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Part 2

Detailed sectoral trajectories

Section A: Lighting and appliances

Context

Ownership of lighting and appliances such as refrigerators, ovens, televisions and computers has increased significantly over the past 40 years. Most (more than 90%) of the fuel demand for these technologies is met by electricity, while the rest is mainly met by gas.[23] Unless the supply of this fuel is decarbonised, or we reduce demand for energy for these products, their use will continue to contribute considerably to the UK's greenhouse gas emissions.

Innovative technologies could significantly improve the energy efficiency of lighting and appliances and the way we use them. For example, televisions or computer monitors that automatically dim when no-one is using them could help save electricity in our homes, schools, shops and offices; lighting that detects motion in a room and turns on or off in response is already in use in some buildings; and smart meters show how much energy we use in our homes, thereby helping us to identify sources of energy wastage. It may be that at some point in the future, our homes, offices, vehicles and heaters are equipped with technologies that communicate as one integrated system, helping us to use energy more efficiently across the board.

While we can reasonably expect substantial improvements in the energy efficiency of these products, and in technologies that help us manage our use of them, it is impossible to predict accurately all technologies that will be invented by 2050, let alone how quickly they can be rolled out or which of those could significantly reduce energy demand by 2050. For this analysis, we consider technologies that are either already available or could be expected in the next 10 years.

Sector segmentation used

For this analysis, we consider domestic lighting and appliances and non-domestic lighting and appliances separately. The broad range of products that are used in these sectors are categorised according to *Energy Consumption in the UK 2009*.[24] Domestic products include consumer electronics, home computing, cold appliances, wet appliances and lighting. Non-domestic products include lighting, catering and computing, with other appliances grouped in a separate category.

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[23] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.10 and Table 5.6.

[24] http://www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx

Drivers and enablers

Among other factors, the number of households and non-domestic buildings in the UK is a key driver of energy consumption for lights and appliances. Across this project we have assumed that:

- households will grow in line with projections to 2031 (provided by the Department for Communities and Local Government). These projections imply an annual growth rate of about 1%. In this analysis, this growth rate is assumed to continue to 2050.[25]
- non-domestic properties currently number 1.8 million. We have assumed that this number grows by 1% per year. [26]

Lights and appliances in our homes

Ownership of consumer electronics (such as televisions, DVD players and game consoles) and home computing equipment has increased rapidly since the late 1970s. Electricity use for these technologies per household has increased almost six-fold since the 1970s.[27]

However, we have already made significant progress in using more energy-efficient lighting and appliances in our homes. The use of less energy intensive products helps to reduce energy bills, and as such they are attractive purchases. In addition, product policy helps to reduce energy wastage by promoting the sales of the more energy efficient products. While electricity use for consumer electronics and home computing has increased significantly since the 1970s, this increase has been largely compensated by a decrease in energy use for other home lighting and technologies.

For example, only about half of the bulbs in our homes are now standard inefficient incandescent light bulbs – a significant decrease from 90% in 1970.[28] In addition, over the past 20 years, despite the increase in population, the amount of energy used for cooking has dropped very slightly (about 3% in total). This trend could continue as, for example, increasing efficiency of cooking appliances offsets any increasing demand caused by the rise in population.

Overall, although we own about 45% more lights and appliances per household than we did in 1990, the amount of energy used for these products has increased by only 2% per household over the same period.[29] Energy consumption for lighting and appliances per household has therefore been largely stable since about 1990.

But we can still make further improvements. Many of these technologies can be replaced relatively easily and new, highly efficient technologies are already available or are in the pipeline.

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[25] http://www.communities.gov.uk/housing/housingresearch/housingstatistics/

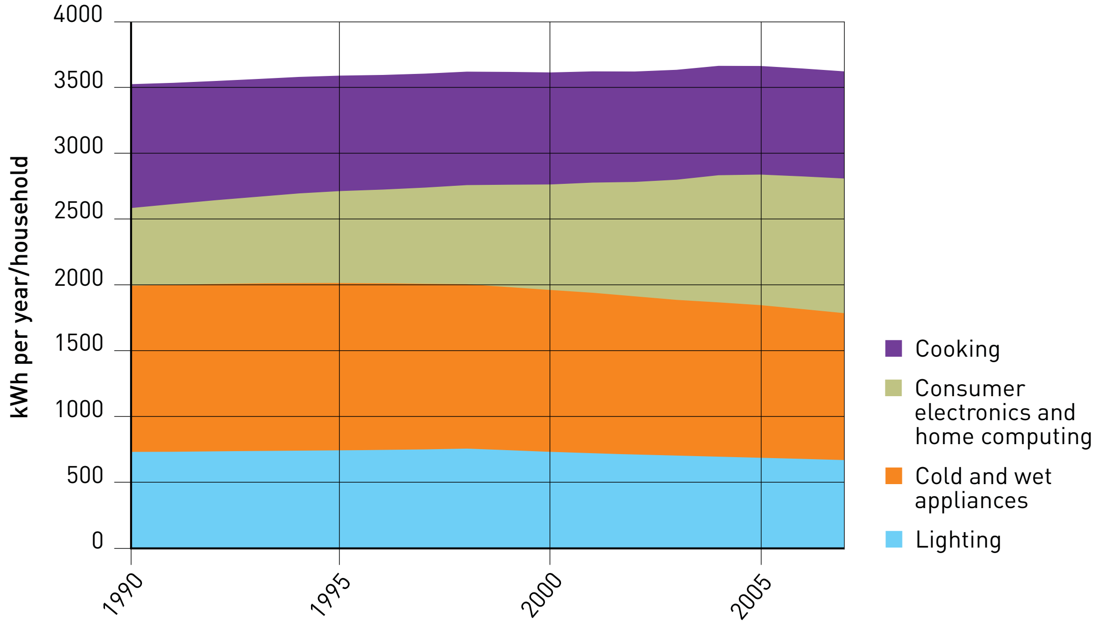
[26] The Carbon Trust (2009) *Building the Future, Today*, page 7.

[27] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.3 and 3.10.

[28] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.10.

[29] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Tables 3.6, 3.10 and 3.11.

Figure A1: Energy consumption for lighting and appliances per household since 1990[30]



Lighting and cold appliances – such as refrigerators – represent the greatest opportunities for savings in this sector. There is also some potential to save energy by changing the way we use lights and appliances without significantly affecting our quality of life – for example, by turning off lights when we are not using them. Analysis suggests that we could save up to 15% of our energy consumption by managing the use of lights and appliances more effectively.[31]

Consumer electronics and home computing present the biggest challenges to reducing energy demand in the domestic sector. Ownership of these products is likely to continue to rise over the next 40 years. For example, televisions account for the largest share of the energy used by consumer electronics, and their number in households is expected to rise by 21% between now and 2020.[32] However, technological developments, such as new display technologies, reducing standby consumption and reducing on-power consumption, could curb increases in demand for electricity for these products.[33]

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[30] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.7 and 3.10.

[31] Darby, S (2006) *The Effectiveness of Feedback on Energy Consumption, A Review for DEFRA of the Literature on Metering, Billing and Direct Displays*, http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

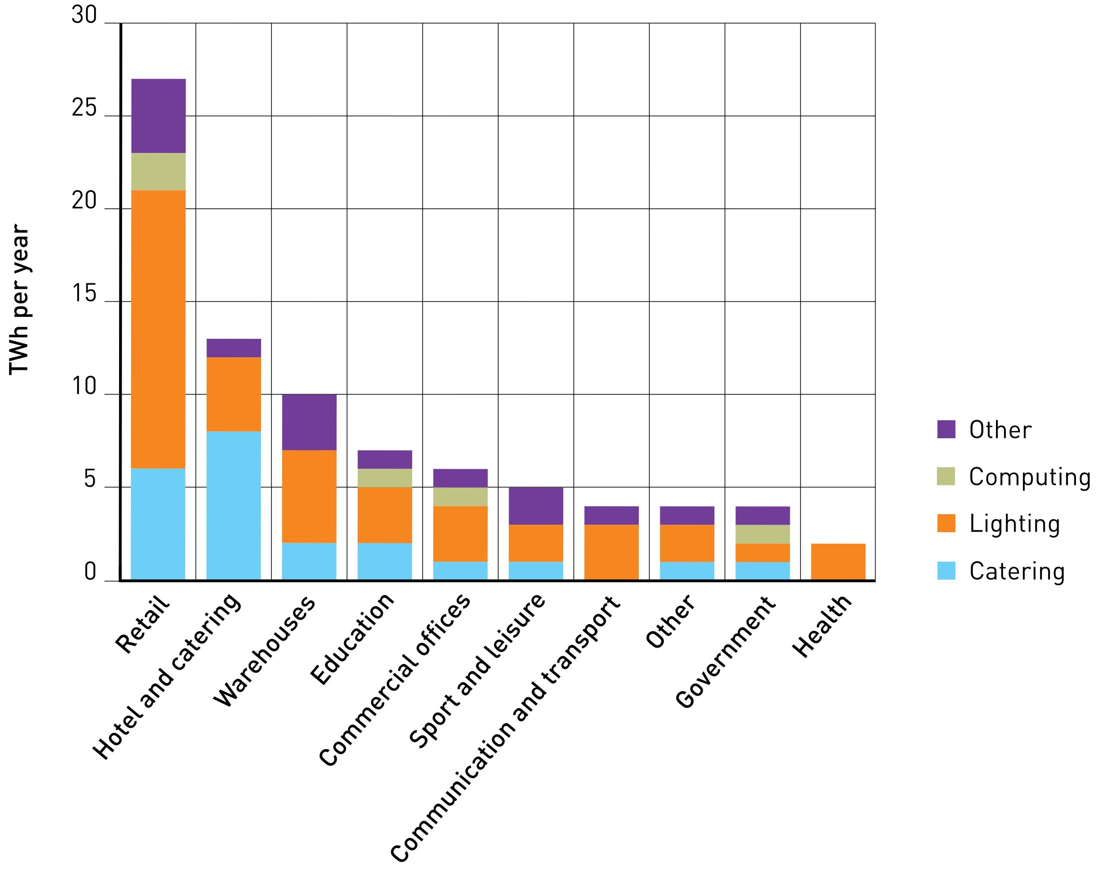
[32] Department for Environment, Food and Rural Affairs (2009) *Consultation document on Saving Energy through Better Products and Appliances*, page 36, http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm

[33] Department for Environment, Food and Rural Affairs (2009) *Consultation document on Saving Energy through Better Products and Appliances*, pages 37–41, 85, http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm

Lights and appliances for non-domestic use

In addition to what is used in our homes, a wide range of needs are met through lighting and appliances in other sectors such as hotels, restaurants, shops, commercial offices, schools and gyms. The technologies that are used in these non-domestic sectors range from traffic lights, office computers and printers to walk-in cool rooms and low-temperature cabinets in supermarkets.

Figure A2: Consumption of energy for lighting and appliances in non-domestic sectors in 2009[34]



As with domestic lighting and appliances, there is considerable potential for further savings in the non-domestic sector. This sector is clearly diverse with different kinds of buildings using different kinds of technologies. New, more efficient technologies will generate different amounts of energy savings for different sectors. In general, however, given the potential of new technologies in the pipeline, and the frequency with which some appliances are upgraded, savings are likely mostly to affect consumption of energy for lighting, cold appliances and computing.

The non-domestic lighting and appliances sector presents opportunities for relatively quick, significant reductions in demand. In many of these buildings (for example, retail stores, commercial offices, etc), the environment and equipment are controlled and monitored by a central monitoring system or facilities team. It is therefore possible for technologies in many of these locations to be updated on a large scale in an efficient way and without considerable disruption. Improving the technologies used by a number

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[34] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 5.6.

of people in a large building would in general reduce demand more rapidly than it would in, for example, an average-sized household.

Technologies to reduce energy consumption while servicing demand

Many technologies that are currently available or can be expected in the near term could reduce energy consumption for lighting and appliances over the coming years, even with the expected increases in ownership of products, population, households and non-domestic properties.

For example, Compact Fluorescent Lamps (CFLs), the most commonly used 'energy saving light bulbs' use about a quarter of the energy of standard tungsten bulbs. Energy saving halogen light bulbs use about 30% less electricity than standard halogen bulbs and Light Emitting Diodes (LEDs) currently use about a tenth of the electricity of conventional bulbs.[35]

New backlighting technologies and variable brightness control could double the efficiency of liquid crystal display (LCD) televisions. Likewise, the efficiency of plasma technology for plasma televisions is expected to double over the next few years.

Some products, such as computer monitors and televisions, consume electric power while they are left on standby or even when they are switched off and plugged in. For some products this power enables useful features such as responsiveness to remote control, but in other products it does not offer any such advantages. The amount of un-used power that these products draw could be reduced further through technological enhancements.

In addition, vacuum insulated panels on cold appliances such as fridge-freezers could significantly improve the thermal performance of these appliances and thereby reduce the energy they use.[36]

These technological developments, along with many others, could reduce overall energy consumption for lighting and appliances considerably, while still servicing demand.

Implications for heating and cooling

The use of more efficient products could have an effect on other energy uses. Inefficient lights, computing equipment and poorly insulated ovens, for example, emit heat, which consequently warms our homes and buildings. Sometimes this heat is useful to maintain a comfortable indoor temperature. At other times the additional heat is not necessary and we use other technologies (such as air-conditioners) to bring the temperature back to comfortable levels.

As the efficiency of products improves, the amount of heat generated by lights and appliances will drop. When this heat is not useful to maintain comfortable temperatures, improving the efficiency of lights and appliances will have the additional benefit of there being less need for energy for cooling. In cases where this heat is used,

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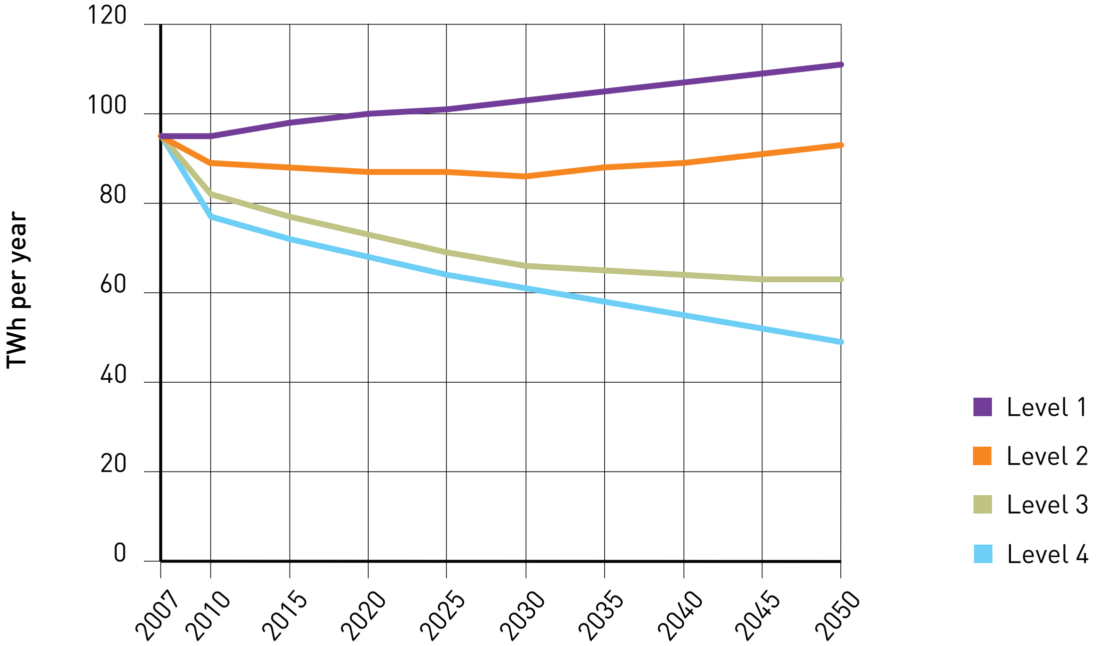
[35] http://www.energysavingtrust.org.uk/Resources/Features/Features-archive/; see also Environmental Change Institute, University of Oxford (2007) *Home Truths: A Low Carbon Strategy to Reduce UK Housing Emissions by 80%*, page 26, Table 3.3.

[36] Environmental Change Institute, University of Oxford (2005) *40% House*, http://www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf

the comfortable temperatures in our homes and buildings would need to be maintained in other ways. This is addressed in the analysis on heating and cooling in Section D.

Levels for domestic lighting and appliances

Figure A3: Trajectories for domestic lighting and appliances under four levels of change



Level 1

If we do not make much effort to reduce demand further in this sector, a hypothetical trajectory describing the amount of energy that we might need for lighting and appliances in our homes could involve the following:

- Total demand for energy for lighting could stabilise at today's levels as efficiency levels continue to improve as they have in the past.[37]
- Demand for energy for cold and wet appliances, such as refrigerators and washing machines, could increase very slightly in line with historic trends.
- Demand for energy for consumer electronics and home computing could increase by 50% by 2050.[38]
- Demand for energy for cooking could remain stable at current levels, in line with historic trends.

There may be no significant change in the way we manage our use of lighting or appliances.

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[37] Demand for electricity for lighting has increased by only 0.1% per year since 1990. Source: *Energy Consumption in the UK 2009*, DECC, Table 3.10.

[38] See Defra (2009) *Consultation document on Saving Energy through Better Products and Appliances* http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm, pages 39, 85.

This would result in total energy demand for domestic lighting and appliances increasing by about 20% by 2050.

Level 2

We could potentially keep total demand for energy for lighting and appliances stable at today's levels despite increases in population, GDP and households. For example:

- Total demand for electricity for lighting could be reduced by 30%. This could be done by, for example, replacing all lights that are not LEDs and that are not fluorescent strip lights with CFLs (with average efficiency of 50 lumens/watt) by 2050.[39]
- We could replace all cold and wet appliances with more efficient appliances (for example, washing machines and dishwashers with limited standby consumption), reducing demand per household by about a third by 2030. With the expected increase in households, total demand for cold and wet appliances in 2050 would then be stable on today's levels.
- We could limit the increase in consumption for consumer electronics and home computing to 40% (as opposed to 50%) by, for example, reducing the off-mode power consumption of some consumer electronic products, reducing the on-mode power consumption of simple set top boxes, and using auto power down technologies with TVs and set top boxes when in standby for a certain length of time.
- We could improve the performance of cooking appliances, particularly ovens and hobs, such that each household uses about 40% less energy by 2050 (representing a decrease in demand of 10% in total).[40]
- With the help of smart meters and other technologies, we could manage the use of lights and appliances in our homes (for example, turning lights and appliances off when we are not using them) such that we reduce total demand by 5%.

Level 3

We could potentially even reduce total demand by 35% on today's levels. For example:

- We could replace all lights with today's best practice LEDs (about 100 lumens/watt) by 2050.[41]
- We could replace cold and wet appliances with increasingly efficient appliances, so that overall we use 10% less electricity for these products by 2050.

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39 Environmental Change Institute, University of Oxford (2007) *Home Truths: A Low Carbon Strategy to reduce UK Housing Emissions by 80%*, page 26. This achieves a 73% reduction in consumption vs a standard light bulb of 14 lumens/watt and a 50% reduction in consumption vs a halogen at 25 lumens/watt. Ownership is taken from DECC's *Energy Consumption in the UK 2009*, Table 3.10.

40 See Department for Environment, Food and Rural Affairs (2009) *Consultation document on Saving Energy through Better Products and Appliances*, http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm, page 124.

41 MacKay, David JC (2009) *Sustainable Energy – without the hot air*, UIT Cambridge, page 58, and Environmental Change Institute, University of Oxford (2007) *Home Truths: A Low Carbon Strategy to Reduce UK Housing Emissions by 80% by 2050*, page 26. This achieves an 86% reduction in consumption vs a standard light bulb of 14 lumens/watt, a 75% reduction in consumption vs a halogen at 25 lumens/watt, a 50% reduction in consumption vs a CFL at 50 lumens/watt and a 30% reduction in consumption vs fluorescent strip lighting at 70 lumens/watt. Ownership is taken from DECC's *Energy Consumption in the UK 2009*, Table 3.10.

- Through ambitious efficiency improvements we could reduce consumption for consumer electronics and home computing by 35%. These improvements could include TVs that are equipped with technology that detects when no-one is viewing the screen and dims it accordingly; further improvements in the minimum efficiency levels of external power supply units; further reductions in standby consumption; and further improvements in the efficiencies of computers.
- In addition, we could manage our use of these appliances better such that we use 10% less energy.

Level 4

At the extreme end, we could possibly halve demand. For example:

- We could replace all lights with extremely efficient lights (such as LEDs at 150 lumens/watt) by 2050.[42]
- We could replace all cold appliances with extremely efficient cold appliances by 2050 (each appliance uses about 80% less energy through technological improvements).[43]
- When replacing our consumer electronics and home computing products, we could adopt only the best practice products until 2050.

We could use 15% less energy through more careful use of lighting and appliances.

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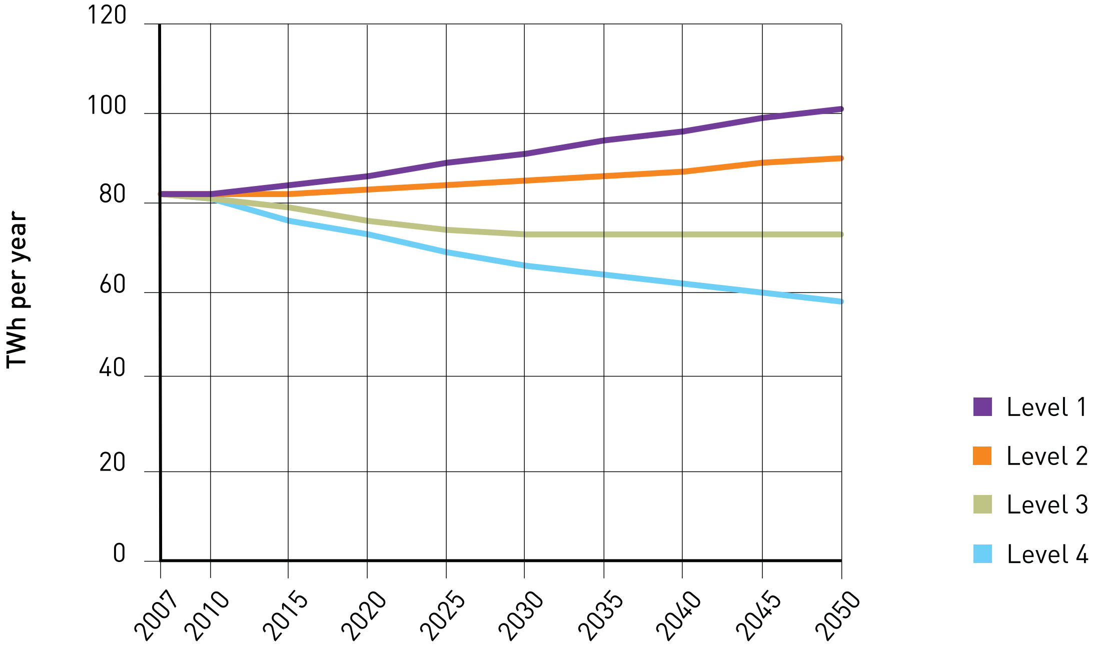
[42] Environmental Change Institute, University of Oxford (2007) *Home Truths: A Low Carbon Strategy to Reduce UK Housing Emissions by 80% by 2050*, page 26. These are "expected to be commercial in 10 years *[sic]* time, already in the laboratory". They achieve a 91% reduction in consumption vs. a standard light bulb of 14 lumens/watt, a 83% reduction in consumption vs. a halogen at 25 lumens/watt, a 67% reduction in consumption vs. a CFL at 50 lumens/watt and a 53% reduction in consumption vs. fluorescent strip lighting at 70 lumens/watt. Ownership is taken from *Energy Consumption in the UK 2009*, Table 3.10.

[43] Environmental Change Institute, University of Oxford (2005) *40% House*, page 49. Per household consumption for cold appliances drops by 81%, assuming that new chest freezers reduce consumption on 2007 levels by 85% (per appliance), new fridge-freezers reduce consumption by 81%, new refrigerators reduce 2007 consumption by 74% and new upright freezers reduce 2007 consumption by 82%. Ownership is taken from DECC's *Energy Consumption in the UK 2009*, Table 3.10.

Levels for non-domestic lighting and appliances

Figure A4: Trajectories for non-domestic lighting and appliances under four levels of change



Level 1

Under this level, the amount of energy that we would need to supply our lighting and appliances in non-domestic buildings until 2050 could involve the following:

- Demand for energy for lighting could continue to increase each year in line with historic trends (increasing by 25% by 2050).[44]
- Demand for energy for catering could stabilise (ie, stop decreasing).[45]
- Demand for energy for computing could drop by about 10% per property through basic efficiency improvements.[46]
- Demand for energy for all other appliances per property could stabilise.
- Demand for non-domestic lighting and appliances in the UK increasing by about 25% by 2050.

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[44] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 5.5. On average, demand for electricity for non-domestic lighting has increased 0.6% each year from 2002 to 2009.

[45] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 5.5. On average, demand for electricity for non-domestic catering has decreased 0.2% each year from 2002 to 2009.

[46] Inferred from the Department for Environment, Food and Rural Affairs (2009) *Consultation document on Saving Energy through Better Products and Appliances* http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm

Level 2

We could possibly go further and limit the increase in total UK demand for non-domestic lighting and appliances to 10%. For example:

- Demand for energy for catering could continue to decrease in line with historic trends through, for example, the use of more efficient refrigeration appliances (such as vacuum insulated panels).
- We could limit the increase in UK demand for energy for non-domestic computing to 10% by, for example, shifting from desktop PCs (which consume the most in-use energy in ICT) to laptops and increased sharing of high consumption devices.
- We could reduce demand for energy for lighting by 30% per property through the increased use of CFLs.

Level 3

Total UK demand for non-domestic lighting and appliances could be reduced by about 10% by 2050. For example:

- Demand for energy for catering could be reduced by a fifth by 2050 through further efficiency improvements.
- Demand for energy for lighting per property could halve by 2050 through, for example, the increased use of LEDs instead of other, less efficient lighting technologies and through the use of motion detective lighting.
- Through increasing adoption of more efficient technologies, we could reduce energy demand for computing by a quarter by 2050.

Level 4

At the extreme end, we could reduce demand in this sector by 30%. For example:

- For commercial lighting, LEDs could be introduced over time, reaching 90% of the stock by 2050. New lighting installations on major roads could be more efficient high pressure sodium (HPS) lamps and new installations on residential roads could be more efficient ceramic metal halides. This could help reduce demand for lighting by more than 50% by 2050.
- Demand for energy for catering could drop by a quarter by 2050 through the use of current or future best practice products. This would involve implementing measures such as defrost on demand technology for low temperature cabinets, reducing refrigerant leakage and improving designs of refrigeration systems (for example, designing a system to exploit low ambient temperatures).

Demand for energy for computing could drop by 70% by 2050 through extremely ambitious efficiency measures.[47]

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[47] Department for Environment, Food and Rural Affairs (2009) *Consultation document on Saving Energy through Better Products and Appliances* page 82 http://www.defra.gov.uk/corporate/consult/energy-using-products/index.htm

Section B: Transport

Context

Domestic transport currently accounts for 21% of the UK's greenhouse gas emissions.[48]

Recent forecasts suggest that, largely as a result of anticipated improvements in new car fuel efficiency and increased uptake of biofuels, domestic transport emissions are likely to be around 15% lower by 2020 compared to 2008.[49] It is of course important to think beyond 2020, but looking to the long term introduces significant uncertainties. In the analysis contained in this report, these uncertainties have been illustrated through the range of levels shown.

Transport plays a fundamental role in supporting our economy and quality of life. As individuals, we rely on the opportunities created by transport, such as access to jobs, healthcare, education, goods and services and of course seeing family and friends. And transport plays a vital role in facilitating economic activity through: enabling a highly mobile and flexible labour market; transporting goods and people efficiently and reliably around the country; and enabling the UK to play a leading role in the international market place for high value goods and services.

Most domestic passenger travel is for four key purposes: in 2008 leisure trips accounted for 40% of distance travelled; getting to and from work 19%; shopping 13%; and business travel 9%.[50] The majority of personal travel is currently by car, accounting for 84% of distance travelled per year (2007).[51]

Since the 1970s, on average the number of trips people make and the time per trip have remained broadly constant, but the length of those trips has increased by around 50%,[52] indicating that journeys can be made more quickly. Evidence is beginning to suggest that some of the drivers and enablers of this trend towards trip lengthening will gradually weaken over time.

Freight shows an increasing trend, but in contrast to historical trends since the late 1990s, activity (measured in tonne kilometres) appears to have decoupled from economic growth: UK GDP increased by 32% between 1997 and 2007 yet the quantity of freight moved by all modes rose by just 11%.[53] There are a range of factors that might have contributed to this recently observed trend and it is not yet clear whether it will continue into the future. This uncertainty has been reflected in the freight transport activity levels below.

Transport's energy use and carbon emissions are closely linked to the level of travel activity, but are also influenced by other important factors. These include the mode

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[48] DECC 2008 final UK figures http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2008_final/2008_final.aspx

[49] DECC Energy and Emissions projections, http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx

[50] Department for Transport (2009) National Travel Survey data 2008, Table C4.1b , page 28.

[51] Department for Transport (2009) Transport Statistics Great Britain 2009, Table 1.1.

[52] From 4.7 miles to 7.0 miles, Department for Transport (2009) National Transport Survey 2008, Table 2.1.

[53] ONS Transport Statistics Great Britain (2009), Table 4.1.

of travel chosen to make a given journey (car, van, bus, rail, walking, cycling, freight mode, motorcycling and air travel); the efficiency of the vehicle (how much fuel is required per mile); how the vehicle is powered (petrol, diesel, electricity etc); the carbon content of the fuel used and behavioural factors such as occupancy and how efficiently the vehicle is driven (such as the extent of 'eco-driving').

Transport technology has made significant advances over the last two to three decades. New car fuel efficiency has improved 22% since 1995,[54] with average new car CO_2 emissions in 2009 at 150g CO_2 per vehicle kilometre in the UK. Approximately 40% of the rail network (in track miles) is currently electrified. Electric traction accounts for a little under half of passenger miles operated and around 5% of freight train mileage.[55] With the current carbon content of UK electricity, an electric train emits around 24%[56] less carbon per passenger kilometre than a diesel train; intercity trains emit on average 49g CO_2 per passenger kilometre.[57] This compares with an average for cars of 128g CO_2 per passenger kilometre, assuming an average number of passengers.[58]

Improvements in efficiency are not, however, evident across all modes. Evidence suggests that between 1997 and 2008, bus fuel efficiency actually fell by around 21%.[59] This worsening is mainly due to buses becoming heavier and meeting higher consumer expectations such as air conditioning, as well as tighter standards on air quality and accessibility, resulting in a fuel penalty.

Drivers and enablers

Drivers

There are several key drivers of travel activity in the UK. Population, GDP and the costs of travel are the main drivers, but other factors including the location of economic activity; population growth; land use and population density; household wealth; the weather; topography of the landscape; and local amenities have a substantial influence on both how much people travel, and how they travel. Looking at averages can mask the complexities.

For consistency across this analysis, the transport levels described below have been developed assuming that population grows in line with the ONS projections at on average 0.5% per year[60] and that GDP grows on average at around 2.5% per annum. A relaxation of these assumptions would allow a wider range of potential transport scenarios for 2050 to be developed. The levels of transport activity were developed following a review of a wide range of published studies and discussions with stakeholders. As far as possible, they reflect stakeholder views of how the nature and level of travel activity could vary under alternative assumptions to 2050. They have been developed with a view to maintaining consistency with the assumptions on population and GDP in this analysis, as key drivers of travel.

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[54] SMMT data UK New Car Registrations by CO_2 Performance 2004 Annual Report and DVLA vehicle licensing statistics 2009, Table 18.

[55] Network RUS, Electrification, Network Rail, October 2009. http://www.networkrail.co.uk

[56] DfT analysis.

[57] DfT Rail Network Modelling Framework (NMF) data and National Rail Trend Yearbook 2008/09, Office of Rail Regulation.

[58] Defra Company Reporting Guidelines, 2009. Average car loads are currently 1.58 people per car (average of last 5 years, NTS 2008, Table 7.3).

[59] DfT Bus Service Operator Grant claims and Transport Statistics Great Britain (2008).

[60] Note that the DfT's transport models rely on TEMPRO population forecasts which are derived from ONS projections of population resident in households.

It is recognised that alternative views of travel activity have been published, some involving much more significant reductions in overall travel than has been illustrated in this report. But such studies did not typically assess the extent to which the measures required to bring about very significant behaviour change may impact on GDP.[61] Within this report, the analysis has sought to illustrate behaviour changes that might be expected to be consistent with the underlying assumed GDP growth, including radical mode shift away from the car towards public transport; significantly higher cycling levels; significantly lower car use relative to the baseline; higher public transport and car occupancy; and lower overall travel due to, for example, some trips perhaps being replaced by IT links or people working at home.

As transport is an enabler of other activities in the economy there are strong interactions with other sectors, which, due to the nature of scenario analysis, have not always been possible to capture. For example, a significant amount of freight is used to move energy production materials (coal, oil etc) and construction materials.[62] Trajectories in other sectors of this report may imply changes in freight requirements that are not reflected here.

In some cases, a behavioural or technology change may have unintended consequences that have not been possible to take fully into account in this scenario analysis; there is therefore no feedback of efficiency improvements into the activity scenarios shown (ie, no 'rebound effects'). Such effects are important to recognise, and if policies aimed at delivering emissions reductions are to succeed they may require complementary action or policies to 'lock-in' the full benefits.

Enablers

Emissions reductions are enabled through a combination of demand- and supply-side transport actions, and depend on actions in other sectors.

To enable the technology changes described in the levels below to take place, the right conditions would need to be in place. This would include, for example, technological breakthroughs carried through to deployment; conducive relative costs between different fuels and vehicles; supportive policy frameworks with public acceptance; and consumer confidence in using new technologies. There are potentially very significant energy savings to be made through vehicle efficiency improvements between now and 2050.

The pathways show the potential importance of electrifying much of road and rail surface passenger transport. Delivery of this depends on a wide range of factors combining. For example:

- the key perceived barriers to electric vehicle uptake would need to be overcome or significantly reduced, including a rapid decrease in the costs of batteries;
- technology improvements which allow increased driving range between charging;
- the roll out of plug-in-hybrids as an intermediate or synergistic step to greater electric vehicle and fuel cell vehicle uptake;

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[61] For example, the UK Energy Research Centre (UKERC) report (2009) 'Making the transition to a secure and low carbon energy system', looks at a 'Lifestyle Change' scenario.

[62] For example, in 2008, 46% of rail freight tonne kilometres were to transport coal or oil/petroleum.

- the most extreme levels of electrification discussed below would require significant investments in electric vehicle charging and other complementary infrastructure, and the possible effects on the grid would need to be accounted for (see Section P on electricity balancing); and
- the provision of adequate electric rail infrastructure.

Further challenges would need to be overcome for other low carbon fuels and power sources, such as fuel cells, to play a role. Electric vehicles are closer to market today than fuel cell vehicles, and to enable fuel cell vehicles to play a part, improvements in the fuel cells would need to be made for them to become cost-effective options for the mass market. They would also require the relevant fuel distribution infrastructure.

The analysis set out in Section F suggests it is unlikely that sufficient sustainable biofuel would be available, either from domestic sources or from the UK's share of global imports, to power the entire transport sector in the UK and bioenergy is likely to be required in others sectors as well as transport. However, it could be particularly important in road haulage vehicles, particularly for long haul operations, and in aviation fuel. This would require changes in vehicle design and the associated fuel infrastructure. The international nature of aviation means the changes in aviation fuel would require international efforts as well as UK action.

Similarly, to enable changes to transport activity as set out in the levels below, a range of policy interventions, investments and behavioural changes would be required to reverse trends in travel over the past five decades and deliver radical modal shifts with increasing levels of public transport use, walking and cycling. Incentives could be provided through the policy framework, information provision, and regulation, for example. Additional investment in transport infrastructure, facilities, and complementary investment and policy would be part of this process.

Strong growth in rail use would require new infrastructure and capacity provision, particularly on the already-busy parts of the network. The higher levels of demand on public transport illustrated in the more ambitious levels below would be likely to require more dense networks and additional capacity as well as complementary infrastructure such as interchanges and waiting facilities. Land use change could help ensure that public transport, buses in particular, is a commercially viable and attractive option. Bus networks tend to be more effective in dense urban areas.

To enable significant growth in cycling, lifestyle change would be required, accompanied by additional infrastructure and cycling facilities and a supportive policy framework, along with complementary measures, for example a re-allocation of road space.

Changes to driving behaviour could also result in emissions reductions. Car sharing has the effect of allowing the same passenger distance to be travelled, but in fewer vehicle miles.[63] Such car sharing may be difficult to achieve in some locations given the variations in travel patterns, and it would require a supportive policy framework.

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[63] Average occupancy across the trajectories ranges from the current occupancy rate, of an average of 1.58, to around 1.66 (ie, 5% higher) than the national average level.

Eco-driving[64] reduces the energy required to travel a given distance by appropriate vehicle maintenance and more efficient driving practices.[65]

A reduction in the overall distance travelled could possibly be enabled by spatial planning and land use changes, primarily through shortening trips. This could include, for example, the replacement of some trips by IT and 'virtual' activity.

Sector segmentation used

For the purposes of this analysis, transport activity has been split into UK passenger transport (including domestic aviation); UK freight transport (including domestic shipping); and international aviation and shipping. Only domestic transport is currently included in the UK's carbon budgets, because there is no internationally agreed framework for allocating international aviation and shipping emissions to nations. However, the Government is required to take into account emissions from international aviation and international shipping when setting the UK's carbon budgets.[66]

To convey the development of transport over time under different assumptions, the illustrative levels below look out to 2050. These levels do not in any way represent the Government's view of how transport will or should develop over time; they are merely illustrative 'what-if' futures for the purposes of this analysis only, and have been discussed with a wide range of stakeholders.

To represent the development of transport under the different levels, three different factors can be varied:

- travel activity, both in terms of overall amount of travel and travel mode (mileage travelled by walking, cycling, car, van, bus, rail, motorcycling, heavy goods vehicles, shipping and air travel);
- changes in technology and power source (the use of internal combustion engines, hybrid vehicles and electric vehicles; the use of diesel or electric rail); and
- changes in efficiency (more efficient vehicles and improving freight vehicle utilisation and changes in occupancy rates).

Levels for domestic passenger transport

Level 1

Passenger transport activity

Under level 1, travel activity in terms of overall mobility and mode shares is consistent with past trends broadly continuing but with growth in demand slowing over time, as certain drivers of demand growth such as car ownership are expected to have a gradually weakening relationship with income. It is assumed that the implied average number of people per vehicle (occupancy rate) is the same as today, i.e. an average of 9 passengers per bus, 1.6 people per car and 1 person per van. Emissions from

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[64] Eco-driving is driving behaviour which avoids unnecessary fuel consumption by for example avoiding unnecessary braking and accelerating, keeping tyres inflated to optimal levels and minimising the use of auxiliary equipment.

[65] Eco-driving has been reflected by illustrating a 3% reduction in fuel per km, as was used in Department for Transport (2009) *Low Carbon Transport: A Greener Future*, based on evidence of long term potential.

[66] Section 10 of the Climate Change Act.

domestic aviation are those associated with flights that take off and land within the UK. Domestic aviation activity (and efficiency) reflects the 'likely scenario' developed by the Committee on Climate Change in its advice to Government published in December 2009.[67] Figure B1 below shows a comparison of transport modes under the different levels.

Technology

For cars and vans, this would mean internal combustion engines (ICEs) continue to dominate these fleets. By 2050, plug-in hybrid electric vehicles (PHEVs) would cover 20% of the distance travelled by cars and vans, and fully electric vehicles (EVs) would cover only a small proportion of travel (2.5% of distance). See Figure B2 for a comparison of technology roll-out under the different levels. For buses, the majority of the fleet remains ICE vehicles and the share of ICE-hybrids is assumed to continue to grow at current trends, based on current purchase rates of ICE-hybrid buses, ending up with a roughly 60–40 split in the distance covered by these two types of vehicles respectively, with a handful of trial electric buses (see Figure B3 for a comparison). For rail, the share between diesel and electric trains would stay much as it is today (around 36% of rail seat miles are diesel, and 64% electric) – see Figure B4 for a comparison.

Efficiency

Efficiency improvements include some engine advances and other vehicle improvements such as light-weighting and downsizing. The trajectories show only one level of change in car and van efficiency rates, in order to keep the model manageable. The efficiency improvements included are ambitious and can be seen in Figure B5. ICE cars and vans show an average 54% improvement by 2050; EVs improve by 37%, and PHEVs by 50% by 2050. All types of buses (ICE, ICE-hybrid and full electric), have a 31% efficiency improvement by 2050 – see Figure B6. On rail, efficiency remains constant at current levels across all years.

Level 2

Passenger transport activity

This assumes some 'smarter choices' policies to encourage a shift from car use to other modes. No 'rebound effect' is considered, as a policy mechanism is assumed to lock-in the benefits. The implied average number of people per vehicle is as Level 1 for cars and vans, but a third higher, at 12, for buses. Transport activity growth is assumed to slow after 2035. (See figure B1 for a comparison of transport modes under the different levels). Domestic aviation activity (and efficiency) reflects the CCC's 'likely scenario'. To make the Calculator model manageable, only one trajectory is shown for domestic aviation emissions, and this is the same across all levels.

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[67] Committee on Climate Change (December 2009) *Meeting the UK Aviation target – options for reducing emissions to 2050*, http://www.theccc.org.uk/reports/aviation-report. It should be noted that the Committee's analysis assumed a continuation of the policies set out in the Air Transport White Paper (2003), http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/about/strategy/whitepapers/air/executivesummary.

Technology

By 2050 the majority of car and van distance travelled is in PHEVs (54%) with ICE vehicles still significant (35%), and a modest proportion of pure EVs (10%) and fuel cell vehicles, FCV, (1%). In terms of fleet share, EVs make up a larger proportion of the fleet than under level 1 (more like 20% in this level), but it is assumed that they will mostly be used for shorter journeys. This assumes a supportive policy framework along with relevant supporting infrastructure and a reduction in battery cost. An increased share of ICE-hybrid buses is expected, envisaging 20% being ICE-hybrid by 2020 and reaching 34% in 2022. It is then assumed the share of ICE-hybrid buses continues at this rate of growth, which is rapid due to the assumption that economies of scale in hybrid bus production are achieved. By 2050, all ICE buses are replaced by ICE-hybrids, with only a handful of electric buses. There is a small increase in electrification of rail, which includes the following electrification schemes: Great Western Main Line, Liverpool to Manchester and North West triangle.

Efficiency

For cars and vans and buses this is the same as level 1. Compared to level 1, by 2050 rail efficiency is 6% and 7% higher respectively for electric and diesel traction. This efficiency improvement is achieved through a range of measures such as driver training and energy metering.

Level 3

Passenger transport activity

Under level 3, significant mode shifts would be seen by 2050, with public transport, walking and cycling accounting for almost a quarter of all distance covered by 2050, and distance travelled as a car driver or passenger accounting for around three quarters. A shift would be seen towards greater car sharing, and the average number of bus passengers per vehicle rises to 18. Car travel would be around 9% lower by 2050 than in level 2, with bus use 50% higher than in level 2, tripling between 2010 and 2050; rail demand would be 40% higher than in level 2, growing by almost 80% between 2010 and 2050. Cycling would be 8% higher in level 3 than level 2, growing 140% between 2010 and 2050. Domestic aviation activity (and efficiency) reflects the CCC's 'likely scenario'.

Technology

There is a substantial switch away from ICEs so that by 2050 these account for only 20% of distance by cars and vans (and are mostly hybridised), and a big uptake in distance by PHEVs (32%) and EVs (28%). There is also a significant amount of distance accounted for by FCVs (20%). It should be noted that most plug-in hybrid distance is driven electrically by 2050, and again the electric fleet share is higher than the distance share. This assumes significant reductions in battery costs, hydrogen technology costs and the availability of infrastructure to support EVs and FCVs. The last ICE buses are replaced by 2030, and by 2050 78% of bus distance is ICE-hybrid, and 22% is electric. For rail, the share between diesel and electric switches more substantially to electricity, reflecting a mid-point between level 2 and full electrification by 2050.

Efficiency

Cars, vans and buses are as level 1. On rail, by 2050 the diesel train fleet is 40% more efficient on average than current designs and the electric fleet is 30% more efficient. These efficiencies are assumed to be delivered through both technical improvements to rolling stock – lighter designs, more efficient engines and motors – as well as through more efficient management of train movements (for example by reducing unnecessary stopping and starting).

Level 4

Passenger transport activity

Reflecting the availability of alternatives to travel, this level assumes a 5% reduction in total distance travelled in 2050, compared to levels 2 and 3. This reflects a combination of factors, including some very long trips being replaced by teleconferencing, a shortening of trips if people shop or undertake recreational activities more locally, or perhaps take opportunities to work at home.

Level 4 shows a radical mode shift such that public transport and cycling account for 36% of all distance travelled by 2050, and travel by car as a driver or passenger accounts for 62%. Within this, the implied average car occupancy is assumed to increase to reflect a greater level of car sharing. By 2050, cycling use relative to car use would be approaching that currently seen in the Netherlands, and UK mode shares would reflect far lower reliance on the car. Despite population growth over the period, car use (passenger miles) would be 5% lower in 2050 than in 2010, with public transport and cycling absorbing the activity that might otherwise have been made using the car.

Overall activity would be 25% higher in 2050 than in 2010 compared to being 33% higher in level 1, and 31% higher in levels 2 and 3. For level 4 this would mean bus demand (passenger miles) would be over 3.3 times higher, with implied average passengers per bus the same as Level 3 (18 passengers); rail use (passenger miles) would more than double and cycling activity would increase 10-fold above 2010 levels. For this to be the case, public transport would need to be sufficiently attractive to passengers (in terms of price, service provision, comfort etc) to make it a viable way to travel; and the conditions for cycling on highways and cycle lanes conducive to very high willingness to cycle. In addition, a mechanism would need to be in place to 'lock in' the reductions in travel activity to prevent the reductions in trips due to IT and such simply being replaced by other trips. Domestic aviation activity (and efficiency) reflects the CCC's 'likely scenario'.

Technology

This represents the maximum of what is considered to be technologically feasible by 2050. The majority of the surface passenger transport system is electrified apart from buses, which have a roughly equal share of EVs and conventional hybridisation, potentially using alternative fuels where possible. The last ICE buses are replaced by 2030. Passenger cars are entirely EVs or powered by a breakthrough in fuel cell technology. This assumes significant reductions in battery costs, hydrogen technology costs and the availability of infrastructure to support such vehicles. ICE light duty vehicles are completely removed from the market. By 2050, around 80% of passenger car distance is powered by electricity, with the remainder accounted for by fuel cells (which could be acting as the range extender in PHEVs rather than an ICE range extender as in other plug-ins). The whole rail network is powered by electric traction.

Efficiency

Cars, vans and buses improve efficiency as in level 1. Rail efficiency improves as in level 3.

Notes

Walking is included within the analysis as a constant share of distance travelled (ie, it increases over time in line with overall activity). The time taken to walk places implies constraints on the extent to which this can increase significantly.

The levels cover the main technologies for use in light duty vehicles within the 2050 timeframe that have been highlighted by stakeholders or published in studies. It is possible that new technologies not yet in development may come through in this time, and that other fuels, such as synthetic fuels, may also play a part. For the purposes of this study, the levels reflect largely proven technologies as well as anticipated breakthroughs, for example in battery performance.

Figure B1: Percentage of passenger distance by mode in 2050 under four levels of change

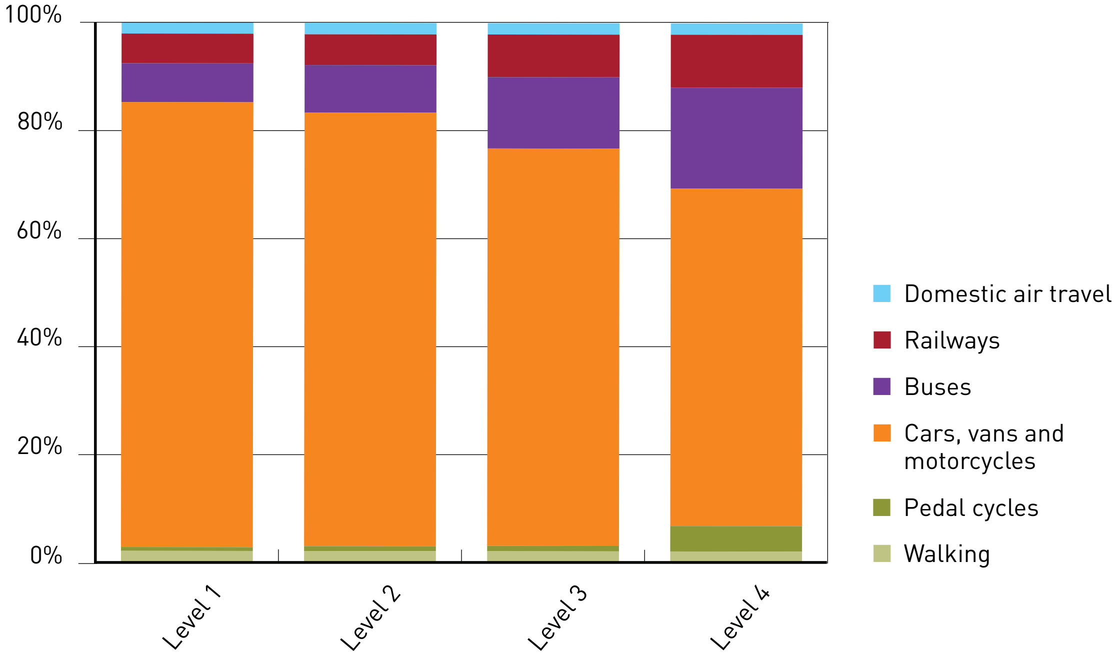


Figure B2: Proportion of car and van distance travelled by different power sources in 2050, under four levels of change[68]

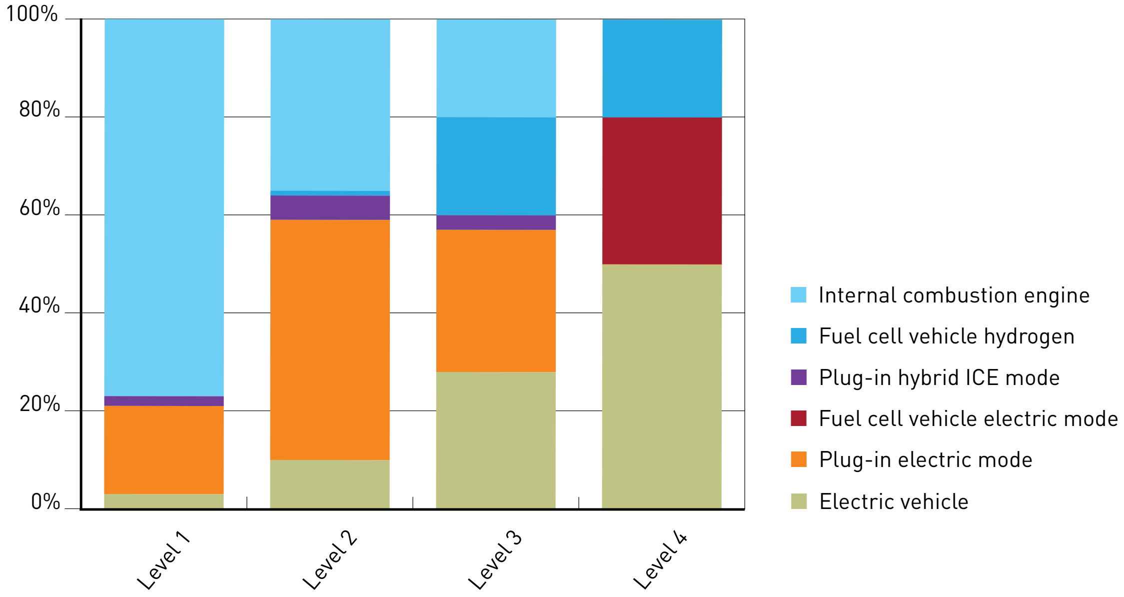
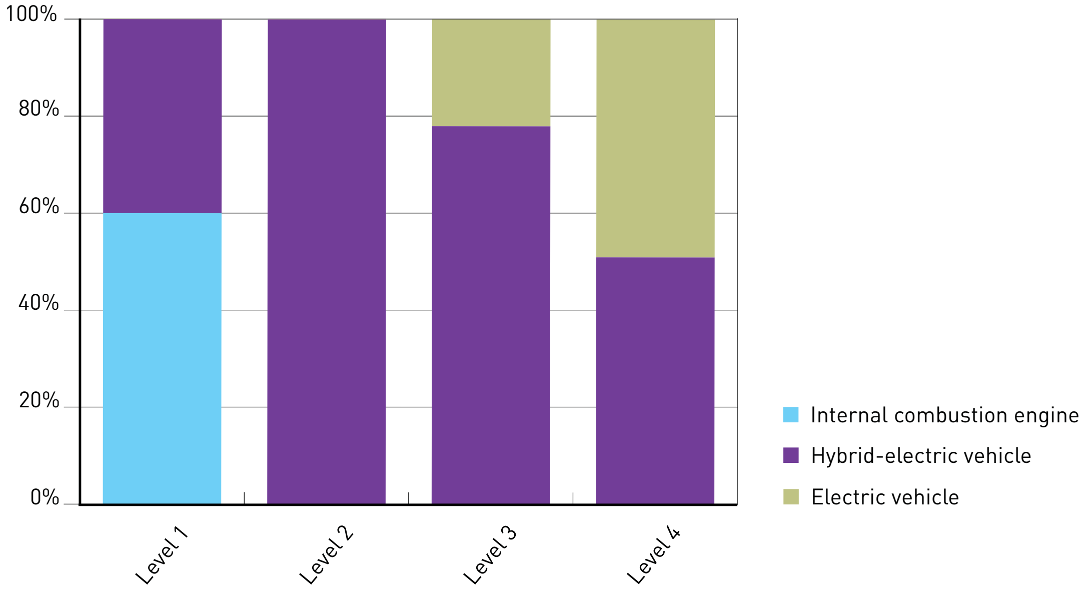


Figure B3: Proportion of bus distance travelled by different power sources in 2050, under four levels of change



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68 In level 4 the lighter vehicles used in and around cities are assumed to be fully electric and represent 50% of the vehicle fleet, fuel cell plug in hybrids or fuel cell vehicles represent the remaining 50% of the fleet, and tend to be larger vehicles driven more often and for longer distances. On average these vehicles are driven using hydrogen 40% of the time and electricity 50% of the time, although this will vary considerably for individual vehicles depending upon vehicle type and driving behaviour.

Figure B4: Proportion of rail distance travelled by different power sources in 2050, under four levels of change

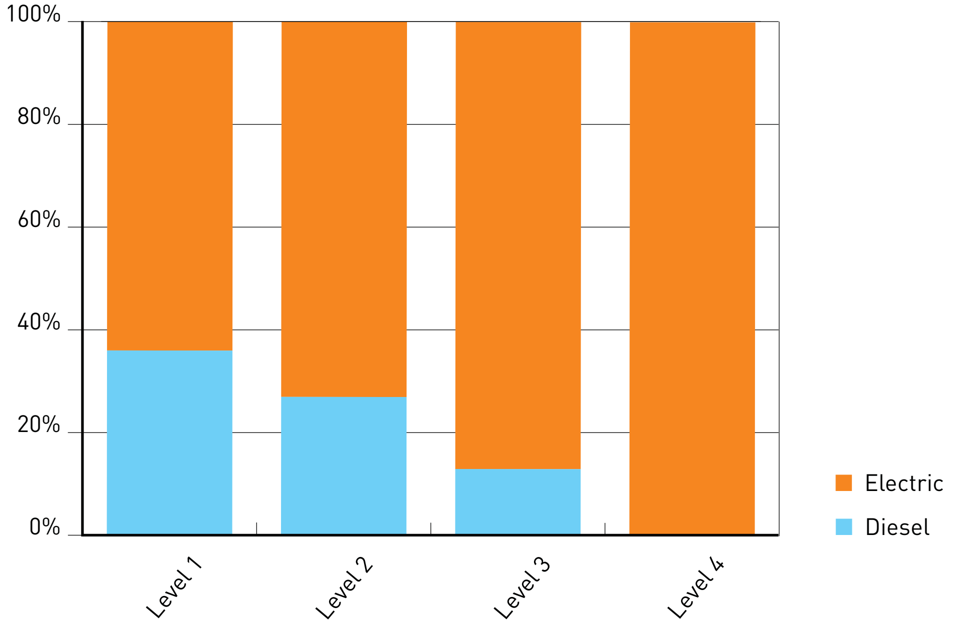
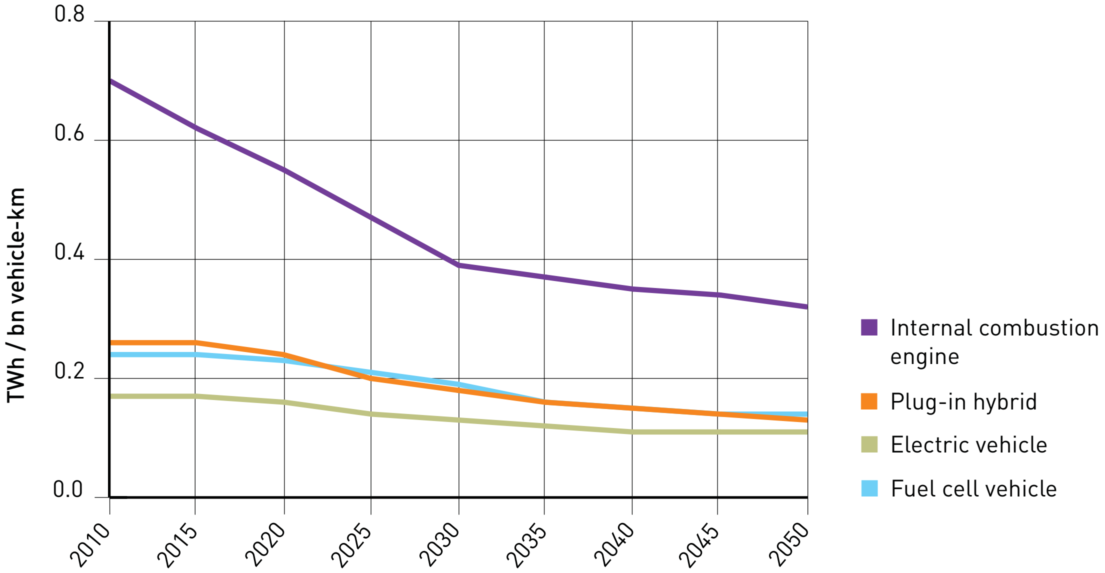


Figure B5: Efficiency improvements in the car and van fleet[69]



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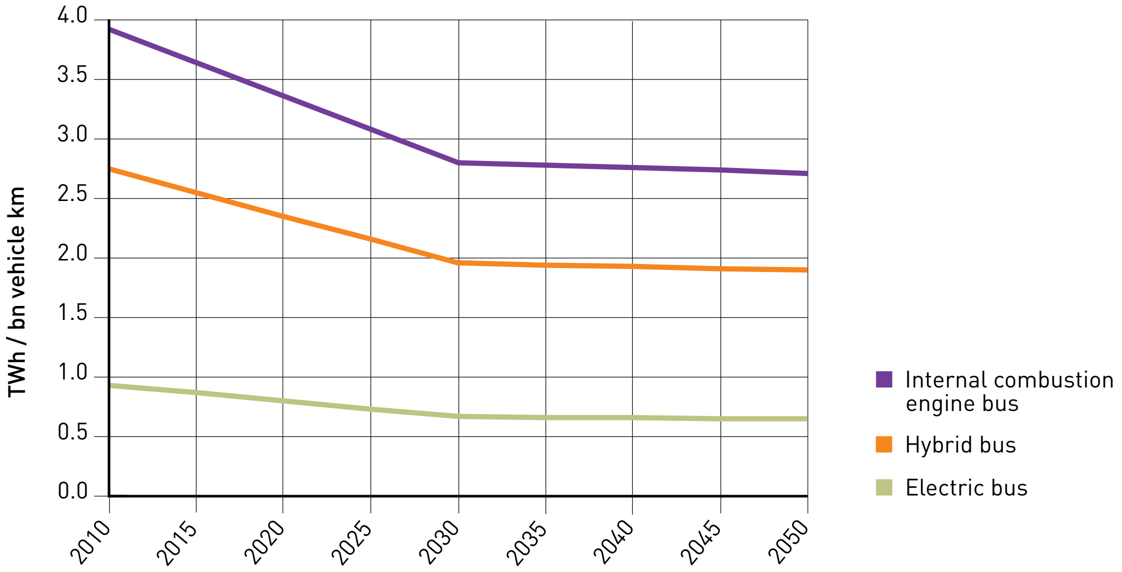
[69] This assumes that increasingly efficient vehicles enter the fleet over time, and the fleet turnover rate is 10%.

Figure B6: Efficiency improvements in the bus fleet



Levels for freight transport

For domestic freight transport activity the levels have been based on DfT baseline projections, rolled out to future years, combined with similar work undertaken by Heriot-Watt University.[70] The domestic shipping levels are based on the Department for Transport's 'Carbon Pathways Analysis'.[71] This includes forecasts of CO_2 emissions to 2022 based on bunker-fuel sales for UK domestic shipping. These forecasts have been extrapolated to 2050 using forecasts of tonnes- lifted at UK ports produced by MDS Transmodal for the Department for Transport.[72]

Level 1

Freight activity

The level of freight activity and mode share is based on DfT baseline projections rolled out to 2050. Under this level, road transport would make up 73% of distance, rail 9%, water 13% and pipeline 4%. For a comparison of freight mode shares under the different levels, see Figure B7.

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[70] McKinnon, A C and Piecyk, M I (2009) 'Logistics 2050: Road Freight Transport in a Low Carbon World' in Sweeney, E (ed) *Supply Chain Management and Logistics in a Volatile Global Environment*, Blackhall Publishing, Dublin. Government projections based on National Transport Model, National Rail Freight Route Utilisation Strategy, and MDST UK Port Demand Forecast.

[71] DfT (2008) *Carbon Pathways Analysis – Informing Development of a Carbon Reduction Strategy for the Transport Sector*, available at http://www.dft.gov.uk/pgr/sustainable/analysis.pdf

[72] MDS Transmodal (2007) *Update of UK Port Demand Forecasts to 2030 and Economic Value of Transhipment study*, available at http://www.dft.gov.uk/pgr/shippingports/ports/portspolicyreview/207015_Final_Report_2.pdf

Technology

Under level 1, almost all rail freight is powered by diesel trains as under today's levels. All road haulage operations use internal combustion engines, and the uptake of readily available lower carbon technologies such as aerodynamic fairings or low rolling resistance tyres is minimal.

Efficiency

Road haulage and rail freight remain at current efficiency levels. Rigid and articulated heavy goods vehicles (HGVs) using ICEs have only a 2% efficiency improvement by 2050. Empty running of 27% is assumed by 2050.[73] For a comparison of freight efficiency improvements under the different levels, see Figure B8.

Domestic shipping

CO_2 emissions after 2022 were assumed to change in line with MDS Transmodal forecasts of (non-unitised[74]) domestic tonnes-lifted at UK ports to 2030. Between 2022 and 2030 this comprises a decline in tonnes-lifted of around 0.26% per annum. After 2030 it was assumed that the annual change in tonnes lifted forecast between 2025 and 2030 continues to apply. No fuel efficiency improvements were assumed.

Level 2

Freight activity

The level of freight activity is based on DfT baseline projections rolled out to 2050, but with the mode share based on current efforts to increase rail and water freight, rolled out to 2050. Mode share shifts lead to: road 66%, rail 11%, water 19% and pipeline 4%.

Technology

The share of electric rail freight is the same as under level 1. HGVs continue to be powered by ICEs.

Efficiency

Road haulage empty running falls to 22% by 2050. There is a significant increase in use of readily available lower carbon HGV technologies, for example aerodynamic fairings, low rolling resistance tyres and automated manual transmissions. Overall, ICE rigid HGVs have an efficiency improvement of 33% by 2050, and articulated HGVs (which use internal combustion engines) have an efficiency improvement of 36% by 2050. Rail freight efficiency improves for both diesel and electric traction by 22% by 2030 compared to current levels and it remains constant thereafter.

Domestic shipping

Domestic shipping increases its mode share, based on current efforts to increase rail and water freight, rolled out to 2050. Mode share shifts lead to 19% of freight activity being carried out by water.

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[73] 'Empty running' is defined as the distance covered by freight vehicles while not carrying any freight, eg after having delivered all their cargo

[74] Non-unitised traffic comprises liquid bulk, dry bulk and other general cargo.

Level 3

Freight activity

The level of freight activity continues increasing at the same rate as for the previous decade, which is less than the historical relationship between GDP and freight activity. Note that as freight activity derives from demand for goods and raw materials (for example, for construction), it is unlikely this relationship would hold if activity in other sectors of the economy entailed the building of significant new infrastructure as demand for freight may increase. Mode share is: road 58%, rail 19%, water 19% and pipeline 4%.

Technology

The share of electric rail freight increases to 53% by 2050. On road freight there is a significant increase in the use of less readily available lower carbon HGV technologies such as ICE hybrids, which offer substantial carbon savings.

Efficiency

Road haulage empty running falls to 17% by 2050. ICE rigid HGVs have an efficiency improvement of 53% by 2050, and articulated HGVs have an efficiency improvement of 53%. Rail freight efficiency improves by 40% by 2050 compared to current levels for diesel traction, and by 30% for electric traction.

Domestic shipping

The mode share for water remains at 19%.

Level 4

Freight activity

The level of freight activity continues increasing at the same rate as for the previous decade, which is less than the historical relationship between GDP and freight activity (and as stated under level 3, this would be unlikely to hold if activity in other sectors of the economy entailed the building of significant new infrastructure. Road mode share falls to 50% by 2050, with rail 23%, water 23% and pipeline 4%.

Technology

Rail freight is all electric. Road freight has greater reliance on hybridisation and alternative fuels, where technically possible. Some smaller trucks are electric.

Efficiency

Road haulage empty running falls to 17% by 2050 as in level 3. ICE rigid HGVs have a 53% improvement in efficiency, while electric rigid HGVs have a 39% efficiency improvement; articulated HGVs have a 63% improvement in efficiency. Rail freight efficiency assumptions are the same as under level 3.

Domestic shipping

Modal share of water increases to 23% of freight activity. It was assumed that for all scenarios, fuel use will increase in direct relation to the change in the volume of goods moved by water.

Figure B7: Freight transport mode share in 2050, under four levels of change

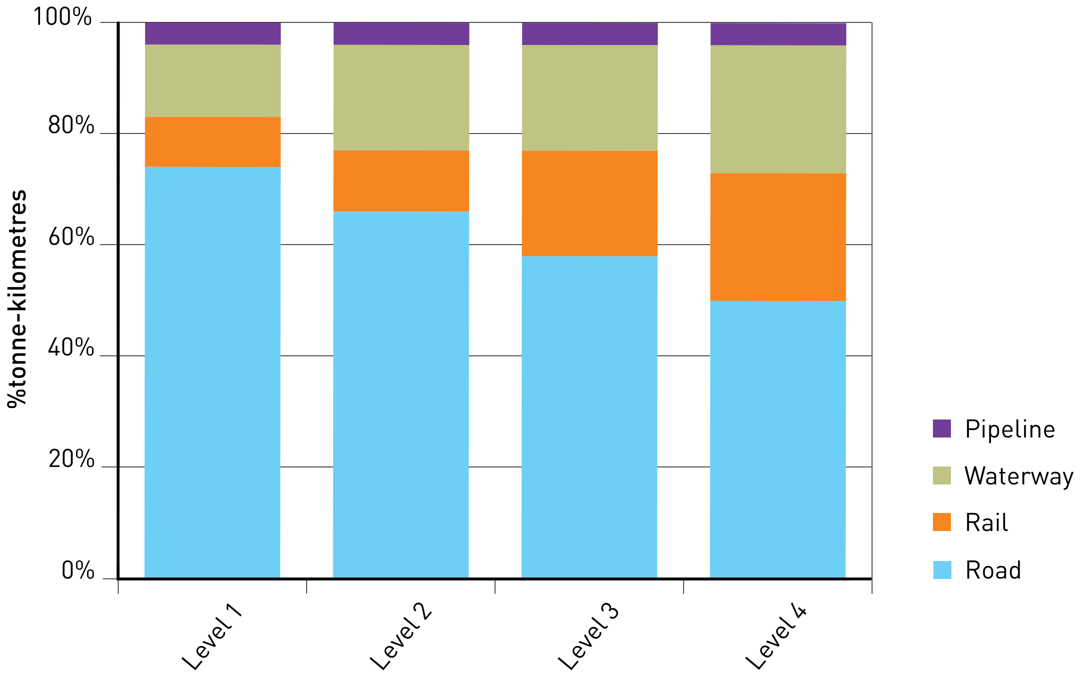


Figure B8a: Energy use per kilometre by rigid HGVs under four levels of change

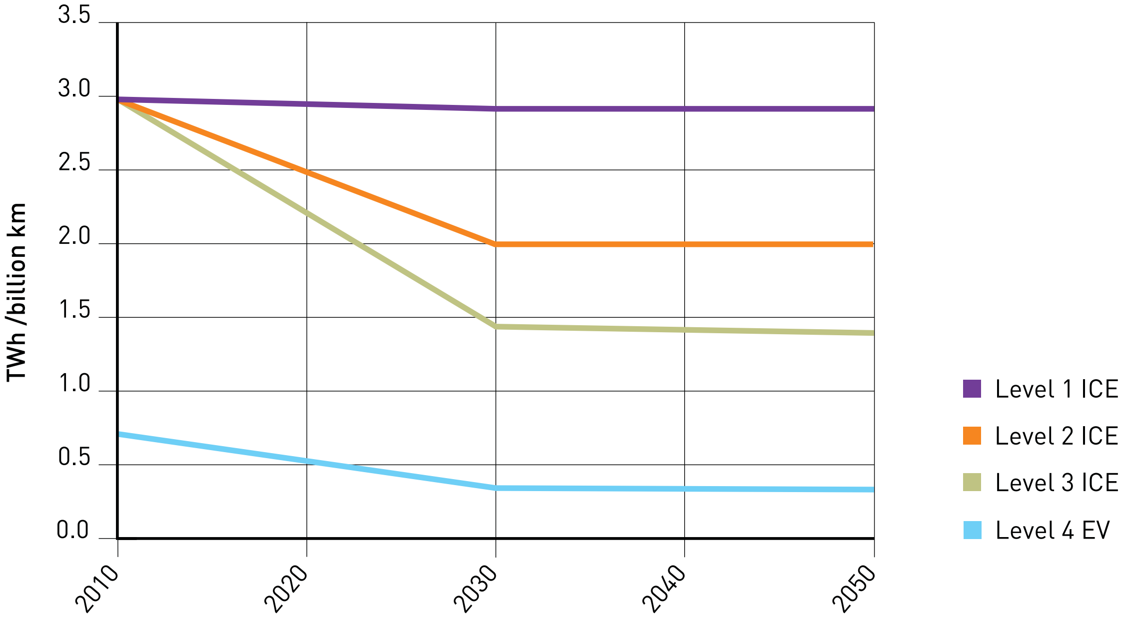
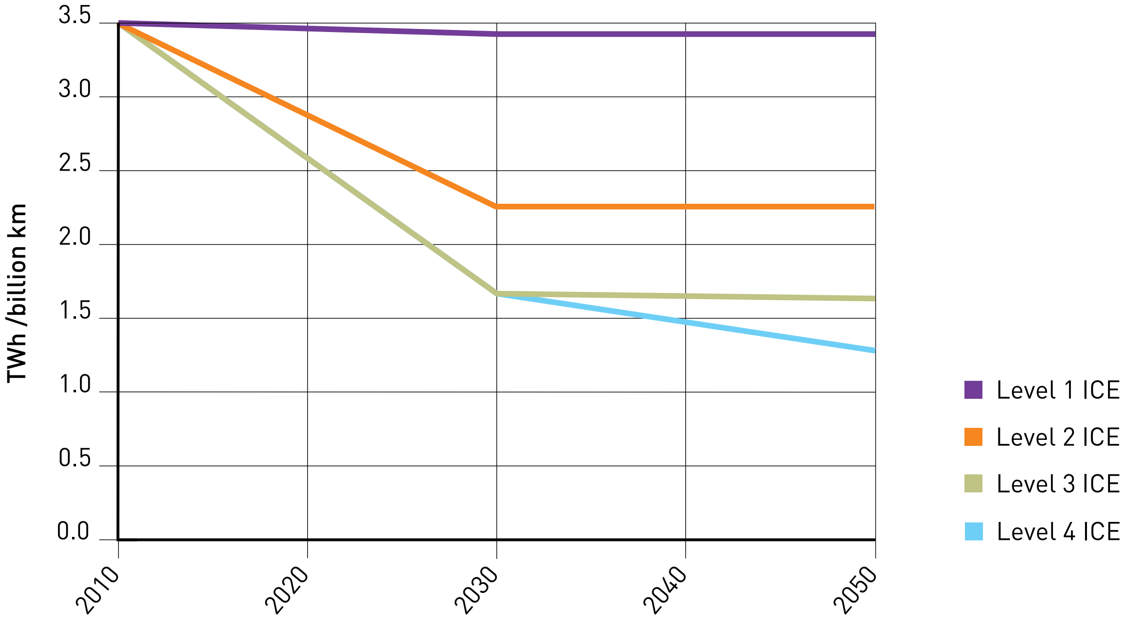


Figure B8b: Energy use per kilometre by articulated HGVs under four levels of change



Levels for international aviation

The levels of change for domestic and international aviation reflect the three scenarios developed by the Committee on Climate Change (CCC) in its advice to Government in December 2009.[75] A comparison of the energy used under each of the different levels can be seen in Figure B9.

For the purpose of this 2050 analysis, international aviation emissions have been assigned to the UK on the basis of all flights departing from the UK, consistent with the methodology used by the CCC.

Level 1 - CCC Likely scenario

This level reflects lower demand for aviation compared to the CCC's reference case and carbon intensity improvements that are likely to be achieved given current policies, investment levels and the pace of technological advance.

- **Activity:** This level does not specify a particular change in the level of aviation activity. The CCC estimates that its 'Likely' scenario would result in passenger demand of about 115% above 2005 levels.
- **Efficiency:** This level assumes annual improvements in fleet fuel efficiency of 0.8% together with 10% biofuels penetration by 2050. It should be noted that the analysis underpinning this 2050 report does not assign biofuels to a specific demand sector such as aviation, and so the level here is not fully comparable with the CCC scenario.

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[75] Committee on Climate Change (2009) *Meeting the UK Aviation target – options for reducing emissions to 2050*, http://www.theccc.org.uk/reports/aviation-report

Level 2 – CCC Optimistic scenario

This level requires a significant shift from current policy (for example, to high speed rail), an increase in the level of investment in new aircraft technologies and/or in the pace of fleet renewal, as well as improvements in the efficiency of air transport movements and operations so as to make a 1.0% per annum improvement in carbon efficiency attainable. It would also require the progress of biofuel technologies which would lead to a 20% penetration of biofuels, if compatible with our aims of sustainability.

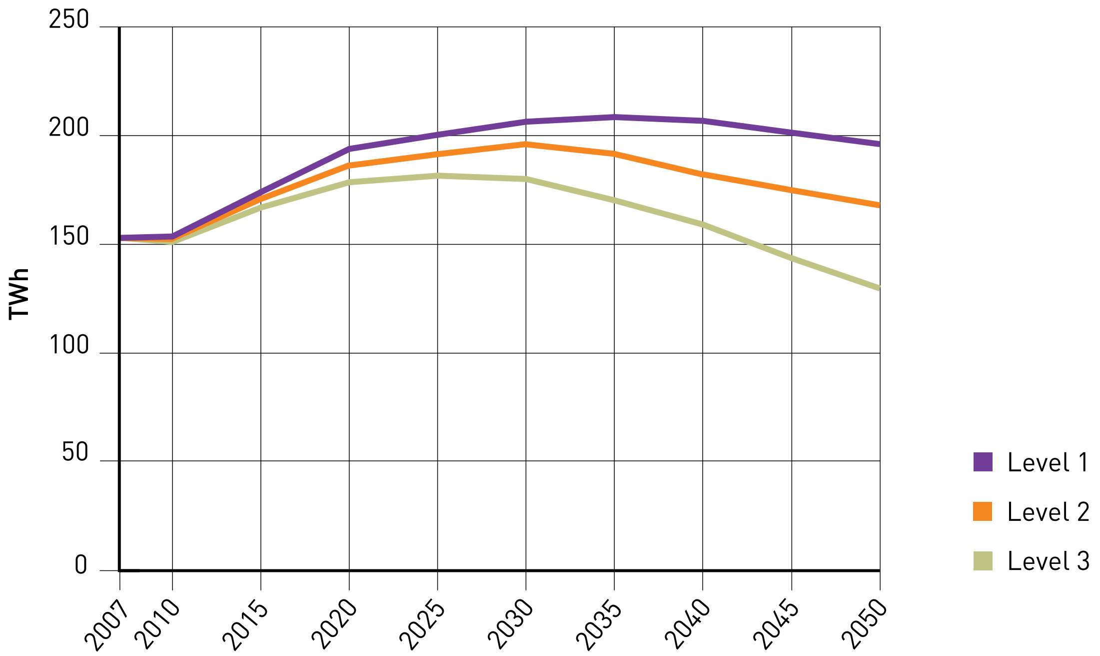
- **Activity:** This level does not specify a particular change in the level of aviation activity. The CCC estimates that this scenario would result in passenger demand of about 105% above 2005 levels.
- **Efficiency:** This level assumes annual improvements in fleet fuel efficiency of 1.0% per annum and 20% biofuels penetration by 2050. The above caveat on biofuels also applies.

Level 3 – CCC Speculative scenario

This level would require both technological breakthroughs and a significant increase in the pace of aircraft fuel efficiency improvements. In addition, it would require the development of sustainable biofuels which are currently speculative (such as biofuels from algae), or an evolution of global population, food demand and agricultural productivity which would make possible the sustainable and large scale use of current agricultural land and water to grow biofuel feedstocks.

- **Activity:** This level does not specify a particular change in the level of aviation activity. The CCC estimates that this scenario would result in passenger demand of about 90% above 2005 levels.
- **Efficiency:** This level assumes annual improvements in fleet fuel efficiency of 1.5% and biofuels penetration of 30% in 2050. The above caveat on biofuels also applies.

Figure B9: Total energy for international aviation under three levels of change

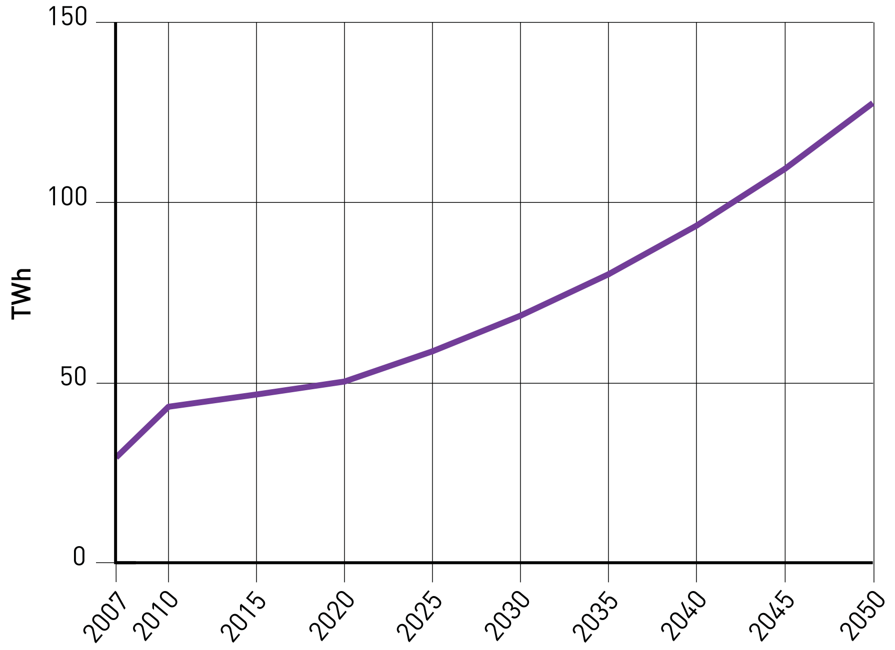


Levels for international shipping

As with international aviation, there is no globally agreed methodology for allocating emissions from international shipping to countries. For the purposes of this report, one illustrative scenario was used. The approach taken was to use the International Maritime Organization's (2009)[76] activity-based projections of CO_2 emissions from international shipping globally to 2050, and to attribute a share of these emissions to the UK on the basis of estimates by the International Energy Agency.[77] These estimates suggest that the UK's share of the total CO_2 emissions from international marine bunkers was around 1.2% in 2007. This percentage was assumed to be constant going forward.

Projections for the IMO's 'A1B' (base) scenario were used. These assume that global fleet activity grows by around 3.3% per year, with aggregate improvements in efficiency (including speed reductions, operational measures and regulatory developments) of 39% in 2050 (compared to 2007). Some liquefied natural gas fuel penetration is also assumed. Figure B10 shows the associated estimate of total energy for UK international shipping out to 2050.

Figure B10: Total energy for UK international shipping under the level 1 trajectory



Unlike other sectors, only one level of change is shown. This is because there is little data available to inform understanding of potential changes to UK international shipping emissions, meaning it was not possible to present a range of changes.

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[76] IMO (2009) *Second IMO GHG Study 2009*, http://www.imo.org/Environment/mainframe.asp?topic_id=1823

[77] IEA (2009) *CO_2 Emissions from Fuel Combustion, Highlights*, http://www.iea.org/co2highlights/CO2highlights.pdf

Section C: Industry

Context

The UK is the world's sixth largest manufacturer,[78] with a diverse industrial base spanning the manufacture of basic metals, food and drink, and cutting-edge composites. The UK manufacturing industry makes an important contribution to the economy and accounted for 12.4% of UK Gross Value Added in 2007.[79]

The transition to a low carbon economy represents a significant opportunity for the UK economy as a whole, and industry in particular. The Low Carbon and Environmental Goods and Services (LCEGS) sector already makes a significant contribution to the UK economy, worth over £112 billion in sales in 2008/9 (globally the 6th largest LCEGS market). The sector employs an estimated 910,000 people within the specialised sectors and wider supply chain and is forecast to achieve between 4 and 5% sales growth per annum to 2015/16. The global LCEGS market was £3.2 trillion in 2008/9 and is projected to grow on average at 4% annually over the next 5 years presenting global export opportunities as well as UK firms serving domestic needs.[80]

The transition also presents fundamental challenges. Industry is a major energy user and greenhouse gas emitter. In 2007, it produced 93 $MtCO_2e$ of greenhouse gas emissions (not including indirect emissions from use of electricity produced off-site) and demanded 408 TWh of energy, 15% and 21% percent of the UK respective totals.[81] This is despite falls in output from some of the most energy intensive sectors, and significant efficiency improvements.

The trajectories described in this section explore possible levels of energy demand and emissions from industry. The majority of industrial emissions are produced by fuel combustion and can be reduced by improvements in energy efficiency. Energy consumption per unit of industrial output has fallen by 66% since 1970.[82] Total industrial energy consumption has fallen by 51%, while industrial output has risen by 45%. These declines in energy intensity have been driven by the international competition these industries face and the need to achieve incremental efficiency improvements, as well as improvements with machinery and changes within the industrial base. More recently, the EU Emissions Trading System (ETS) and UK Climate Change Agreements (CCAs) have prompted a renewed focus on emissions. However, improvements in energy efficiency in most sectors are flattening out. Figure C1 illustrates the change in energy intensity of UK steel production between 1972 and 2008.

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[78] United Nations National Accounts Main Aggregates Database, 2008 data (latest available).

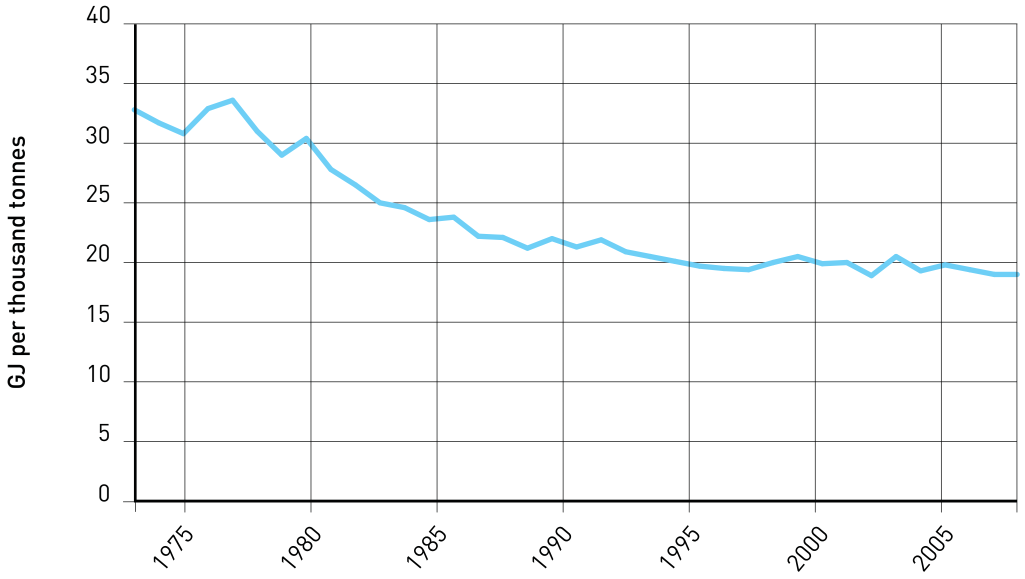
[79] ONS Blue Book, 2009 edition.

[80] Innovas (2009, 2010) *LCEGS industry analysis* available at: http://www.berr.gov.uk/policies/business-sectors/low-carbon-business-opportunities/market-intelligence

[81] DUKES 2009 and UK GHG Inventory (2009), using the definition of industry adopted by the 2050 calculator which is wider than the DUKES definition (eg, it includes blast furnace emissions).

[82] Digest of United Kingdom Energy Statistics (DUKES), 2009 Edition,Table 4.4 .

Figure C1: Energy intensity in UK steel production (1972-2008)[83]



The EU ETS covers CO_2 emissions from power stations and energy-intensive industries. The system puts a price on carbon through the use of a cap and trade mechanism, which incentivises industry to invest in low carbon technologies and energy efficiency. The first phase (2005-07) was very much a learning-by-doing phase for participants.

For Phase II (2008-12) the cap was tightened, which is resulting in a marginally higher and more stable carbon price, making it more cost effective for industry to reduce emissions. However, the carbon price remains at fairly low levels and there are concerns that this is not providing a sufficient incentive for low carbon investment.

From Phase III (2013 onwards), the cap will be significantly tightened and the ETS will deliver emission reductions of 500 $MtCO_2e$ per year across the EU by 2020. If the EU adopts a higher mitigation target (ie a 30% reduction on 1990 emissions), then the ETS cap will be tightened further and the amount of emission reductions will increase.

In addition, the Climate Change Levy (CCL) has taxed the use of energy in industry, commerce and the public sector since 2001. Energy-intensive industries can obtain a discount from the Climate Change Levy, provided they meet challenging targets for improving their energy efficiency or reducing their carbon emissions. Climate Change Agreements (CCAs) set the terms under which eligible companies may claim the levy reduction.

From April 2010, the CRC (Carbon Reduction Commitment) Energy Efficiency scheme has operated a mandatory emissions reductions programme for organisations that are not covered by the ETS and Climate Change Agreements. This is designed to promote energy efficiency in large organisations.

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[83] EEF (2009) UK Steel Key Statistics.

Drivers and enablers

Industrial emissions – both direct process and combustion emissions and indirect emissions from the use of non-decarbonised electricity – will be determined by the combination of future output levels and the emissions produced per unit of output. Emissions from freight are included within this report's transport section and indirect emissions from the use of off-site electricity are accounted for within the electricity generation sections of this report. This section only considers direct industry emissions resulting from fuel combusted on site for energy as well as process emissions resulting from industrial chemical reactions. Emissions reductions for industry from using biofuels (rather than fossil fuels) for on-site energy are not factored into the industry section of the 2050 Pathways Calculator. Biofuel emissions savings are not assigned to specific sectors in the Calculator; instead, they are assigned to the UK emissions account as a whole.

The embedded emissions within imported raw materials and manufactured goods are not included within the 2050 Pathways Calculator, in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) and UK carbon budget accounting systems. However, if the UK begins to shift towards importing more carbon intensive industrial outputs, the embedded emissions will clearly increase.

Key drivers of industrial emissions considered below are: energy intensity; process emissions intensity; carbon capture and storage (CCS); fuel switching; and production output levels.

Energy intensity

The International Energy Agency reports that globally 'the energy intensity of most industrial processes is at least 50% higher than the theoretical minimum determined by the laws of thermodynamics'.[84] However, within the UK, the currently available cost-effective savings have already largely been made and a 50% reduction was considered unrealistic by many stakeholders consulted for this report.[85] Scope for efficiency improvement remains, but the more radical shifts will require investments that go beyond the level of what is currently cost effective. In some sectors, substantial further reductions are likely to involve high levels of investment in new technologies, materials and processes.

If the costs of making such investments made these sectors uncompetitive relative to their international counterparts, purchasers of such products may be forced to turn to imports. This could, for example, mean that the high value pharmaceutical and specialist chemicals sectors begin importing base chemicals currently produced in the UK which have significant levels of embedded emissions from both their manufacture and transport.

Combined Heat and Power (CHP) will continue to contribute to declines in energy wastage. However, once the electricity grid has been decarbonised, onsite power production will no longer reduce emissions.[86] Therefore, it has not been examined in detail in this report.

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[84] IEA (2006) *Energy Technology Perspectives 2006 – Scenarios and Strategies to 2050*.

[85] Two workshops and a number of bilateral discussions were held with members of the Business and Climate Change Group (BCEG) and the Manufacturers' Climate Change (MCC) groups in January 2010.

[86] Parsons Brinckerhoff (2009) *Mapping our low carbon path to 2050*.

Process emissions intensity

Some industrial sectors produce direct emissions from chemical reactions involved in their activities. These are more difficult to reduce. Substantial reductions in process emissions will require new techniques, such as electrolysis within the steel industry; use of inert anodes within aluminium production; and new catalysts within chemicals manufacturing. Most of these techniques are still in development and are therefore unlikely to be deployed until the latter part of the period to 2050. Technological advances will also be needed to find substitutes for naphtha and other oil and gas fractions used as raw materials within the chemicals industry.

Carbon Capture and Storage

Industrial CCS offers the potential to capture combustion and process emissions. CCS will be essential to minimise emissions in industries such as cement and steel, where viable alternatives to high-emitting processes are still a long way off. With a few exceptions[87] however, it is not yet proven commercially and needs to overcome a number of technical and logistical challenges.

Technology

The technology for industrial CCS is less developed than in the power sector and its deployment is likely to lag behind by at least five years. CCS demonstration sites are being developed for the steel industry as part of the ULCOS project[88] and research is taking place in other sectors, such as cement.[89] Both pre- and post-combustion CCS are being investigated. However, significant technological issues remain unresolved.

Transport and storage

It is assumed that industrial CCS would use storage sites and transport networks developed primarily for the power sector. Some major industrial plants, such as the Scunthorpe steel plant, could be well placed to tap into proposed CCS pipelines and infrastructure hubs. The location of major cement plants could make it more difficult for onsite CCS to link into developing infrastructure. However, options such as rail transport may be available.

Investment

Both retrofitting existing plants and building new plants with CCS capacity will require a high level of investment and may be impractical for plants emitting less than about 0.1MtCO_2e/year. CCS will also increase energy demand and operating costs.[90] However, assuming that the research and development currently underway on lowering CCS cost

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[87] CO_2 is already captured within fertiliser production, but it is either vented or sold for use in carbonated drinks.

[88] The Ultra Low Carbon Steelmaking (ULCOS) project is a consortium of 48 European companies. It develops and pilots new technologies within the steel industry, to cut emissions by 50%. www.ulcos.org

[89] Mineral Products Association (2009) *Carbon Capture and Storage (CCS) in the cement industry*. This document states that the European Cement Research Association (ECRA) is currently undertaking research into CCS within the cement industry.

[90] Pocklington, D and Leese, R (2009) *Towards Zero Emission Production – Potential of Carbon Capture in Energy Intensive Industry* states that oxy-combustion CCS could raise cement production costs by 24%.

is successful, application of this technology to industrial CO_2 sources could begin before 2030 and be widespread after that date.[91]

Fuel switching

28% of energy demanded by industry is in the form of electricity.[92] In the longer term, an increase in the proportion of electricity demanded offers a key opportunity to reduce emissions. It is assumed that, in theory, most industrial energy could be supplied in the form of electricity, with the exception of some high-temperature heating processes.

There are also opportunities to switch to biomass fuels across all forms of heating, including a higher proportion of biomass in the highest temperature processes. Proportions of waste and biomass fuels are growing in many industries. For example, the paper industry makes use of waste paper pulp as an energy source and waste tyres are burned within some cement plants. However, the use of biomass feedstocks will be limited by their availability. Renewable fuels and waste can also increase overall energy demand due to the need to process these fuels prior to burning.

Sector segmentation used

UK industry is diverse. Different industrial sectors will follow their own pathways to 2050. The energy demand and emissions from different parts of industry will depend on how fast the sector grows or shrinks; the extent to which it has already improved its energy efficiency; the development and deployment of new technologies; market and policy drivers; plus a range of other factors. This analysis does not look at every sector and technology individually, but looks in more depth at the chemicals, metals and minerals sectors, due to their high energy and emissions intensity.

- **Chemicals and petrochemicals** (excluding refineries): this sector includes the manufacture of pharmaceuticals, paints, plastics and fertilisers. It consumes high levels of energy and also uses oil and gas fractions, such as naphtha, as raw materials.
- **Metals**: this sector includes iron, steel and aluminium production. In the 2050 Calculator, it also includes coke manufacture and blast furnaces, which are associated with the metals industry. The metals sector produces emissions from fuel combustion and energy use, and industrial processes. Proportionally, the aluminium industry is more energy intensive and the steel industry produces relatively higher levels of process emissions.
- **Minerals**: emissions within this sector are dominated by the cement industry, which produces a high proportion of process emissions within the industry sector industry. Limestone and dolomite production also generate process emissions. The sector takes up only a small share of overall output, however.
- **Wider industry** includes the production of food and drink, paper, textiles, construction, vehicles and a wide range of other products. This sector produces very

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[91] IPCC Fourth Assessment Report: Climate Change 2007.

[92] Digest of United Kingdom Energy Statistics (DUKES). 2007 Edition, Table 1.14, Summary of industrial use of fuel for heat .

few process emissions directly[93] but has the highest overall emissions from energy use.

Figures C2-C4 below show how proportions of total output, energy demand and process emissions vary across the sectors.

Figure C2: Percentage share of UK manufacturing output (2007)[94]

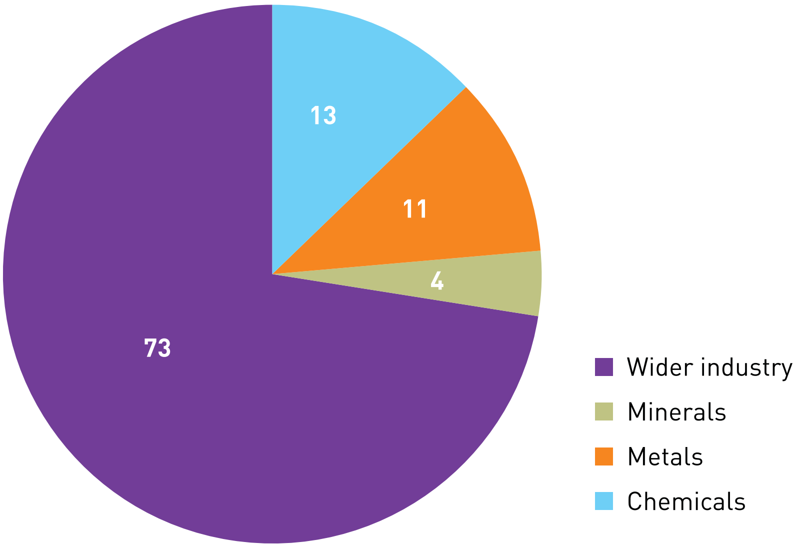
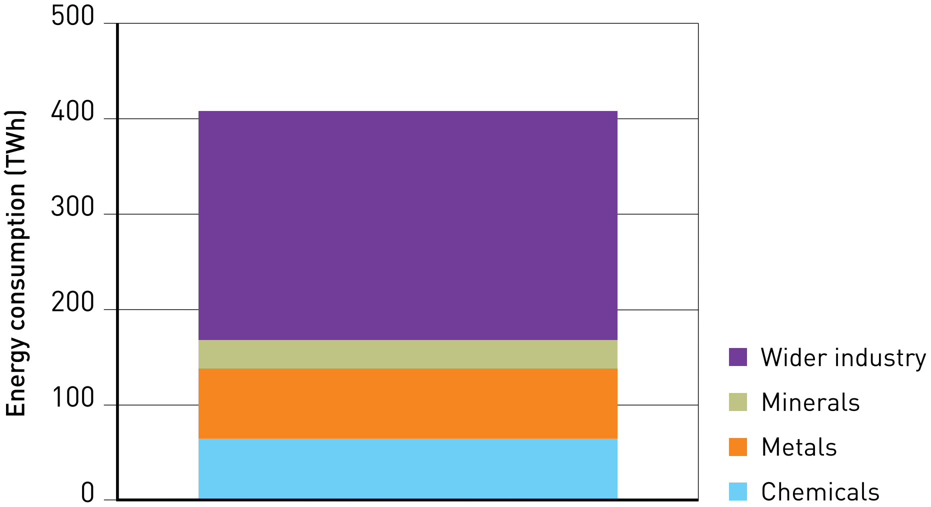


Figure C3: Energy consumption by UK industrial sector (2007)[95]



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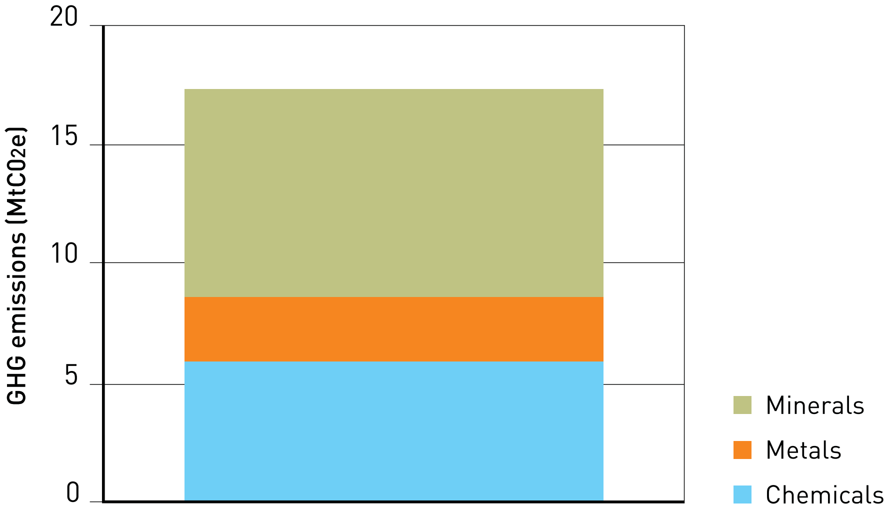
[93] However, it produces a number of products containing F-gases, which constitute a significant source of emissions and which are covered in the wider industry section of the 2050 Pathways Calculator.

[94] ONS Blue Book, 2009 Edition.

[95] DUKES 2009 Edition.

Figure C4: UK Industrial process emissions by sector (2007)[96]



The trajectories

The trajectories described below explore possible levels of energy demand and emissions from industry. The fastest reductions in industrial emissions would be achieved through a dramatic decline in output, but this would lead to greater imports of goods and a rise in embedded emissions.[97] It would also have impacts on the wider economy (with macro-economical, fiscal and employment impacts). Therefore, trajectories A-C focus on potential reductions from a growing industry.

Trajectories A-D are not ordered to reflect a ramping up of effort. Instead, for each of the four industrial sectors, the report sets out high, medium and low output levels (described in detail in 'Output assumptions' below), and also three levels of energy and emissions intensity (described in detail in the 'Sector specific assumptions' below). These are then combined in different ways to generate the four energy and emissions trajectories for industry up to 2050, as summarised in Table C1. Figures C5 and C6 illustrate the energy demand and emissions associated with the four trajectories respectively.

Table C1: Energy and emissions trajectories for industry

	Low output	Medium output	High output
Highest energy intensity and process emissions	X	Trajectory A	X
Medium energy intensity and process emissions	X	Trajectory B	X
Lowest energy intensity and process emissions	Trajectory D	X	Trajectory C

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[96] UK GHG Inventory, National Inventory Report 2009. F-gases not included as process emissions in this chart.

[97] It would also lead to a rise in net global emissions, assuming that the goods were produced in countries with more carbon intensive processes and require transporting.

Trajectory A: historic growth, rising emissions

This trajectory assumes a continuation of historic trends on output and little progress on reducing energy intensity and process emissions. Energy demand increases by 13.5%, while output rises by more than a third. Emissions rise slowly (4% over the whole period).

Trajectory B: historic growth, lower emissions

Again, this trajectory assumes that historical trends on output continue. It includes moderate improvements in energy intensity and process emissions. Energy use remains almost constant (falling by 3% by 2050) while output increases in most sectors. Emissions fall by over a quarter.

Trajectory C: high growth, large emissions reductions

In this trajectory, industrial output increases across all sectors, rising by 130% overall. However, energy intensity and process emissions reduce dramatically meaning that energy use rises only by a quarter. This assumes that the greater efficiency of new plants and the influence of the ETS cap would drive improvements in energy and emissions intensity within an expanding industry. Emissions reduce to 56% of 2007 levels, with steeper falls after 2030 due to the deployment of CCS.

Trajectory D: smaller industrial base, large emissions reductions

This trajectory assumes a smaller, highly efficient industrial sector and that lower levels of output would be accompanied by lower energy intensity as the least energy efficient plants shut first. Heavy emitting industries decline and overall output falls to two thirds of 2007 levels. Energy intensity and process emissions decline dramatically, driven by high energy and carbon prices. Energy demand is 2.5 times lower by 2050 and total emissions fall by almost 80%. However, there is a higher level of imported goods.

Figure C5: Energy consumption under four industry trajectories

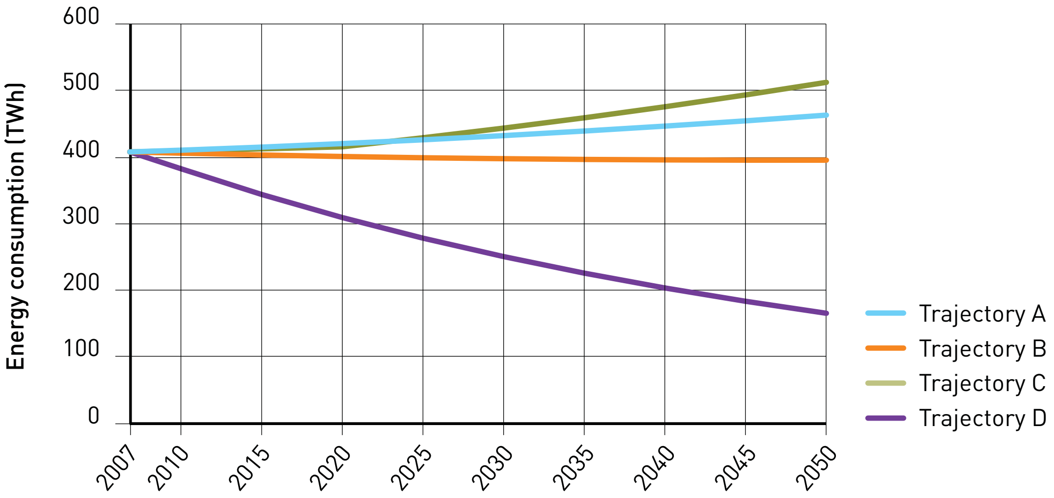
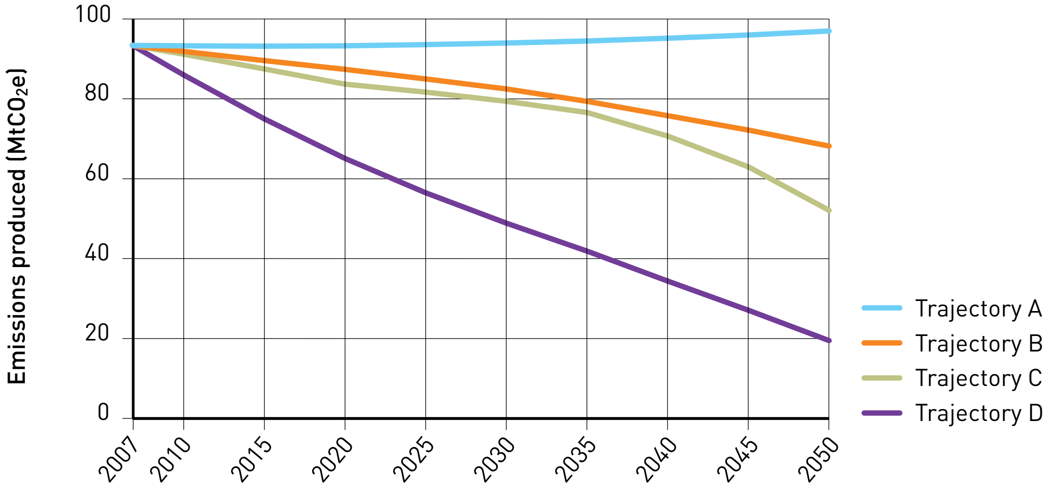


Figure C6: Emissions produced under four industry trajectories[98]



A thriving, expanding industrial sector can reduce emissions levels. All trajectories, except trajectory A, see a decline in overall emissions.[99] In trajectory C, output more than doubles, but emissions decline by 44%. Declines are driven by fuel switching, new industrial processes, energy efficiency improvements, CCS and also by higher growth rates within less intensive sectors. An 80% reduction in industrial emissions is achieved in trajectory D, but this relies on an overall fall in output. In this report we do not assume that all sectors need to reduce their emissions in equal measure, and we recognise that the industrial sector faces particular challenges.

In trajectories A – C, energy demand stays flat or rises moderately. It is only in trajectory D – where ambitious reductions in energy and emissions intensity are combined with a substantial decline in output across sectors – that we see a steep decline in demand for energy. It is difficult to achieve an overall decline in energy use while output grows in line with historical trends or above. Increases in output can be offset to a high degree by reductions in energy intensity. However, by the end of the period, the 'high output' trajectory C demands the most energy, despite ambitious reductions in energy intensity.

Output assumptions

All industry trajectory assumptions below have been formed following discussions with representatives from industry,[100] academics and analysis of relevant literature. A wide range of scenarios were proposed, reflecting different technological assumptions, approaches, scope and timescales.

The high, medium and low output assumptions that underpin the trajectories are set out below and aim to reflect the range of opinion and evidence encountered. These have been developed from analysis of historical trends from 1970-2008[101] using a measure of

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[98] Includes f-gases.

[99] Note that emissions savings from burning biomass are not included. These would increase emissions reductions. Indirect emissions from electricity use are not included. These will be minimal from 2030-2050, assuming that the grid has been largely decarbonised.

[100] Two workshops and a number of bilateral discussions were held with members of the Business and Climate Change Group (BCEG) and the Manufacturers' Climate Change (MCC) groups in January, 2010.

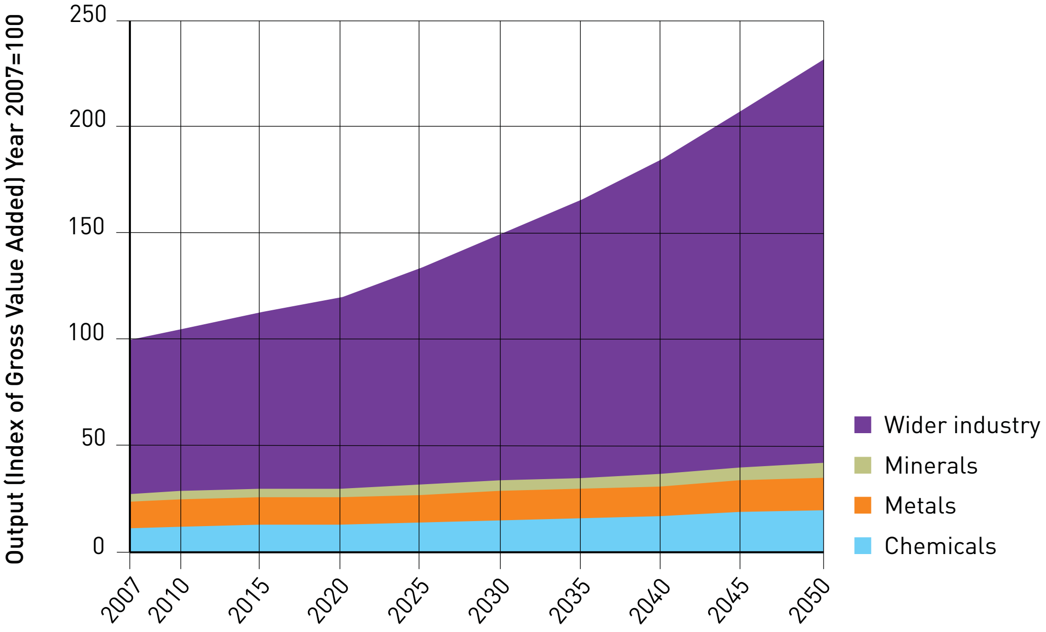
[101] Office of National Statistics (ONS), GVA output index.

Gross Value Added. This work assumes a constant rate of economic growth across different pathways. However, it is recognised that in reality, a shrinking industrial sector will have impacts on employment rates and the wider economy. A wide range of possible growth rates are considered – both positive and negative.

High output

The highest output figures assume that UK industry is renewed by the transition to a low carbon economy. UK industry starts to ramp back up to achieve high levels of output growth seen in previous decades. Once the green industrial base is firmly established, wider industry's industrial output growth squarely matches GDP growth to 2050. A high proportion of consumed goods are produced domestically. UK industry is able to compete on a level playing field, due to a global carbon price and/or ambitious international agreements on emissions. A healthy economy fuels a strong construction industry and a thriving wider manufacturing industry. UK chemicals firms take a leading role in developing low carbon chemical substitutes. Rising demand for new transport and energy infrastructure fuels demand for basic metal production.

Figure C7: High industrial output



Wider industry	Assuming a return to the high growth rates of the 1980s and 1990s. 1.7% per year until 2025, then 2.5% to match the assumed GDP growth rate.
Minerals	Assuming quick recovery from the 2008 recession and then continuation of 1980-2007 growth rates (1.4% per year).
Metals	Assuming 1993-2008 growth rate (0.4% per year).
Chemicals	Assuming growth at half of the 1970-2008 average annual growth rate (1.3% per year).[103]

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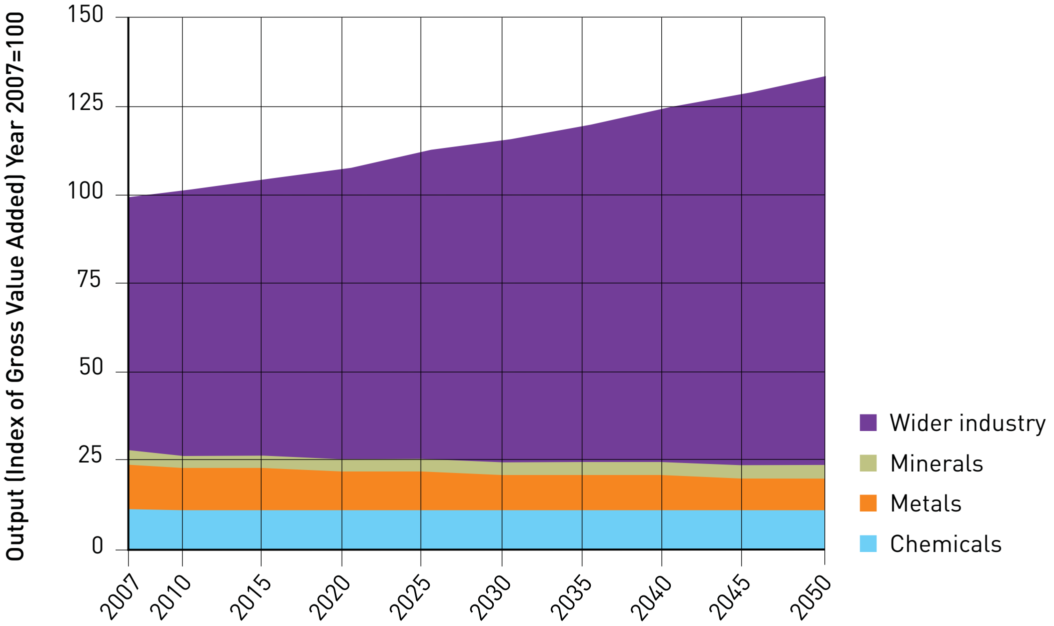
[102] The recent historical growth rate is 2.7% per year, but this was felt to be too high by representatives of the Business and Climate Change Energy Group (BCEG), at a workshop on 07 January 2010.

Medium output

The medium output figures assume a continuation of historical trends, except within the chemicals industry.

Figure C8: Medium industrial output



Wider industry	Assuming 1970-2008 trajectory continues (1.0% growth per year).
Minerals	Assuming 1970 – 2008 trajectory continues (0.25% growth per year).
Metals	Assuming 1970-2008 trajectory continues (-0.8% per year).
Chemicals	Assuming that the chemicals industry hovers around the 2007 baseline.[104]

Low output

This output assumption sets out the most pessimistic output trajectories for the different sectors. This might mean that the balance of the UK economy has continued to shift away from manufacturing, implying rising imports or reduced consumption levels. Declines in certain industries may also reflect substitution of products, such as a shift from steel to timber within the construction industry. The low output figures are likely to imply that increasing levels of emissions have been exported, as industries move outside the UK. This process would lead to a reduction in UK output, while leaving global emissions unchanged.

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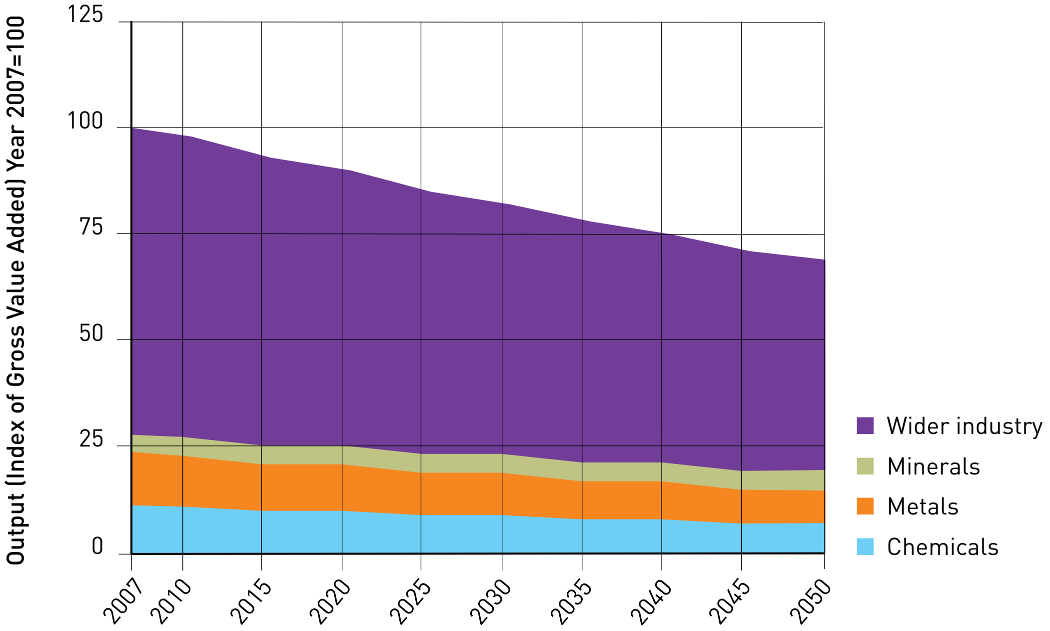
103 The recent historical growth rate is 2.7% per year, but this was felt to be too high by representatives of the Business and Climate Change Energy Group (BCEG), at a workshop on 07 January 2010.

The minerals sector is largely driven by domestic demand for cement, and therefore by the health of the UK construction industry and wider economy. It is assumed that this demand would stay flat, even in a low output scenario (although demand may switch towards imports of both finished cement and clinker, which will make up any shortfall in UK production). Within the chemicals sector, the falls in output assume that declining petrochemical manufacture is not replaced with low carbon alternatives.

A smooth downward trend in output is assumed, though in practice this trend would be a series of marked steps relating to individual shifts in the industrial base.

Figure C9: Low industrial output



Wider industry	Assuming a continuation of the decline seen over the past decade, following the 2000-2008 trajectory (-0.9% per year).
Minerals	Assuming production hovers around the mean output for 1970-2008.
Metals	Assuming significant decline in industry, replicating the decline from 1970-1995 (-1.2% per year).
Chemicals	Assuming that a decline in petrochemical and ammonia industries takes output down to 1990 levels (at -1.1% per year).

Assumptions on energy intensity and process emissions

The assumptions below have been formed following discussions with representatives from industry,[104] academics and through analysis of relevant literature. A wide range of scenarios were proposed, reflecting different technological assumptions, approaches, scope and timescales. The low, medium and high paths aim to reflect the range of opinion and evidence encountered.

Cross-cutting assumptions

CCS

The challenges posed by CCS differ according to the process, size and location of different industries. However, due to the current uncertainties surrounding the technology, deployment rates and impact, a common range of capture rates has been assumed across the process emitting sectors.[105] Within these it is assumed that CCS is fitted on larger steel, ammonia and cement plants. However, there are also opportunities for CCS on Combined Heat and Power plants and, for example, within the food and drink or pulp and paper industries. It is assumed that CCS will capture equal proportions of fuel combustion and process emissions. Table C2 gives the assumption made about CCS for each of the three levels of energy intensity and process emissions.

Table C2: CCS assumptions for the three levels of energy intensity and process emissions

Highest energy intensity and process emissions	No widespread use of CCS (perhaps due to lack of investment, technological failings or cost ineffectiveness).
Medium energy intensity and process emissions	CCS begins to roll out after 2025. By 2050, 24% of emissions in the metals, chemicals and minerals sectors are captured (assuming CCS captures 80% of emissions where installed).
Lowest energy intensity and process emissions	CCS is rolled out quickly after 2025. By 2050, 48% of emissions in the metals, chemicals and minerals sectors are captured (assuming CCS captures 80% of emissions where installed).

Fuel switching assumptions

In 2007, 19% of gas and 64% of solid fuel consumed by industry were used in high temperature processes.[106] The lowest energy intensity and process emissions trajectories (C and D) assume that by 2050 almost all other energy is consumed in the form of electricity, and bioenergy from waste and non-waste sources makes up a high proportion of remaining gas and solid fuels. This shift implies that most space heating is provided by electric heat pumps and that most low temperature heating, separating and drying processes currently fuelled by oil and gas, shift to electricity.

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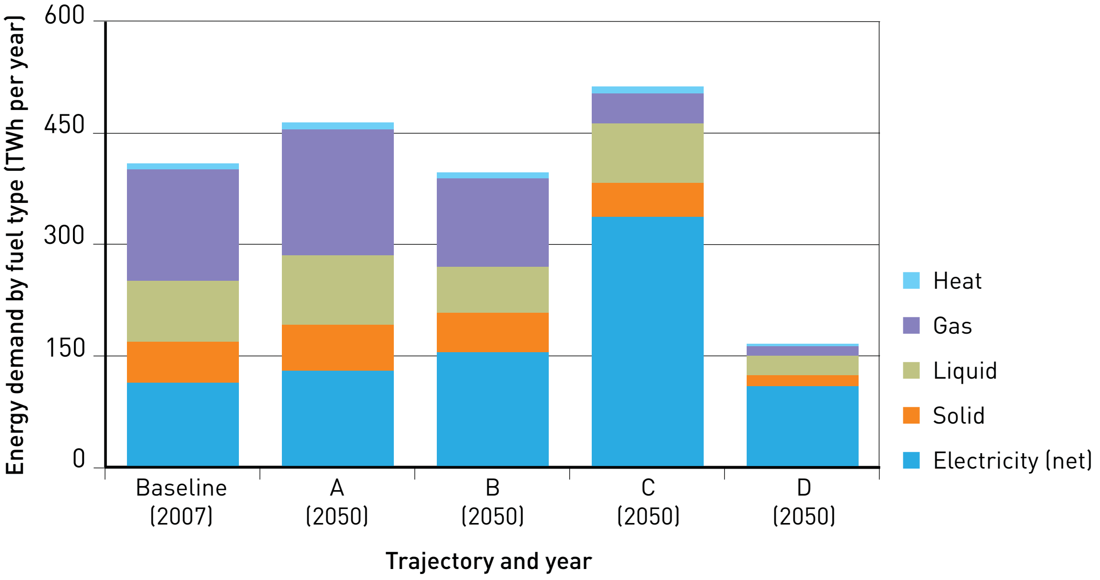
[104] Two workshops and a number of bilateral discussions were held with members of the Business and Climate Change Group (BCEG) and the Manufacturers' Climate Change (MCC) groups in January, 2010.

[105] The Committee on Climate Change (CCC) will produce work looking at industrial CCS later in the year.

[106] DUKES 2007 figures, Table 1.14.

The highest emissions intensity trajectory (A) assumes that there is no change in the balance of fuels to 2050, while the middle trajectory (B) assumes a moderate shift to electricity from 2030. Figure C10 shows the breakdown of energy demand in 2050 under each of the four trajectories.

Figure C10: Fuel breakdown by trajectory



Sector-specific assumptions

Chemicals sector

The majority of the direct emissions from the chemical industry are in the form of CO_2, the largest sources being the production of ethylene and other petrochemicals, ammonia for nitrogen-based fertilizers, and chlorine. These emissions are produced both by energy use and from venting and incineration of by-products.[107]

Opportunities to reduce emissions include broader energy saving measures set out for all sectors – on motors, more efficient use of compressed air and space heating. Sector-specific measures include improved membranes for separations, more selective catalysts for synthesis, increased recycling of plastics and polymers and greater process integration to reduce heating requirements.

The level of process emissions will depend on the extent to which substitute processes and new catalysts are developed and deployed – and the extent to which the sector develops biological substitutes for plastics, ammonia based fertilizers and others.

A move away from producing base and commodity chemicals, towards pharmaceuticals, consumer and speciality chemicals will have the effect of lowering average emissions intensity within the sector.[108] The highest improvements assume that this shift has continued. However, these structural changes imply that emissions would have been exported abroad.

The IEA suggests that, globally, countries should aim to implement Best Potential Technology by 2025. They suggest that this would cut energy demand by around 10%.[109] The highest emissions pathway assumes that these efficiency gains will be more difficult in the UK, as plants are already relatively efficient. Therefore, 10% reductions are achieved only by 2050.

Lowest intensity

Process emissions:
35% lower by 2050

Energy intensity:
50% lower by 2050

Medium intensity

Process emissions:
15% lower by 2050

Energy intensity:
25% lower by 2050

Highest intensity

Process emissions:
No change

Energy intensity:
10% lower by 2050

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[107] IPCC Fourth Assessment Report: Climate Change 2007.

[108] Eurelectric (2007) *The Role of Electricity: A New Path to Secure, Competitive Energy in a Carbon-Constrained World*.

[109] International Energy Agency (2009) *Technologies for a New Industrial Revolution (2009*).

Metals sector

The metals sector includes the steel and aluminium industries.

Aluminium: Primary aluminium metal is produced by the electrolytic reduction of alumina in a highly energy-intensive process. In addition to the CO_2 emissions associated with electricity generation, the process itself is greenhouse gas-intensive.[110]

Energy emissions can be reduced by improving operating procedures and more use of computer-control. Larger reductions in emissions can be achieved by upgrading older cell technology. Inert anodes promise to cut electricity demand by 20% and fuel use by 7% and to eliminate anode-related CO_2 emissions.[111] In the lowest intensity scenario, it is assumed that inert anodes have been successfully commercially deployed in at least one plant.

Steel: There remains some scope to further increase thermal efficiency through enhancing continuous production processes, increased recovery of waste energy and process gases, and efficient design of electric arc furnaces, for example scrap preheating, high-capacity furnaces, and fuel and oxygen injection.[112] Better smelting technologies could bring longer term improvements. Recycling rates are already high, but could be raised marginally, particularly if demand begins to flatten out.[113]

Reducing process emissions will be challenging. Electrolysis has the potential to decarbonise steel production, but the technology is still in development.[114] The lowest intensity scenario assumes that steel electrolysis is in use within some plants by 2050. The metals sector assumes modest reductions in energy intensity in recognition that further improvements will be challenging in this sector.

Lowest intensity

Process emissions: 25% lower by 2050

Energy intensity: 30% lower by 2050

Medium intensity

Process emissions: 10% lower by 2050

Energy intensity: 20% lower by 2050

Highest intensity

Process emissions: No change

Energy intensity: 10% lower by 2050

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[110] IPCC Fourth Assessment Report: Climate Change 2007.

[111] Eurelectric (2007) *The Role of Electricity: A New Path to Secure, Competitive Energy in a Carbon-Constrained World.*

[112] Set out in IPCC Fourth Assessment Report: Climate Change 2007. The IEA (2009) *Technologies for a New Industrial Revolution* suggests that these measures could improve energy intensity by 20% at a global level.

[113] Allwood, J and Cullen, J (2009) *Steel, Aluminium and Carbon: Alternative strategies for meeting the 2050 Carbon Emission Targets*, Cambridge.

[114] Ibid.

Minerals sector

The minerals sector is dominated by the cement industry, although limestone and dolomite also produce significant process emissions. 60% of emissions within the cement industry are process emissions; the other direct emissions are from fuel combustion.

Process emissions within the cement industry come from limestone calcination within the kiln. They can be reduced by substituting carbon intensive clinker, an intermediate in cement manufacture, with other, lower carbon, materials with cementitious properties, such as slag or ash.

The industry has already reduced the clinker content of cement, but further clinker substitution or changes in the process will require lengthy testing to ensure that the cement meets building standards. Substantial process emission reductions are not therefore assumed to be possible until around 2030. The lowest intensity scenario assumes that a substantial proportion of cement production shifts to a low clinker, low energy cement, such as geopolymer or novacem by 2050 (although this may require raw materials to be imported).[115]

Some energy efficiency gains can be achieved by improvements within kilns and roller processes.[116] The IEA suggests that a 27% reduction in demand for thermal fuels within the global industry is possible.[117] The IEA's 'Cement Technology Roadmap' expects an 18% decrease in thermal energy used per tonne of cement by 2050.[118] Assumptions used here reflect a range of improvements in energy intensity (from 10–30% by 2050), reflecting different views.

Lowest intensity

Process emissions: 30% lower by 2050

Energy intensity: 30% lower by 2050

Medium intensity

Process emissions: 5% lower by 2050

Energy intensity: 20% lower by 2050

Highest intensity

Process emissions: No change

Energy intensity: 10% lower by 2050.[119]

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[115] Mineral Products Association input, following workshop with the Manufacturers' Climate Change Group, 21 January 2010.

[116] Eurelectric (2007) *The Role of Electricity: A New Path to Secure, Competitive Energy in a Carbon-Constrained World* assume a 3% decrease in energy intensity every 5 years to 2030.

[117] International Energy Agency (2009) *Technologies for a New Industrial Revolution*.

[118] IEA and World Business Council for Sustainable Development (2009) *Cement Technology Roadmap, Carbon emissions reductions up to 2050*.

[119] Industry representatives stressed that scope for further energy efficiency improvements is very limited.

Wider industry

Within wider industry, energy intensity will be reduced through diverse and incremental improvements that vary across different sectors and plants. This work does not attempt to quantify the opportunities presented by individual energy efficiency measures.

In the short term, improvements within the wider manufacturing industry can continue to be achieved through ensuring that operating and maintenance procedures maximise energy efficiency and by choosing optimal technology for motors, boilers, compressed air vents and other machinery.

Although improvements have been made, space heating, lighting and machinery can still be used more efficiently in many industries. Better use can be made of waste heat, through recycling, locating different parts of the process more closely together, or CHP. In the longer term, technological advances and new plants will be needed to continue improvements.

The IEA states that an annual reduction in energy demand of 1.3% per year is needed within industry in OECD countries, in order to meet global emissions targets.[122] This is taken as the lowest intensity assumption.

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

Lowest intensity

Energy intensity: 43% lower by 2050[120]

Medium intensity

Energy intensity: 24% lower by 2050[121]

Highest intensity

Energy intensity: 10% lower by 2030

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[120] International Energy Agency (2009) *Technologies for a New Industrial Revolution*.

[121] Ibid.

[122] Parsons Brinckerhoff (2009) *Powering the Future: Mapping our low carbon path to 2050* assumes a 0.62% pa improvement in overall energy efficiency across industry (based on the metals sector historical rate of improvement).

Section D: Space heating, hot water and cooling

Context

In 2007, fuel use for space heating and hot water in the domestic and service sectors amounted to 535 TWh. The domestic sector accounted for 78% of this and the service sector 22%.[123] Energy used for cooling in the UK in 2007 is estimated at 9 TWh, almost all of which was used in the service sector.

Figure D1: Energy consumption in 2007

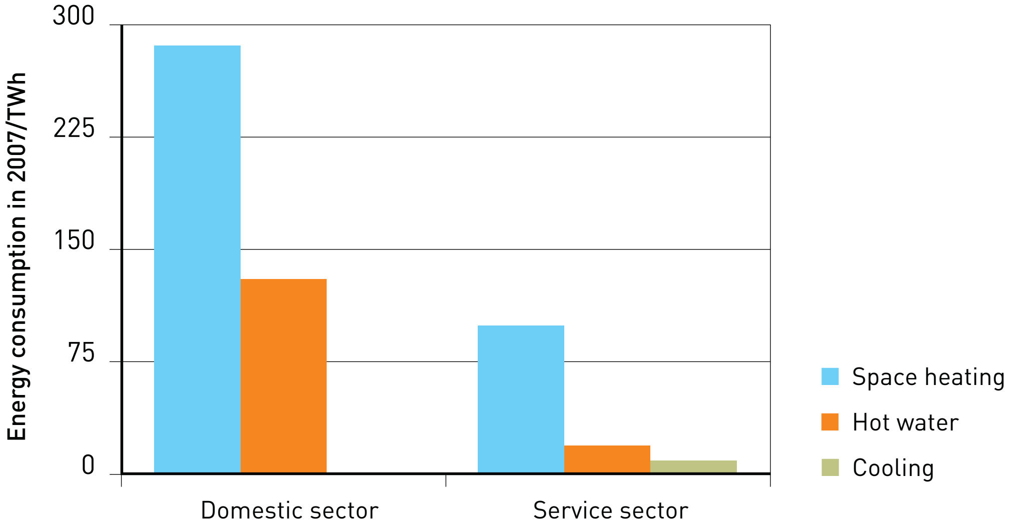
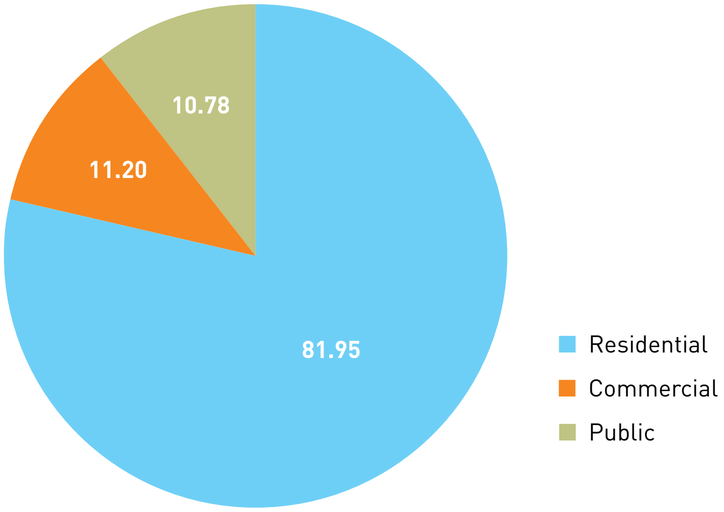


Figure D2: Direct emissions from the residential and service sectors in 2006 $MtCO_2$



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[123] Department of Energy and Climate Change, *Energy Consumption in the UK, July 2009*, Table 1.14.

Over the past 40 years there has been a radical technology shift in the UK heat sector, with gas boilers rising from a low market share in 1970 to become the dominant heating technology. In the domestic sector this has been coupled with an increase in central heating, which has led to significant changes in the way homes are heated; for example, it is now common for all rooms in a household to be heated. Average internal temperatures in households have therefore risen from 12ºC in 1970 to 17.5°C in 2007.[124] Increased heating system efficiency and uptake of insulation has however reduced the fuel demand for space heating and hot water that would otherwise have resulted from these increased comfort levels.

Energy use for cooling has progressively risen since 1970, largely driven by an increase in the number of air conditioned offices and shops.

The Government has an active programme underway to deliver energy savings in homes and non-domestic buildings, recognising the role of heat in terms of meeting emission reduction targets, fuel poverty and security of supply, particularly gas supply.

Sector segmentation used

This section looks at both the overall demand for energy for heating and cooling and the technologies required to service that demand. The heat sector as discussed here comprises space heating, hot water and cooling for domestic and non-domestic buildings. Non-domestic buildings include buildings within the service sector but exclude buildings in the industrial sector.[125] Synergies between industrial heat loads and other types of heat demand may lead to renewable and/or low carbon solutions that overlap between the two sectors.

In the following analysis, the energy demand for domestic and non-domestic sectors is examined separately, and different levels are set out for:

- domestic internal temperature (the comfort level);
- domestic thermal efficiency (level of insulation) based on a demolition rate, efficiency of new households, and the refurbishment rate of existing households;
- domestic hot water demand;
- domestic cooling demand;
- non-domestic space heating demand;
- non-domestic hot water demand; and
- non-domestic cooling demand.

The heating, hot water and cooling demands presented in this report are all ‘service’ demands, representing the amount of heat required (for space heating or hot water), or the amount of heat that must be removed (for cooling). The heating and cooling technologies that could meet these demands are then examined. The fuel input required depends on both service demand and the efficiency of the technology

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[124] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.16. October to March average.

[125] The service sector incorporates commercial and public sector buildings. Heat for the industrial sector – that needed for both industrial process heat and a small amount of space heating – is included within the Industry sector. Heat used for cooking and catering is addressed under Lights and Appliances, along with refrigeration.

Domestic space heating, hot water and cooling

Drivers and enablers

UK demand for domestic heating, hot water and cooling is driven by many factors, including internal temperature, the thermal efficiency of the building stock, the impact of incidental gains, numbers of households, refurbishment rates, demolition rates, and so on.

The average household's internal temperature in winter was 17.5°C in 2007.[126] The effect of average internal temperature is important because the reduction in space heating demand from even small drops in internal temperatures is significant: a 1°C reduction would reduce heating system energy demand by up to 10%. It may be possible to reduce average internal temperatures in households without adversely affecting the comfort of occupants, for example through greater control of the temperature in individual rooms, and avoiding the heating of buildings when they are unoccupied.

The fabric of a building (including its level of insulation) determines how efficient the building is at keeping warmth inside. The rate of heat lost from a household is proportional to the difference in internal and external temperature, and the thermal 'leakiness' of households. The 'leakiness' is quantified by the 'Heat Loss Coefficient' (HLC)[127] which takes account of both fabric losses and ventilation losses. The amount of heat loss can be obtained by multiplying the rate of heat loss by the length of time it persists.

The future average HLC[128] of the UK domestic stock in a given year is influenced by:

- the demolition rate;
- the new build rate;
- the level of refurbishment in the remaining stock; and
- new build fabric thermal efficiency standards.

Within this report, the demolition rate for the existing stock is assumed to be 0.1% per annum for each year to 2050. This equates to the demolition of 25,000 dwellings per annum; about twice the current rate.[129] The current rate is low by historic standards – an historic high of 130,000 dwellings per annum occurred in the 1970s.[130] However, there are implications for embodied energy, social acceptance and financial cost associated with increased demolition rates, which this project does not consider. The assumed demolition rate is based on current trends without any major demolition programmes, but with some scope for an increase in selective demolitions.

The new build rate assumed for dwellings is based on government demographic projections of households, given that the household is a reasonable proxy for the number of dwellings in terms of energy consumption. For 2031, this would mean just

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[126] Department of Energy and Climate Change, *Energy Consumption in the UK 2009*, Table 3.16.

[127] The units for the Heat Loss Coefficient are Watts/ °C.

[128] The calculation of HLC in this report takes into account the different age bands and built forms within the UK stock and is based on the Government's Standard Assessment Procedure (SAP) methodology.

[129] 40% House Project background material B: Foresight scenarios for the UK domestic sector (2005), page16.

[130] 40% House Project background material B: Foresight scenarios for the UK domestic sector (2005), page16.

over 33 million households for the UK, implying an annual growth rate from 2007 of approximately 1% per annum.[131] Projecting this growth rate results in 40.2 million UK households in 2050. Given the demolition rate of 0.1% assumed above, the new build rate assumed averages 1.1% per annum[132] until 2050. The new build mix assumes a higher proportion of flats and a lower proportion of detached houses than in the existing stock because of expected demographic changes.[133]

As well as build rates and demolition rates, the extent of refurbishment is also an important factor in determining the efficiency of the stock. The level of refurbishment of the existing stock is based on different penetration levels of the following six measures:

- solid wall insulation;
- cavity wall insulation;
- floor insulation;
- super-glazing (equivalent to triple glazing);
- loft insulation; and
- draught-proofing.

The impact these measures can have is set out in Tables D1 and D2.

Table D1: Impact of insulation measures for domestic buildings

Measure[135]	Assumed average U-value (W/m^2.°C) before measure	Assumed average U-value (W/m^2.°C) after measure
Solid wall insulation	2.20	0.35
Cavity wall insulation	1.60	0.35
Floor insulation	0.60	0.16
Triple-glazing or equivalent	2.20	1.00
Loft insulation[136]	0.29	0.16

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[131] Department for Communities and Local Government (November 2009) *Household estimates and projections 1961-2031*, Table 401.

[132] Equivalent to an average of 285,000 new build dwellings per annum. The new build rate during the 1990s was approximately 150,000 new dwellings per annum. The highest annual total of 413,700 new build dwellings occurred in 1968 (House of Commons Library (1999) *A Century of Change: Trends in UK Statistics since 1900*, page 12).

[133] Analysis in support of 'Definition of Zero Carbon Homes' Impact Assessment, Department for Communities and Local Government (July 2009).

[134] The insulation and glazing measures reduce heat loss through the element to which they are applied (wall, floor, window, etc). These losses are quantified by the 'U-value', which is the rate of heat loss per unit area of the element, per unit temperature difference across the element.

[135] Measure equivalent to topping up a loft with 145mm of mineral wool insulation to 270mm.

Table D2: Impact of draught-proofing for domestic buildings

Measure	Assumed average air permeability (m^3/m^2. hr@50Pa) before measure	Assumed average air permeability (m^3/m^2. hr@50Pa) after measure
Draught-proofing[137]	15	5

The uptake of insulation measures in the domestic sector can in practice be limited by a number of factors. Consumers are sensitive to upfront costs, even when a measure is cost effective. The type of building ownership can affect take up, with private landlords having little incentive to invest in energy saving measures benefitting their tenants. There is a significant fraction of the population who do not take up measures regardless of how cost effective they are (estimated at 28% of the owner-occupier population).[137] People can be put off by the disruption associated with some measures, for example floor insulation and internal solid wall insulation. In the case of internal solid wall insulation there can also be a significant loss of floor area.

The savings achieved by energy efficiency improvements can also be reduced by 'comfort taking', in which the measures partly support warmer internal temperatures rather than increased energy savings.

There are sources other than heating systems which help to heat buildings, known as incidental gains. These include solar radiation, hot water storage and pipework, cooking, lights and appliances, and people and pets (metabolic gains). Some of the heat provided from these sources is not useful because it contributes to warming when none is required, for example some of the solar gains during the summer. However, the effect of these heat sources is very significant within the UK domestic stock today: in 2006, the useful effect is estimated to have been more than half of the total domestic heating requirement.[138]

Owing to climate change, average external temperatures in the UK are expected to rise by approximately 2-2.5°C by 2050.[139] This will reduce the need for heating in winter, but is likely to increase the need for air conditioning in warmer months.

In terms of domestic hot water demand, there has been a recent trend towards increased use of 'higher-flow' showers, increasing the demand for hot water for showering. This has been offset by increases in the efficiency of white goods that use hot water. With limited scope for further efficiency improvements in white goods, an increase in overall hot water use may soon start to emerge.[140] Potential reductions in demand for hot water will be very dependent on consumer behaviour.

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[136] Draught-proofing reduces heat losses, and its effect is quantified in terms of the air permeability. Air permeability is measured by the volume of internal air lost to the outside environment per square metre of building envelope at a particular pressure condition (cubic metres per square metre per hour at a certain number of pascals).

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

[138] Building Reseach Establishment (2008) *Domestic Energy Factfile*, page 62.

[139] UK Climate Projections 2009 (UKCP09), Department for the Environment, Food and Rural Affairs and the Department of Energy and Climate Change under licence from the Met Office, Newcastle University, the University of East Anglia and the Proudman Oceanographic Laboratory.

[140] The Environment Agency and the Energy Saving Trust (April 2009) *Quantifying the energy and carbon effects of water saving* Full Technical Report.

Energy demand levels for domestic space heating, hot water, and cooling

Four levels of change have been developed for each of the relevant variables, and these are set out below.

Level 1

- **Internal temperature**: Average internal temperature in UK households rises to 20ºC by 2050, based on recent historic trends, stabilising in 2030. This represents a 2.5°C rise on the 2007 winter average.
- **Thermal efficiency**:[141] The average Heat Loss Coefficient for the UK domestic stock falls from 247 watts/°C per household in 2007 to around 190 watts/°C by 2050. There are some improvements to dwelling energy efficiency as modest levels of insulation are installed. The uptake of insulation measures shown in Table D3 has been assumed. New buildings are assumed to comply with current standards.[142]
- **Hot water demand**: 50% increase in hot water consumption per household in 2050 relative to 2007. This reflects the impact of economic growth leading to an increased use of hot water, and a greater number of hot water using appliances.
- **Cooling demand**: For level 1, it is assumed that every household in the UK has air conditioning by 2050, in response to increased wealth.[143]

Table D3: Level 1 take up of insulation measures

Measure	Number of UK households receiving measures	Year installations complete	Fraction of 2007 potential addressed on completion of roll out
Solid wall insulation (internal or external)	400,198	2011	5%
Cavity wall insulation	2,287,500	2050	25%
Floor insulation	3,570,000	2050	30%
Triple glazing equivalent	2,366,000	2022	10%
Loft insulation	1,116,665	2022	5%
Improved air-tightness	62,832	2009	0%

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[141] The penetrations for the insulation measures are in part based on work for the Committee on Climate Change, Element Energy, The uptake of energy efficiency in buildings, a report to the Committee on Climate Change (August 2009).

[142] Building Regulations 2000, Part L (Conservation of Fuel and Power), as amended.

[143] Total UK domestic cooling demand under each level for each year to 2050 has been evaluated taking into account projected growth in dwelling numbers, the change in average dwelling heat loss, projected changes in external temperature and the effect of changes to internal gains from hot water heating, lights and appliances. A cooling set point at an internal temperature of 23.5°C has been assumed.

Level 2

- **Internal temperature**: Average internal temperature in UK households rises to 18ºC by 2050, representing a slight 0.5°C rise on the 2007 winter average by 2050.
- **Thermal efficiency**: The average Heat Loss Coefficient for the UK domestic stock falls from 247 watts/°C in 2007 to around 170 watts/°C by 2050. Greater improvements to dwelling energy efficiency are made, as improved levels of insulation are installed. The uptake of insulation measures shown in Table D4 has been assumed. New build fabric standards are assumed to be equivalent to the Energy Saving Trust's Advanced Practice Energy Efficiency standard, but with the air permeability standard relaxed to $3m^3/m^2.hr.$[144]
- **Hot water demand**: The level of hot water consumption per dwelling in 2050 is the same as in 2007.
- **Cooling demand**: It is assumed that 67% of households install air conditioning by 2050.

Table D4: Level 2 take up of insulation measures

Measure	Number of UK households receiving measures	Year installations complete	Fraction of 2007 potential addressed on completion of roll out
Solid wall insulation (internal or external)	2,000,989	2022	25%
Cavity wall insulation	4,575,000	2022	50%
Floor insulation	5,355,000	2050	45%
Triple glazing equivalent	8,281,000	2050	35%
Loft insulation	6,699,990	2022	30%
Improved air-tightness	6,283,194	2020	25%

Level 3

- **Internal temperature**: Average internal temperature in UK households falls to 17ºC by 2050, representing a slight 0.5°C decrease from the 2007 winter average.
- **Thermal efficiency**: The average Heat Loss Coefficient for the UK domestic stock falls from 247 watts/°C per dwelling in 2007 to around 145 watts/°C by 2050. There are very significant improvements to dwelling energy efficiency within the existing domestic stock. The uptake of insulation measures shown in Table D5 has been assumed. As for level 2, new build fabric standards are assumed to be equivalent to

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[144] The new build standard assumed for levels 2 and 3 is the middle specification (Specification C-) of the five considered in the December 2009 consultation on fabric efficiency standards for zero carbon homes (Department for Communities and Local Government (December 2009) *Sustainable New Homes – The Road to Zero Carbon'. Consultation on the Code for Sustainable Homes and the Energy Efficiency standard for Zero Carbon Homes*, page 68).

the Energy Saving Trust's Advanced Practice Energy Efficiency standard, but with the air permeability standard relaxed to $3m^3/m^2$.hr.

- **Hot water demand**: There is a 25% decrease in hot water consumption per household in 2050 relative to 2007.
- **Cooling demand**: It is assumed that 33% of households install air conditioning by 2050.

Table D5: Level 3 take up of insulation measures

Measure	Number of UK households receiving measures	Year installations complete	Fraction of 2007 potential addressed on completion of roll out
Solid wall insulation (internal or external)	5,602,770	2040	70%
Cavity wall insulation	6,862,500	2016	75%
Floor insulation	7,140,000	2050	60%
Triple glazing equivalent	14,196,000	2050	60%
Loft insulation	17,866,640	2040	80%
Improved air-tightness	12,566,389	2020	50%

Level 4

- **Internal temperature**: Average internal temperature in UK households falls to 16ºC by 2050, representing a significant decrease of 1.5°C on the 2007 winter average. The effect that internal temperature has on comfort and health varies depending on the type of occupant, activity levels and clothing. Children, the elderly and those with reduced mobility or certain health problems are more vulnerable to the cold than the general population. The evidence shows that 16°C is a safe minimum in occupied rooms for vulnerable groups.[145]
- **Thermal efficiency**: The average Heat Loss Coefficient for the UK domestic stock falls from 247 watts/°C per household in 2007 to around 120 watts/°C by 2050. The improvements to dwelling energy efficiency within the existing domestic stock under this level of ambition are close to the maximum physically possible. The uptake of insulation measures shown in Table D6 have been assumed. The maximum 2007 potential realised is 96%, not 100% once the effect of demolition (assumed 0.1% per annum) is taken into account. New build standards are assumed to be equivalent to PassivHaus[146].

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[145] Department for Communities and Local Government (2008) *Review of Health and Safety Risk Drivers*, page 30.

[146] PassivHaus is a domestic thermal efficiency standard developed in Europe. It represents close to the limit of what is physically possible in terms of energy demand reduction for heating, and is based on extremely high standards of insulation and airtightness, Only small amounts of heating system top-up are required in winter. http://www.passivhaus.org.uk/

- **Hot water demand**: There is a 50% decrease in hot water consumption per household in 2050 relative to 2007. This is thought to be the limit that could be achieved with greater consumer awareness of hot water efficiency, and more water efficient fittings.
- **Cooling demand**: It is assumed that no additional domestic air conditioning is used relative to today.

Table D6: Level 4 take up of insulation measures

Measure	Number of UK households receiving measures	Year installations complete	Fraction of 2007 potential addressed on completion of roll out
Solid wall insulation (internal or external)	7,659,250	2040	96%
Cavity wall insulation	8,755,936	2030	96%
Floor insulation	11,387,501	2050	96%
Triple glazing equivalent	22,641,032	2050	96%
Loft insulation	21,439,968	2040	96%
Improved air-tightness	24,050,381	2020	96%

Figure D3: Trajectories for total domestic heat demand under four levels of change

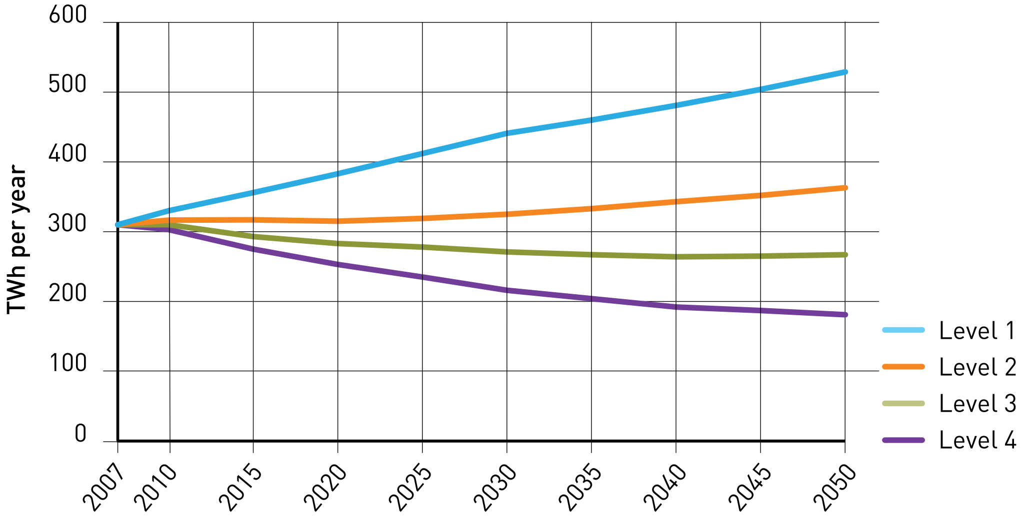
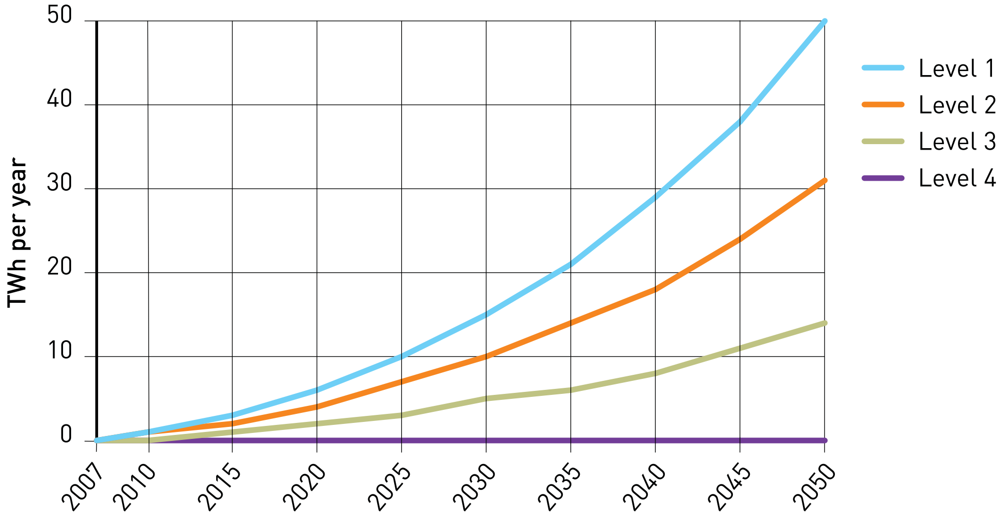


Figure D4: Trajectories for total domestic cooling demand under four levels of change



Non-domestic space heating, hot water and cooling

Drivers and enablers

The non-domestic sector is highly fragmented, containing a wide range of building types with very different energy use patterns. For example, hotels and leisure centres have a relatively high fraction of energy use for hot water compared to other non-domestic building types, while offices and retail buildings have a relatively high need for cooling. The scope for demand reductions is therefore very specific to the type of non-domestic building considered.

General drivers of demand for space heating, hot water and cooling in the non-domestic sector include:

- the number of non-domestic buildings (the 1.8 million non-domestic buildings in 2007 will grow to 2.7 million by 2050 assuming an annual growth rate of 1%);[147]
- the level and rate of energy efficiency improvements to the existing non-domestic stock;
- new build standards for non-domestic buildings;
- the proportion of non-domestic floorspace which is air conditioned;[148] and
- increasing penetrations of information and communication (ICT) equipment.[149]

General constraints on reducing energy demand in the non-domestic sector include:

- complex relationships of ownership, occupation and management, leading to split incentives for energy efficiency measures;

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[147] The Carbon Trust (December 2009) *Building the future today.* The 1% growth rate is assumed to result from a new build rate of 1.5% and a demolition rate of 0.5%.

[148] In 2007, there were 911 million square metres of non-domestic floorspace, of which 27.5% was air conditioned (The Carbon Trust (December 2009) *Building the future toda*y referring to data provided by Harry Bruhns, University College London).

[149] Increases cooling demand due to heat gains

- energy costs forming a relatively small fraction of the total costs of non-domestic building operation; and
- inertia caused by the desire to avoid disruption and ongoing management time.

However, non-domestic refurbishments occur more frequently for domestic buildings, and these can represent a good opportunity to implement measures reducing energy demand.

Energy demand levels for non-domestic space heating, hot water, and cooling

The rationale for the choices of levels was based on considering what the potential demand reductions are for new build non-domestic buildings. The extent to which these can be approached for existing buildings is then limited to site and orientation specific factors once it is recognised that the most radical refurbishments could involve complete replacement of the fabric envelope and building services systems, with only the structural core remaining intact. For these larger scale refurbishments it is recognised that the maximum rate of refurbishment will be lower.

Four levels of change have been developed for each of the demands, and these are set out below.

Level 1

- **Space heating demand**: It is assumed that there is little change in per building space heating demand by 2050. New build standards remain as they were in 2006 and few large refurbishments occur.
- **Hot water demand**: No change is assumed in per building hot water demand in the non-domestic sector.
- **Cooling demand**: It is assumed that refurbishments tend to lead to the installation of air conditioning, and all new build is air conditioned, with the result that by 2050 all non-domestic floorspace in the UK is air-conditioned.

Level 2

- **Space heating demand**: Per building space heating demand in the non-domestic sector drops by 20% by 2050, due to some improvement in average new build demand, some uptake of insulation measures in the existing stock, and behaviour change.
- **Hot water demand**: A 10% reduction in average per building hot water demand is assumed.
- **Cooling demand**: The 2050 penetration of air conditioning reaches 100% for office and retail units and increases by 50% elsewhere, leading to an overall penetration of 40% of non-domestic floor space in 2050. Some energy efficiency improvements reduce cooling demand by 20% for air conditioned buildings. New build is 100% air conditioned but with a 20% demand reduction over the average of the 2007 stock.

Level 3

- **Space heating demand**: There is significant refurbishment of the existing stock (including interventions in the building fabric), leading to a 30% reduction in per building service demand in the 2007 stock.
- **Hot water demand**: A 20% reduction in average per building hot water demand relative to 2007 is assumed.
- **Cooling demand**: The total fraction of non-domestic floor space with air-conditioning remains constant (c28%). All new build is also assumed to be air conditioned, but with a 50% demand reduction over the average of the existing stock.

Level 4

- **Space heating demand**: Refurbishment of the existing stock involves complete replacement of the building fabric and building services, achieving a 40% reduction in per building service demand for space heating. New build achieves 90% reductions in space heating.
- **Hot water demand**: A 30% reduction in average per building demand for hot water is achieved, relative to the 2007 average.
- **Cooling demand**: The fraction of non-domestic floor space with air-conditioning is reduced by 50% due to increase in the use of passive cooling systems. Nearly all new build air conditioning is achieved through passive design measures, achieving a 90% reduction in cooling demand compared with an average air conditioned building within the existing stock in 2007.

Figure D5: Trajectories for total non-domestic heat demand under four levels of change

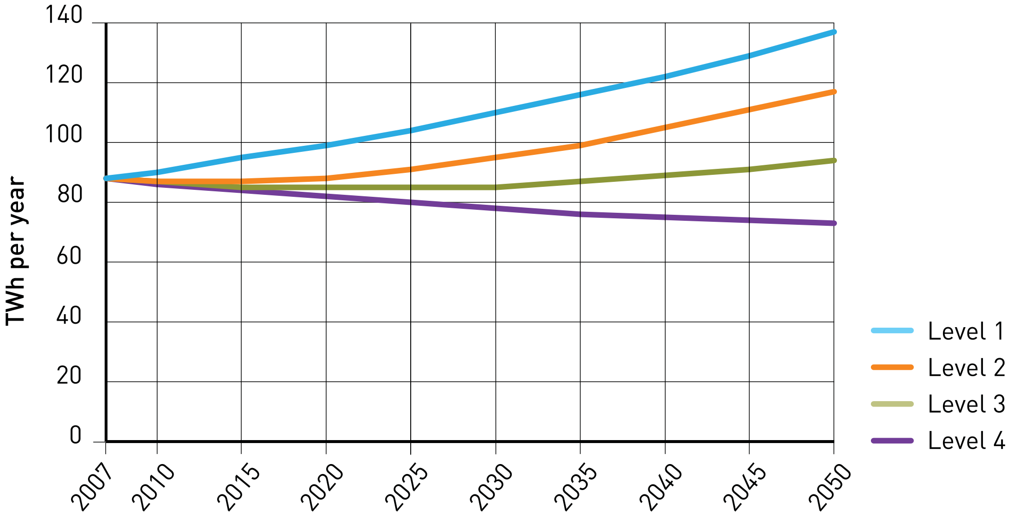
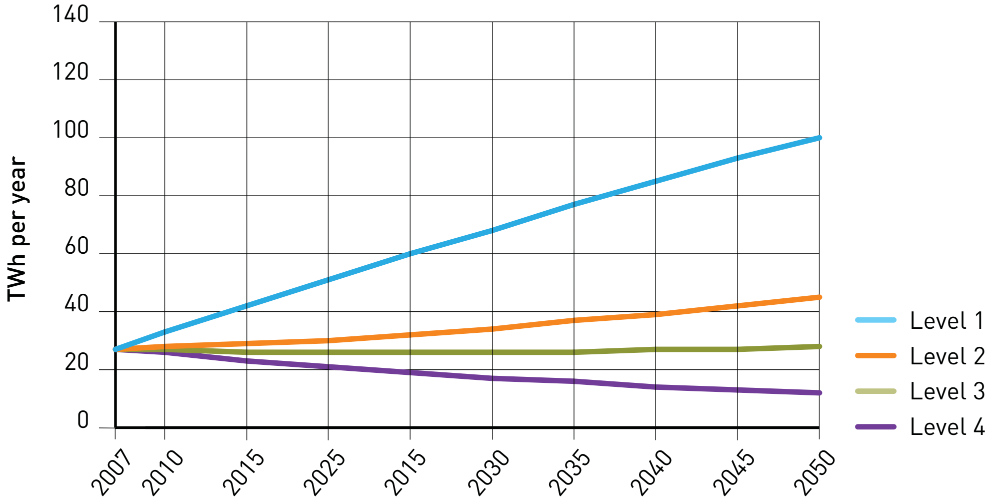


Figure D6: Trajectories for total non-domestic cooling demand under four levels of change



Technology pathways

Specification of technology pathways for domestic and non-domestic heating and cooling

In order to meet the possible heating, hot water and cooling service demands evaluated above, a number of different technology pathways have been evaluated.

Heating technologies are diverse in terms of their suitability for different types of buildings and localities. They also have particular fuel and infrastructure requirements, and the extent to which these requirements can be met in the future is uncertain. The continued role of the gas grid is one strategic question which could alter the technology mix substantially depending on how it is resolved.[150]

The technology pathways examined therefore reflect the wide range of possible heating technology mixes that could result in 2050. They include some that have a heavy dominance of one heating technology, and some that have a more balanced mix, in order that the range of possible outcomes is reflected.

Within the 2050 Pathways Calculator the heating technology pathways are defined by the level of electrification and different mixes of the potential main non-electric fuel types (biomass, biogas and power station heat). The levels of electrification are summarised in Table D7.

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[150] In the long term it is likely that natural gas boilers will be phased out as part of efforts to decarbonise heating, largely removing the need for a natural gas distribution network. However the introduction of biomethane as an alternative heating fuel could allow at least some parts of the gas grid to remain in use.

Table D7: Electrification levels for heating technology pathways

Level	Electrification level	Percentage of UK built environment heat demand met by electric heating technologies
1	Very Low	Max 20%
2	Low	Up to 35%
3	Medium	Up to 90%
4	High	Up to 100%

The non-electric heating fuel scenarios are summarised in Table D8.

Table D8: Non-electric heating fuel scenarios

Scenario	Non-electric fuel type maximised
A	Biogas
B	Biomass
C	Power station heat
D	A mixture of biogas, biomass and power station heat

A number of cooling technologies are also associated with each pathway, and reflect any synergies with the heating technologies in the same pathway. Therefore heat pumps used for heating are also assumed to meet any cooling load, and where power station heat off-take or geothermal district heating is deployed it is assumed that there would also be district cooling via absorption chillers.[151]

A summary of the heating and cooling technology pathways is provided in Table D9. A summary of the heating and cooling technology pathways with respect to electrification level and non-electric fuel scenario is provided in Table D10.

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[151] For instance, the potential of deep geothermal heat-only systems in the UK is not yet well understood and more research in this area is needed.

Table D9: Summary of heating and cooling technology pathways

Pathway	Fuel dependence in 2050[152]	Heating technology split in 2050[153]	Cooling technology split in 2050[154]	Notes
1	100% electric	60% ASHP 30% GSHP 10% resistive heating	100% electric air conditioners	Most demanding pathway in terms of heat pump innovation High electric
2	80% electric 20% biomass	50% ASHP 30% GSHP 20% community scale biomass CHP	100% electric air conditioners	High electric, low biomass
3	85% electric 15% biogas	55% ASHP 30% GSHP 15% community scale biogas CHP[155]	100% electric air conditioners	High electric, low biogas
4	90% electric 3% power station heat off-take district heating	60% ASHP 30% GSHP 7% resistive heating 3% power station heat off-take district heating	97% electric air conditioners 3% absorption chillers	High electric, low district heating from power stations
5	80% biomass 20% electric	70% community scale biomass CHP 10% individual dwelling biomass boilers 20% GSHP	100% electric air conditioners	High biomass, low electric

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[152] % of total UK built environment heat demand met by different fuels.
[153] % of total UK built environment heat demand.
[154] % of total UK built environment cooling demand.
[155] By 2050, community scale fuel cells could also be an alternative to gas CHP.

Pathway	Fuel dependence in 2050	Heating technology split in 2050	Cooling technology split in 2050	Notes
6	68% biomass 24% biogas 7% power station heat off-take district heating 1% geothermal heating	63% community scale biomass CHP 5% individual building scale biomass boilers 24% Stirling engine micro-CHP[156] 7% power station heat off-take district heating 1% geothermal heating	92% electric air conditioners 8% absorption chillers	High biomass, medium district heating from power stations, medium biogas
7	49% biogas 43% biomass 7% power station heat off-take district heating 1% geothermal heating	30% community scale biogas CHP 19% Stirling engine micro-CHP 33% community scale biomass CHP 10% individual building scale biomass boilers 7% power station heat off-take district heating 1% geothermal heating	92% electric air conditioners 8% absorption chillers	Medium biomass, medium biogas, medium district heating from power stations
8	45% biomass 48% electric 7% power station heat off-take district heating	45% community scale biomass CHP 30% GSHP 18% ASHP 7% power station heat off-take district heating	92% electric air conditioners 7% absorption chillers	Medium biomass, medium electric, medium district heating from power stations

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[156] Representing use in larger houses and assuming fuel cell micro-CHP has not become commercially viable.

Pathway	Fuel dependence in 2050	Heating technology split in 2050	Cooling technology split in 2050	Notes
9	80% biogas 20% electric	80% gas boilers 20% resistive heating	100% electric air conditioners	Little innovation in buildings High biogas, low electric
10	63% biogas 30% electric 7% power station heat off-take district heating	33% community scale biogas CHP 20% fuel cell micro-CHP 10% Stirling engine micro-CHP 30% GSHP 20% power station heat off-take district heating	93% electric air conditioners 7% absorption chillers	High biogas, medium electric, medium power station district heating
11	90% biogas 10% electric	90% fuel cell micro-CHP 10% resistive heating	100% electric air conditioners	Fuel cell pathway High biogas, low electric
12	39% biogas 28% biomass 25% electric 7% power station heat off-take district heating 1% geothermal heating	23% community scale biogas CHP 16% fuel cell micro-CHP 23% community scale biomass CHP 5% individual building scale biomass boilers 25% GSHP 7% power station heat off-take district heating 1% geothermal heating	92% electric air conditioners 8% absorption chillers	Medium biogas, medium biomass, medium electric, medium power station district heating

Pathway	Fuel dependence in 2050	Heating technology split in 2050	Cooling technology split in 2050	Notes
13	88% electric 11% power station heat off-take district heating 1% geothermal district heating	30% GSHP 58% ASHP 11% power station heat off-take district heating 1% geothermal district heating	88% electric air conditioners 12% absorption chillers	High district heating, high electric, no biomass
14	40% biomass 34% electric 15% biogas 11% power station heat off-take district heating	25% community scale biomass CHP 15% individual building scale biomass boilers 20% GSHP 14% ASHP 15% community scale biogas CHP 11% power station heat off-take district heating	89% absorption chillers 11% electric air conditioners	High district heating from power stations, medium biomass, medium electric, low biogas
15	45% biomass 43% biogas 11% power station heat off-take district heating 1% geothermal heating	35% community scale biomass CHP 10% individual building scale biomass boilers 24% community scale biogas CHP 19% Stirling engine micro-CHP 11% power station heat off-take district heating 1% geothermal heating	88% electric air conditioners 12% absorption chillers	High district heating from power stations, medium biomass, medium biogas, no electric

Pathway	Fuel dependence in 2050	Heating technology split in 2050	Cooling technology split in 2050	Notes
16	50% electric 30% biomass 13% biogas 7% power station heat off-take district heating	25% GSHP 25% ASHP 20% community scale biomass CHP 10% individual building scale biomass boilers 13% community scale biogas CHP 7% power station heat off-take district heating	93% electric air conditioners 7% absorption chillers	Medium power station district heating, medium electric, medium biomass, low biogas

Table D10: Summary of the heating and cooling technology pathways with respect to electrification level and primary non-electric fuel scenario

Summary of technology pathways				
	(iv) Primary non-electric source			
(iii) Electrification level	1 Gas	2 Solid	3 District	4 Mixed/None
1 Very low	9	6	15	7
2 Low	11	5	14	12
3 Medium	10	8	13	16
4 High	3	2	4	1

Trade-offs, constraints and contingencies for different heating technologies

Electric heating technologies

The following electric heating technologies have been examined:

- resistive heating;
- ground source heat pumps; and
- air source heat pumps.

The 2050 project divides heat pumps into air source heat pumps (ASHPs) and ground source heat pumps (GSHPs). Heat pumps can be used with either wet heating systems (for example, radiators) or dry heating systems (for example, forced air blowers). Heat pump efficiency is usually stated in terms of a Coefficient of Performance ('CoP'), which is the ratio of useful heat output to electrical input.

The second law of thermodynamics limits the maximum CoP that can be achieved by a heat pump. The maximum CoP is dependent on the temperature difference between the cold body and the hot body. For building heating applications, this means that the CoP of the heat pump is reduced if the external temperature (of the ground sub-surface or air) is lower, or if a higher temperature needs to be achieved (for example, to heat hot water).

The variation of heat pump CoP with temperature has a number of implications if heat pumps are to be used for building heating applications.

Building fabric thermal performance

The rate of heat delivery required to maintain an adequately high internal temperature is dependent on the rate of heat loss from the building, which is in turn dependent on its levels of insulation and air-tightness. The first trade-off is therefore between insulation levels and the rate of heat delivery required. Although this is true for all heating systems, for heat pumps the variation in efficiency with delivered temperature makes this trade-off particularly acute.

- Better insulating buildings enables heat pumps with a smaller power rating to be used. This is beneficial, as the size and cost of a heat pump increase as the rated power increases.
- If buildings are well insulated then existing radiator systems could operate at lower temperatures and still meet the demand, which would improve CoPs.
- The noise generated by ASHPs also increases as the rated power increases (for the same size of air to refrigerant heat exchanger). Quiet ASHPs are less likely to be constrained in their deployment, particularly in higher density areas where buildings are in close proximity to each other and there is a greater potential for cumulative noise to become a problem. Future technology improvement may reduce the noise associated with ASHPs.
- Should electric heating achieve a high penetration in UK households, the smaller peaks in space heating demand associated with better insulated dwellings would help reduce the capacity of the electricity infrastructure required to meet peak heat demand, for example upgrades to local sub-stations and networks.

Air-to-air versus air-to-water systems

Once the required rate of heat delivery is fixed, there is a choice of the type of heating system used to deliver the heat.

Air-to-air systems can consist of a centralised warm air fan unit with air ducting for supply to individual rooms. This would involve disruption on installation. Alternatively, refrigerant ducting can be run from the heat pump to small fan assisted heaters in each room. The refrigerant ducting required for this type of system is around 6 millimetres in diameter, greatly reducing the disruption associated with installation. Possible constraints on the uptake of air-to-air systems include fan noise in quiet rooms (such as bedrooms) and different perceptions of thermal comfort compared to radiator systems.

Radiator temperature and size for air-to-water systems

For space heating using wet systems, the rate at which heat is delivered to a room is dependent on both the temperature and surface area of the radiators. Most domestic radiator systems consist of wall mounted hot water radiators designed with a flow temperature of 82°C. A heat pump would be relatively inefficient at this high flow temperature, and so it would be desirable to use a radiator system running at a lower temperature.

The largest form of radiator is an underfloor heating system. This can run at a flow temperature of 35°C, enabling much improved CoPs for heat pump space heating to be achieved. However, underfloor heating systems would be difficult to retrofit into existing buildings due to the disruption and cost involved.

Heat pumps using radiators are much more likely to be installed in a retrofit market if they can supply the existing radiator system. If the original radiators were correctly sized for operation at 82°C, replacement radiators with a larger surface area would be needed to deliver heat at the same rate using lower temperatures. In practice, however, most central heating system radiators are significantly oversized, especially where insulation improvements have been carried out subsequently to the original installation. In many buildings it may therefore be possible to use the existing radiators operating at a lower temperature, with the heat pump operating at a reduced, but still acceptable, CoP.

If larger radiators are required, the radiators themselves can be replaced with double panel and/or finned versions, doubling the effective area, without the need to replace pipework. High temperature heat pump technology also has the potential to advance in future, enabling higher radiator temperatures to be achieved with a smaller sacrifice in CoP.

Variable flow temperature heat pumps are available where the flow temperature is reduced during lower demand periods thus improving the CoP.

Hot water storage

A hot water tank is in practice required if heat pumps are to be used for heating water. Instantaneous water heating requires a large power output. For example, mixer showers typically require 20kW of heat;[157] a hot tap around 10kW.[158] Given the constraints currently associated with high power heat pumps, it would be impractical to supply this instantaneously. A hot water tank enables water to be heated over a longer period of time at a lower power rating. Hot water storage with electric water heating could also provide possibilities for demand side management as part of a smart electricity grid. However, the space requirement for hot water storage is likely to be a constraint in flats and other dwellings with combi boilers which do not already have a hot water cylinder.

Single-phase supply

Domestic electricity supply in the UK is generally single phase, unlike in Europe and America where it is usually three-phase. A heat pump compressor contains an induction motor. There are several advantages to running induction motors (such as those used to run heat pump compressors) on three-phase supply rather than one-phase supply:

- greater efficiency;
- less vibration;
- longer motor lifetime; and
- smaller starting currents (decreasing the disturbance to the local electricity supply).

Heat pumps using a single phase supply will therefore be somewhat less cost-effective than those using three phase supply. Variable speed drives can limit the problem of high starting current but currently increase the cost of the heat pump by around 30%.[159]

It is also generally the case that motors above 7.5kW in size can only operate on three-phase supply. This provides an upper limit of about 23kW on the thermal output from a domestic heat pump.[160] However, the number of domestic properties with heat demands this large is thought to be small.

Commercial and public buildings in the UK generally have three-phase supplies, enabling optimal heat pump operation at lower cost.

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[157] Based on $\Delta T = 30$°C and an average mixer shower flow rate of 9 litres per minute (Market Transformation Programme, 2008). BNWAT28: Water consumption in new and existing homes version 1.0. Referring to WRc CP337). Electric showers are typically rated at about 10kW and have a correspondingly reduced flow rate.

[158] Based on $\Delta T = 50$°C and an average tap flow rate of 3.5 litres per minute (Market Transformation Programme, 2008). BNDW Taps. Briefing note relating to projections of internal tap water consumption).

[159] Mitsubishi Electric. Classic heat pumps – Classic M Series – MSH-GA-VB Heat pump R410A. Available from: http://www.mitsubishi-aircon.co.uk/default. asp?url¼http%3A//www.mitsubishi aircon.co.uk/ mitsubishi electric.asp%3Fid%3D152762.

[160] Assuming that a CoP of 3 can be achieved at times of peak demand.

Biogas technologies

When upgraded to biomethane, biogas has the potential for injection into the gas grid, allowing the continued use of at least parts of the gas grid. The gas-fired heating technologies used today could also continue in use, with little or no adapation required from consumers. This lack of demand-side barriers means that there is the potential for rapid uptake once the supply chain is established. This could help reduce cumulative carbon dioxide emissions.

Possible constraints on the use of biogas for heating include:

- uncertain volumes of biomass and organic waste in the future;
- a high demand pull from other sectors of the economy, particularly transport where use of biogas as a fuel is possible; and
- injection into the high pressure transmission network may be problematic due to the higher concentration of oxygen compared to natural gas.[161]

Biomass technologies

Biomass is already used for heating in the UK in individual buildings and in a few community heating systems. Possible constraints to increased uptake for heating include:

- general demand from other sectors of the economy using biomass, for example for biofuels production;
- relatively high emissions of nitrous oxides and particulates from biomass combustion, which make it unsuitable for large scale deployment in areas with air quality constraints;[162]
- the space requirements for fuel delivery and storage (particularly in urban areas); and
- the carbon intensity of biomass transport. This may become increasingly significant in a carbon constrained world if the transport sector proves hard to decarbonise, though bulk transport by ship has a low carbon impact.

District heating from power stations

This report assumes electrical generation efficiencies from nuclear power stations will typically be around 35%, with coal CCS and gas CCS power stations achieving higher efficiencies (up to 50%). Therefore, depending on the electricity generation mix, more than half of the primary energy input into UK power stations in 2050 could be converted into heat rather than electrcity. This section examines at a high level the constraints and trade-offs associated with taking heat from power stations, improving UK primary energy efficiency.

For a power station to provide hot water for a district heating network, steam must be extracted from an electricity generating turbine. The temperature of the steam required is relatively low, so the extraction point is at a late (lower temperature) stage of the

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[161] NERA Economic Consulting, Entec and Element Energy (July 2009) *Renewable Heat Technologies for Carbon Abatement: Characteristics and Potential. A final report to the Committee on Climate Change*.

[162] The use of larger scale biomass plant enables abatement measures to be more cost-effectively fitted, making community scale schemes preferable to individual dwelling installations in urban areas.

steam's path through the turbine. This minimises the impact on the electricity output of the turbine, which drops slightly. The ratio of heat extracted to electricity sacrificed (known as the z-factor) is typically around 7 for district heating purposes. For higher temperature applications, the z-factor is lower as steam must be extracted at an earlier, higher temperature, point in the turbine, reducing the work that the steam does in the turbine.

The use of heat from large power stations to provide heating and hot water via a district heating network is likely to remain the most efficient use of primary fuel, even allowing for significant improvements in heat pump performance in the UK climate.

Constraints and contingencies for district heating from power stations

From the perspective of primary energy efficiency it would be desirable to maximise the use of power stations for district heating. However, there are several constraints on the use of power stations as heat sources for district heating networks. Given all these uncertainties, there is a need for strategic planning if district heating from power stations is to play a more significant role in the UK heating mix by 2050.

The need for a large heat network

District heating from power stations requires a large district heating network in order to deliver all the useful heat produced. This would have significant upfront capital costs and an uncertain heat load projection if installed in one pass. The capital cost and the uncertainty of future heat load would be reduced if there were already pre-existing smaller scale heat networks in the area, as these could then be connected to the larger network. The likely economic viability of power station heat off-take district heating in the future is therefore to some extent dependent on the number of smaller scale networks deployed in the near term.

Possible heat sources for smaller scale networks include gas-fired CHP in the near term (to 2030),[163] and biomass CHP or biogas CHP in the longer term. Heat from waste incineration or pyrolysis CHP is also a possibility. However, the continued emission reduction benefit from gas CHP is time limited due to the projected decarbonisation of the electricity grid, and the supply of biomass and biogas for heating may be constrained by demand from other sectors of the economy. It is also possible that waste volumes will fall significantly as a result of waste reduction policies.

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163 Electricity produced from a CHP unit displaces that from generating capacity switched on and off in responses to demand (ie, the marginal generating plant). The marginal electricity generating plant in the UK is projected to be unabated gas CCGT until 2030 (Interdepartmental Analysis Group, January 2010).

The need for a back-up heat source

In common with other energy systems, heat sources for heat networks generally require a back-up heat source in the event that the primary source becomes unavailable. For example, gas CHP engines typically have a gas boiler back-up system. For economic reasons, it is also common for the back-up system to provide top-up heat to the network in order to meet the peak winter demand.

The fraction of heat delivered by the back-up system can be reduced to a minimum by achieving a heat demand profile with little seasonal variation (for example, that resulting from a mix of commercial and residential buildings), and the use of thermal storage to store the heat until needed. Increasing insulation levels, particularly within domestic buildings, will also help reduce the size of seasonal peaks in heat demand.

On connecting a heat network to a large power station, the need to build new back-up plant is mitigated by the fact that, in practice, smaller networks using smaller heat sources are likely to have built up in the area previously. On connection of the joined up network to the power station, the pre-existing infrastructure would provide the space and network connections for back-up heat sources embedded within the network.

It is also possible for one set of generating turbines to provide back-up for another. This is particularly true for gas CCGT power stations, which commonly have several smaller generating sets compared with coal generation and nuclear. However, this does not provide security of supply in the event that the heat main from the power station fails, unlike the embedded back-up described above.

The need for proximity of heat demand and heat supply

In order to maximise the economic potential for district heating from power stations, they would need to be sited near to large areas of high heat density, ie, large towns and cities. Gas fired CCGTs with CCS are likely have the greatest flexibility in siting, followed by coal CCS, and then nuclear.

Carbon Capture and Storage (CCS) may prove not to be viable at commercial scale, drastically reducing the number of thermal power stations (coal or gas) that may be available for heat off-take to 2050. If CCS does prove viable, the cost of carbon dioxide pipelines will be an extra factor in the siting of thermal power stations, and may tend to result in CCS power stations being located on the Eastern side of the United Kingdom, for access to storage sites under the North Sea.[164]

It seems likely that any further nuclear generating capacity will be located close to existing sites (and possibly new sites in remote locations). In this eventuality, only a limited number of sites would be able to provide district heating with a heat main of less than 50km in length. Public perceptions of district heating from nuclear power stations may also be negative.

It is therefore sensible to consider how heat demand and the availability of power stations could correlate in 2050. Long term strategic planning in relation to power station siting and the most suitable communities for heat networks is required if the optimal use of UK primary energy is to be achieved in 2050.

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[164] Imperial Centre for Energy Policy and Technology, Imperial College and the Centre for Environmental Strategy, University of Surrey (2010) *Building a roadmap for heat: 2050 scenarios and heat delivery in the UK*, page 31.

Heating technology packages

The heating technology pathways are based on 18 heating technology packages. These are as defined in Table D11. The technology packages have been chosen in order to best reflect the range of conversion processes, fuel types, scales, and efficiencies that might become available in the UK between now and 2050. Each package has an efficiency or CoP defined for each of space heating and hot water, reflecting the difference between the two for some technologies (for example, heat pumps).

As an approximation it is assumed that the penetration of technology packages as a fraction of total UK built environment demand is the same as the fraction of UK households with installations. The reduced heat loss of higher density dwellings in urban areas (which would tend to lead to an overestimate of the fraction of heat supplied on an installations basis) is to some extent counteracted by the additional heat required for non-domestic buildings in these areas. A similar assumption is made for cooling technologies. This is a poor assumption in the case of GSHPs if residential cooling demand remains low relative to non-domestic demand, but is reasonable for all other cases.

There are a number of hard constraints on this process. Firstly, there is a global limit on the number of installations possible in a year. This has been set at 1.3 million installations per annum[165] across all technologies. This possible maximum rate is assumed to rise in line with the number of buildings so that it reaches 2 million installations per annum in 2050. For each package there are also:

- a maximum penetration (as a fraction of the number of UK houses); and
- start year (a year sufficiently far into the future that the supply chain has been able to build up to install technologies at the maximum install rate).

The same approach is taken for cooling technologies, and the maximum installation rate for these is also assumed to be 1.3 million per annum.

It should be noted that the penetrations, installation rates and start years assumed here are based on a high level analysis which looks to a 2050 end point. They are not based on any analysis of what might be economic, and assume that any regulatory, uptake and technology barriers can be quickly overcome. The policy framework that currently exists for the deployment of renewable energy technologies to 2020 is based on a more detailed analysis of these extra complexities.

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[165] In 2009 there were approximately 100,000 installers registered on the Gas Safe Register, with a further 30,000 registered under associated Competent Person Schemes. Assuming a 250 day working year, this implies a potential national resource of 33.5 million person-days of installations per annum. The largest number of central heating installations in the UK (1.308 million) occurred in for 2002-2003, (Department of Energy and Climate Change, *Energy Consumption in the UK, July 2009*, Table 3.14). It is therefore assumed that 1.3 million installations per annum across all heating technologies is a reasonable upper limit subject to supply side, demand side and other barriers being overcome.

Table D11: Packages of heating technologies

Package	Space heating efficiency/CoP	Hot water efficiency/ CoP	Maximum penetration[166]	Maximum penetration[167]	Start year for maximum installation rate[168]
Gas boilers (old)	0.76[169]	0.76	90%[170]	36	Now
Gas boilers (new)	0.91[171]	0.91	90%	36	Now
Stirling engine µCHP	0.63 (gas to heat) 0.225 (gas to electricity)[172]	0.63 (gas to heat) 0.225 (gas to electricity)	90%	36	2015
Fuel cell µCHP	0.45 (gas to heat) 0.45 (gas to electricity)[173]	0.45 (gas to heat) 0.45 (gas to electricity)	90%	36	2020[174]
Electric heating	1	1	100%	40	Now

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[166] % UK built environment heat demand.

[167] Number of installations in 2050 millions. Total number of buildings in 2050 assumed to be 40.2 million households + c.2.7 million non-domestic buildings. Dwelling numbers in 2050 based on government projections to 2031 (Department for Communities and Local Government (November 2009) Household estimates and projections, United Kingdom, 1961-2031, Table 401. with a 1% growth rate for all household types assumed thereafter; non-domestic building number based on 1.8 million at present (The Carbon Trust (December 2009) *Building the Future Today*), with a 1% annual growth rate to 2050.

[168] Now: established technologies which are freely available on the global market and do not require significant extra skill in the workforce; 2015: technologies near market or on the market in small numbers, also allowing some time to build supply chains and experience in the workforce; 2020: technologies requiring significant lead time.

[169] Faber Maunsell AECOM and Poyry Energy Consulting (April 2009) *The Potential and Costs of District Heating Networks, A report to the Department of Energy and Climate Change*, page 104.

[170] The current penetration of gas-grid connections within the domestic stock is 81%, based on 5 million UK homes currently off the gas grid (Faber Maunsell AECOM and Poyry Energy Consulting (April 2009) *The Potential and Costs of District Heating Networks, A report to the Department of Energy and Climate Change*, page 19) and 25.8 million UK households in 2006 (Department for Communities and Local Government (November 2009) *Household estimates and projections, United Kingdom, 1961-2031*, Table 401.) It is assumed that the proportion of non-domestic buildings with gas grid connections is the same. Assuming an increase in the proportion of households connected to the gas grid in Northern Ireland, and adding those currently fuelled by LPG [ref], increases the proportion to 90%.

[171] Under the SEDBUK scheme, an A-rated boiler must have an efficiency greater than 90% (HHV) http://www.sedbuk.com/.

[172] Tokyo Gas Limited, Gas Industry micro-CHP Workshop 2008. "The Japanese experience in micro-CHP for residential use" (2008), page 7.

[173] Tokyo Gas Limited, Gas Industry micro-CHP Workshop 2008. "The Japanese experience in micro-CHP for residential use" (2008), page 6; US Department of Energy (2004) *Fuel Cell Handbook, 7th Edition*, pages 7-44.

[174] 100 UK installations per year assumed at present; it is assumed that the supply chains for emerging technologies can scale up by an order of magnitude every 3 years.

Package	Space heating efficiency/CoP	Hot water efficiency/ CoP	Maximum penetration[166]	Maximum penetration[167]	Start year for maximum installation rate[168]
Air Source Heat Pump (ASHP)	3[175]	2	100%[176]	40	2015
Ground Source Heat Pump (GSHP)	4[177]	3	29% (all detached houses in all areas, plus semi-detached and terraced houses in rural and lower density sub-urban areas)	11.6	2015
Oil boilers	0.97[178]	0.97	74% (all detached, semi-detached and terraced houses)	29.6	Now
Individual biomass pellet boilers	0.87[179]	0.87	74% (all detached, semi-detached and terraced houses)	29.6	Now

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[175] Staffell, I (April 2009) *A review of domestic heat pump coefficient of performance*, page 7.

[176] Noise from multiple ASHPs is considered likely to be problematic in high density areas, so this is contingent on future technology improvements.

[177] Staffell, I (April 2009) *A review of domestic heat pump coefficient of performance*, page 7.

[178] Seasonal efficiency of boilers database UK. www.sedbuk.com

[179] Faber Maunsell AECOM and Poyry Energy Consulting (April 2009) *The Potential and Costs of District Heating Networks, A report to the Department of Energy and Climate Change*, page 107.

Package	Space heating efficiency/CoP	Hot water efficiency/ CoP	Maximum penetration[166]	Maximum penetration[167]	Start year for maximum installation rate[168]
Biomass boiler community heating	0.87*0.9[180] = 0.78	0.87*0.9 = 0.78	68% (all households in city centres and other urban centres plus semi-detached houses, terraced houses, and flats in higher density suburban areas)	27.2	Now
Gas CHP community heating. Gas within scope includes natural gas and biogas from anaerobic digestion or other processes	0.42[181]*0.9= 0.38 (gas to delivered heat) 0.38 (gas to electrical energy)	0.42*0.9= 0.38	68% (all households in city centres and other urban centres plus semi-detached houses, terraced houses, and flats in higher density suburban areas)	27.2	Now

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[180] The factor of 0.9 is introduced to reflect 10% heat losses in the heat network for community and district schemes.

[181] Faber Maunsell AECOM and Poyry Energy Consulting (April 2009) *The Potential and Costs of District Heating Networks, A report to the Department of Energy and Climate Change*, page 94.

Package	Space heating efficiency/CoP	Hot water efficiency/ CoP	Maximum penetration[166]	Maximum penetration[167]	Start year for maximum installation rate[168]
Biomass CHP community heating	0.63[182]*0.9= 0.57 (gas to delivered heat) 0.17 (gas to electrical energy)	0.63*0.9= 0.57	68% (all households in city centres and other urban centres plus semi-detached houses, terraced houses, and flats in higher density suburban areas)	27.2	2015
Geothermal community heating			1% (estimate of total UK households near sources of geothermal heat)	0.5	2020
Large power station heat-off take district heating. Types of power station within scope include energy from waste, coal CCS and gas CCS plants.	Electricity lost from thermal electricity generation plants in a ratio of 1 unit of electricity for every 7 units of heat supplied (z-factor = 7).	Electricity lost from thermal electricity generation plants in a ratio of 1 unit of electricity for every 7 units of heat supplied (z-factor = 7).	11% after optimising Pathway X power station locations.	14.0	Now

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[182] Faber Maunsell AECOM and Poyry Energy Consulting (April 2009) *The Potential and Costs of District Heating Networks, A report to the Department of Energy and Climate Change*, page 99.

Table D12: Packages of cooling technologies

Package	Seasonal Energy Efficiency Rating (SEER)[183] for cooling	Conversion	Maximum penetration (% UK cooling demand)	Start year for maximum installation rate
Electric air conditioner (old)	2.5[184]	Electricity to Cool_{th}	100%	Now
Electric air conditioner (new)	6[185]	Electricity to Cool_{th}	100%	Now
Absorption chiller	0.7	Heat to Cool_{th}	68%	Now

Solar thermal

Solar thermal has been modelled separately from other heating technology packages. This is because, unlike the other packages modelled, in the UK solar thermal is incapable of supplying the whole annual heat demand of a building (although the development of inter-seasonal heat stores might make this possible for some buildings). As an approximation it is assumed that solar thermal installations would only occur in non-flat domestic buildings to help meet hot water demand. Table D13 summarises the different levels of ambition modelled for solar thermal. The conversion efficiency (solar energy to heat) is assumed to be 50%.

Table D13: Trajectories for solar thermal under four levels of change

Domestic solar thermal installed area m^2 (average, per household)										
Trajectory	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
1	–	–	–	–	–	–	–	–	–	–
2	–	0.1	0.2	0.3	0.4	0.5	0.70	0.8	0.9	1.0
3	–	0.2	0.6	0.9	1.3	1.6	2.0	2.3	2.7	3.0
4	–	0.4	1.1	1.8	2.5	3.2	3.9	4.6	5.3	6.0

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[183] This is the ratio of annual cooling demand to the annual electrical energy required to meet it. It represents the average efficiency of an air conditioner.

[184] Within the existing stock, the average air conditioner is estimated to having a cooling CoP of approximately 2.5 (Tuohy (2009) 'Robust Low Carbon Buildings' *Building Research and Information* Volume 37, Issue 4, pages 433-445, page 436; Building Research Establishment (2000) *Local Cooling, Global Warming? UK Carbon Emissions from Air-Conditioning in the Next Two Decades*, page 4).

[185] Tuohy (2009) 'Robust Low Carbon Buildings' *Building Research and Information* Volume 37, Issue 4, pages 433-445, page 436.