overseas carbon capture costs energy but this energy cost does not appear in the 2050 Calculator, which describes UK energy consumption only. The total carbon sequestered in the UK and overseas is around 110 $MtCO_2$ a year.

Interaction with other choices

Electricity is required to power the sequestration machines in levels 3 and 4. If the options chosen for the supply sectors mean greenhouse gases are released in the production of this electricity, then the net sequestration will be lower.

There is significant demand for CO_2 transport infrastructure and storage capacity under three sectors: industry, carbon capture and storage, and geosequestration. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

Figure 1. Professor David Keith at the University of Calgary, standing next to the tower of a prototype carbon sequestration machine, capable of capturing about 1 tonne of CO_2 per day.

	2007	Level 1 2050	Level 2 2050	Level 3 2050	Level 4 2050
TWh/y				99	99

Storage, demand shifting and interconnection

To avoid power outages, electricity demand needs to balance with electricity supply at all times. This is a tricky task as both demand and some forms of supply fluctuate throughout any day, over a week and between the seasons. Some electricity generation fluctuates more than others, as for example the supply from many renewables depends on the weather conditions.

At present the UK has a number of tools to balance the electricity network, including the UK's 2 GW interconnector with France. During 2007 the UK imported 8.6 TWh and exported 3.4 TWh. In addition the UK has 3.5 GW of pumped storage, with the largest site being Dinorwig in North Wales which has a storage capacity of around 9 GWh and a peak output of around 2 GW. There is very limited ability to shift demand in a co-ordinated way: a few large industrial electricity users are on interruptible contracts, receiving discounts in return for being switch-offable if the grid has a shortfall in supply. In the future we could have a smart grid that could shift the timing of millions of pieces of demand, to help balance the grid.

Level 1

Level 1 assumes that by 2050 the UK has developed 3.5 GW of storage and 4 GW of interconnectors. Smart demand shifting is not implemented.

Level 2

Level 2 assumes that by 2050 the UK has developed 4 GW of storage, with a storage capacity of 30 GWh, and 10 GW of interconnectors. Around 25% of all electric vehicles and plug-in hybrid electric vehicles allow flexible charging, enabling co-ordinated electricity demand shifting.

Level 3

Level 3 assumes that by 2050 the UK has developed 7 GW of storage, with a storage capacity of 100 GWh, and 15 GW of interconnectors. This level also assumes that around 50% of electric cars allow flexible charging for co-ordinated demand shifting.

Level 4

Level 4 assumes that by 2050 the UK has 20 GW of storage, with a storage capacity of 400 GWh, and 30 GW of interconnectors. This level also assumes that around 75% of electric cars allow flexible charging for co-ordinated demand shifting.

Figure 1. Part of the Dinorwig hydroelectric power station, a system that stores energy by pumping 6.7 million m^3 of water up around 500 metres and then releasing it to supply 9 GWh of energy at a rate of around 2 GW. Photo © Denis Egan.

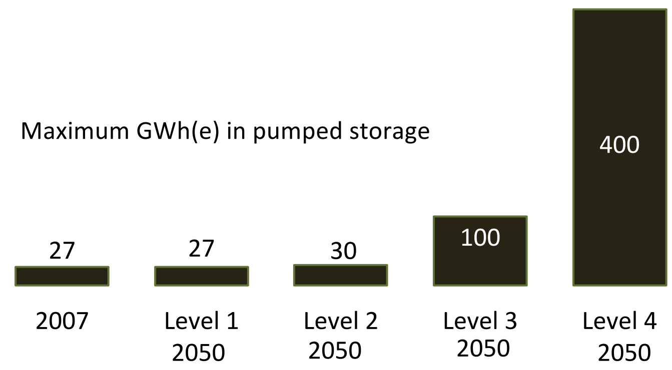


Figure 2. The assumed maximum energy that can be kept in pumped storage in GWh. Note that this energy can be stored and then released many times over a year, and therefore these figures are not directly comparable to the TWh/y charts that appear at the bottom of other sector notes.

The balancing stress-test

To avoid power outages, electricity demand needs to balance with electricity supply at all times. This is a tricky task as both demand and some foms of supply fluctuate throughout any day, over a week and between the seasons.

For comparison, today's average electricity consumption is 42 GW and in several possible pathways to 2050 Britain's average electricity consumption is 84 GW. The output from 236 GW of offshore wind, the maximum level assumed in the 2050 Calculator, could vary between 0 GW and 236 GW. For comparison, Britain's average electricity consumption in 2050 could possibly be 84 GW (today's average consumption is 42 GW).

Significant additional interconnection, demand shifting and storage requirements could be needed. For example, the existing interconnector between England and Scotland is 2.2 GW and the Cruachan and Foyers pumped storage facilities have a capacity of 0.7 GW. But level 4 for onshore wind assumes 50 GW of capacity in 2050, and if half of this were located in Scotland then the scale of balancing systems required might involve the construction of about 4 GW of additional interconnection from Scotland to England and new storage systems in Scotland able to absorb a further 10 GW.

The 2050 Calculator includes a 5-day 'stress-test' which models the impact of a period of cold temperatures and low winds, in order to understand the scope of the balancing challenges during such adverse weather conditions. It is assumed that over a 5-day period the UK temperature drops to below zero which increases heating demand (to a degree that depends on buildings' insulation levels). It is also assumed that the output of both onshore and offshore wind drops to 5% of installed capacity, and solar generation levels are below 80% of average output. Each 2050 pathway which is selected by a user generates a different electricity balancing challenge, and the 5-day stess-test indicates how much of the total capacity of the electricity network is used. If the chosen pathway exceeds 100% of that capacity then the Calculator contains 2 further options:

1. The user can increase the level of storage, demand shifting and interconnection.
2. The Calculator computes the capacity of backup generation required to cover the electricity shortfall, assumed to be unabated gas-fired power stations.

Interaction with other choices

The renewable technologies chosen (in particular onshore wind, offshore wind and wave power), the degree to which heating is electrified, and the number of electric cars chosen under the transport option determine what the requirement for back-up generation is and how much demand shifting is possible.

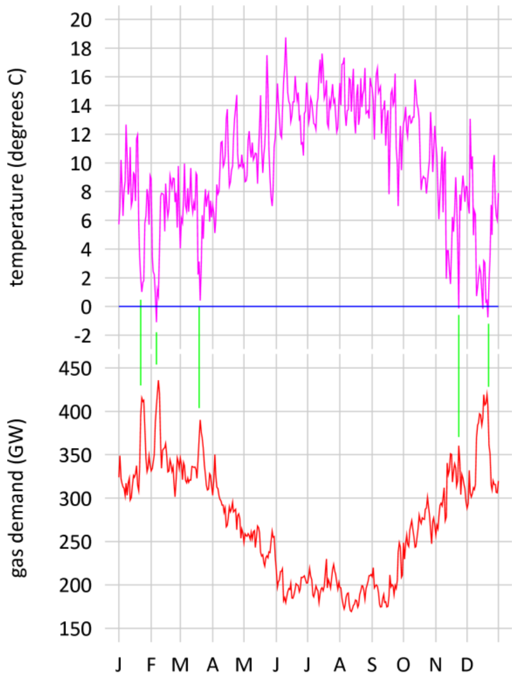


Figure 1. The stress-test assumes that a drop in wind occurs during a cold winter day, such as those illustrated in the 2007 temperature data in the top graph on the left. On these days, heating demand can increase by more than 100 GW above the annual average, as illustrated in the 2007 gas data in the bottom graph on the left.

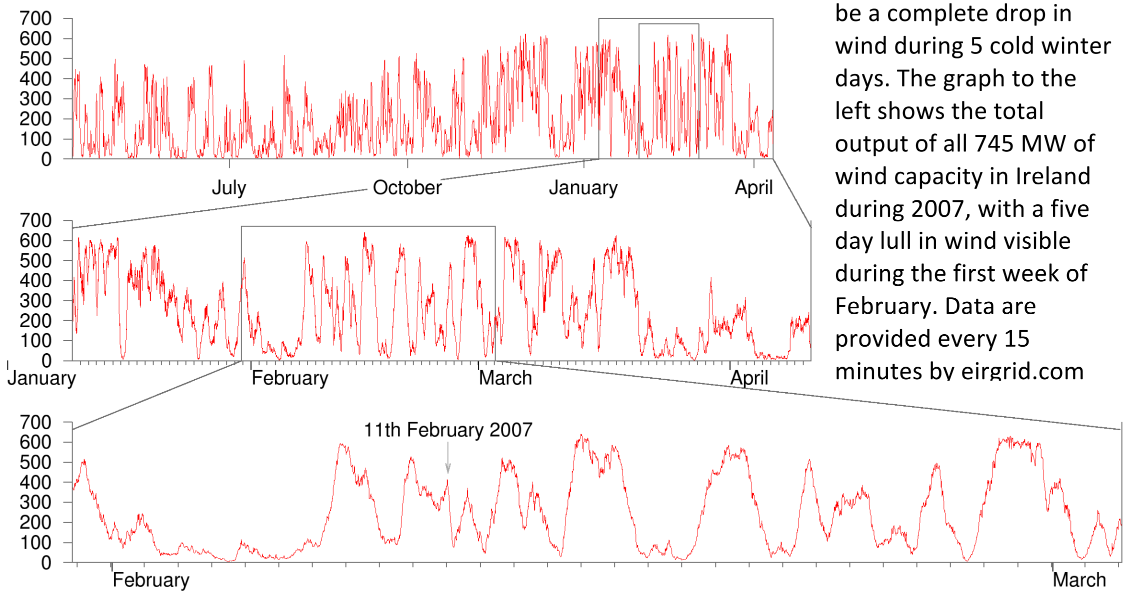


Figure 2. The stress-test assumes that there could be a complete drop in wind during 5 cold winter days. The graph to the left shows the total output of all 745 MW of wind capacity in Ireland during 2007, with a five day lull in wind visible during the first week of February. Data are provided every 15 minutes by eirgrid.com