Chapter 3: The cost-effective path to 2050

1. Current emissions and projections to 2020
2. Meeting the 2050 target – what this means for the fifth carbon budget
3. Scenarios for the fifth carbon budget
4. Further progress required from 2033 to 2050

The Climate Change Act requires that carbon budgets are set on track to meeting the 2050 target to reduce emissions by at least 80% relative to 1990, taking into account the range of considerations discussed in Chapter 1.

In this chapter we set out our analysis of the cost-effective path to the 2050 target.

Significant ongoing reductions in emissions will be required to 2030 if the UK is to credibly remain on track to the 2050 target. Based on the latest evidence we estimate that the cost-effective path involves around a 61% reduction in emissions by 2030 relative to 1990. That compares to a 36% reduction from 1990 to 2014.

Emissions across the economy would need to fall by around 13 $MtCO_2e$ (3%) per year on average from 2014 to 2030. Emissions in the 'non-traded' sectors (i.e. outside the EU Emissions Trading System - transport, heat in buildings, agriculture) would need to fall around 6 $MtCO_2e$ (2%) each year.

We base our assessment on an analysis of the potential future path of UK emissions and the opportunities to reduce those emissions along with the associated uncertainties. We identify alternative ways of delivering our central scenario for emissions reduction and identify opportunities to go further in some areas to compensate for potential under-delivery in others. This evidence is set out on a sector-by-sector basis in the accompanying Technical Report, *Sectoral scenarios for the fifth carbon budget*[1].

Given the time required to develop and implement new policies, we consider the emissions path to 2020 to be largely locked in. However, policies have not yet been put in place for the 2020s, and investments are yet to be made[2]. The challenge now is therefore to determine the cost-effective path from 2020 to meeting the 2050 target.

We begin our analysis by assessing the likely entry point to the 2020s. We then consider potential scenarios beyond 2020, through the fifth budget period (2028-32) and out to 2050, and we consider the impact of these scenarios for the various criteria set out in the Climate Change Act.

This approach is set out schematically in Figure 3.1. For ease of presentation wider economic and social considerations are described in the next chapter, and our conclusions for budget-setting in Chapter 6. The scenarios are presented in this chapter under the following sections:

1. Current emissions and projections to 2020
2. Meeting the 2050 target – what this means for the fifth carbon budget
3. Scenarios for the fifth carbon budget
4. Further progress required from 2033 to 2050

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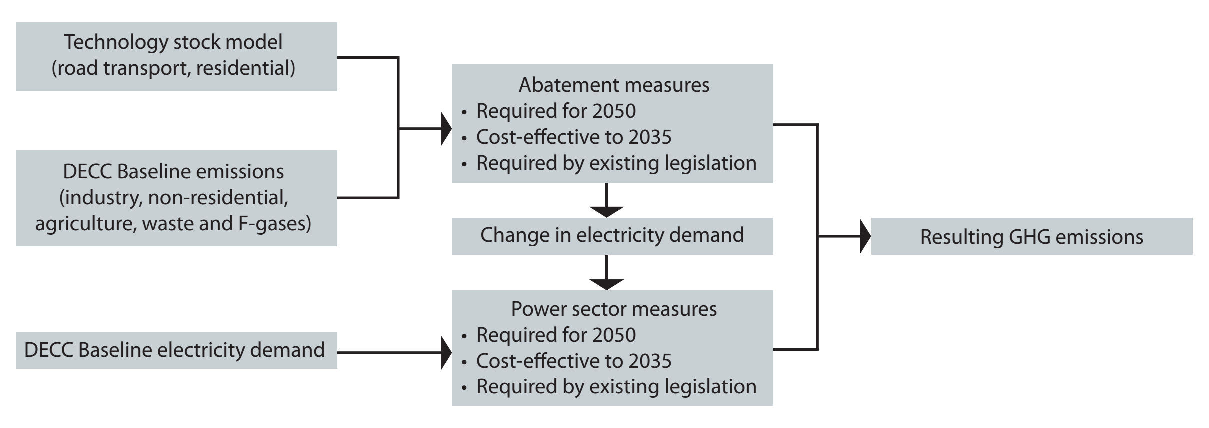
[1] Available on our website, www.theccc.org.uk

[2] Whilst the fourth carbon budget (2023-27) has been legislated, policies to meet it are not in place.

Figure 3.1: Approach to constructing CCC scenarios



Source: CCC analysis.

1. Current emissions and projections to 2020

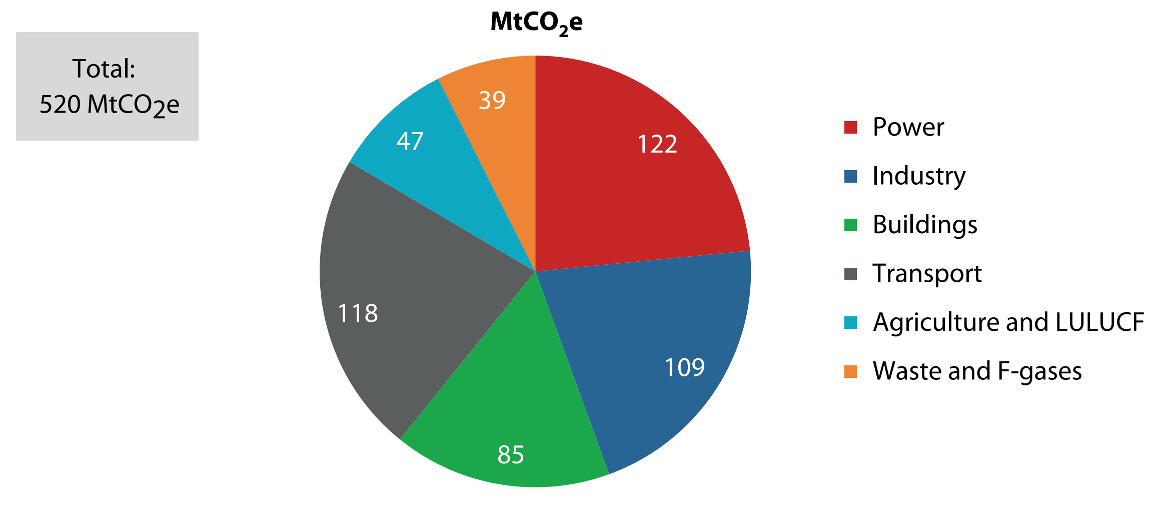
Current emissions and changes since 1990

UK emissions of greenhouse gases (GHGs) covered by carbon budgets were 520 $MtCO_2e$ in 2014. This excludes emissions from international aviation and shipping, for which 2014 estimates are not yet available but were 41 $MtCO_2e$ in 2013.

The UK's net carbon account adjusts these emissions for any implied trading of carbon credits (see Chapter 1). The rest of this chapter refers to actual ('gross') emissions, rather than the net carbon account.

UK emissions are split between six sectors (Figure 3.2): power/electricity generation (23%), industry (21%), buildings (16%), transport (23%), agriculture and land-use, land-use change and forestry (LULUCF) (9%), and waste and fluorinated gases (F-gases) (7%).

Figure 3.2: Current UK emissions of greenhouse gases (2014)



Source: DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis.
Notes: Values include non-CO_2 GHGs allocated to sectors according to their 2013 share (Data are not available for non-CO_2 emissions by sector in 2014).

UK greenhouse gas emissions in 2014 were 36% below 1990 levels and 25% below 2005 (Figure 3.3). In part this is due to the economic downturn, in particular a 9% reduction in GHG emissions in 2009. However, the reductions since 1990 also reflect some longer-term trends and more recent impacts of policies aimed at reducing emissions:

- Power sector GHG emissions decreased 28% between 1990 and 2013. This is due to a move away from coal and oil towards gas in generation, and an increase in electricity generated from waste and renewable energy sources. Data are not yet available for total GHG emissions by sector in 2014; however, power sector CO_2 emissions decreased a further 18% in 2014[3], and 41% overall between 1990 and 2014.
- Industry sector direct GHG emissions (i.e. excluding electricity use) decreased 33% between 1990 and 2013. This partially reflects a structural shift away from energy-intensive industries (including iron and steel, for which output decreased by over 30% over the same period). Industry sector CO_2 emissions decreased a further 6% in 2014, and 37% between 1990 and 2014.
- Transport sector GHG emissions rose by 9% between 1990 and 2007, but have subsequently declined such that over the period 1990-2013 they are down 4%. The overall (and recent) decreases are due to improvements in average fuel efficiency of vehicles, the switch from petrol to diesel cars, a reduction in traffic volumes and some substitution of biofuels for fossil fuels since 2002. Transport sector CO_2 emissions increased 1% in 2014, potentially linked to rising incomes.
- Buildings sector direct GHG emissions (i.e. excluding electricity use) fell by 5% between 1990 and 2013, with improved efficiency of boilers and buildings more than offsetting the effect of increased internal temperatures. Buildings sector CO_2 emissions decreased a further 15% in 2014, due largely to higher 2014 temperatures[4], such that overall, CO_2 emissions decreased 19% between 1990 and 2014.
- GHG emissions from land use, land-use change and forestry (LULUCF) and agriculture decreased 31% between 1990 and 2013. This mainly reflects an 18% reduction in methane emissions, due primarily to decreased cattle numbers, and a 17% reduction in nitrous oxide emissions, due primarily to a decline in animal numbers and a decrease in synthetic fertiliser application. GHG data are not yet available for 2014.
- Waste GHG emissions decreased 67% between 1990 and 2014, due to a reduction in biodegradable waste sent to landfill, and the implementation of methane recovery systems. F-gas emissions remain close to 1990 levels.

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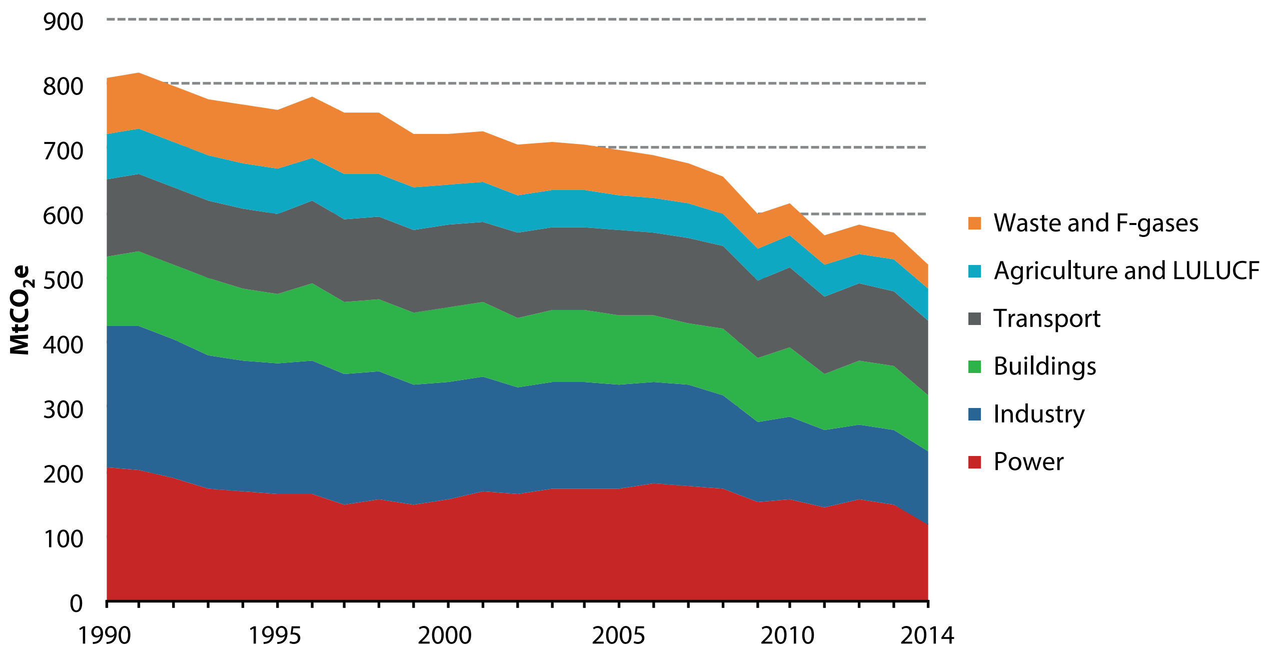
[3] Note: all 2014 GHG data are provisional.

[4] Figures are outturn (i.e. not temperature-adjusted). Had temperatures followed their long-term trend, the reduction in emissions from buildings would have been much smaller.

Figure 3.3: Historical UK emissions of greenhouse gases (1990-2014)



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013;* DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis.

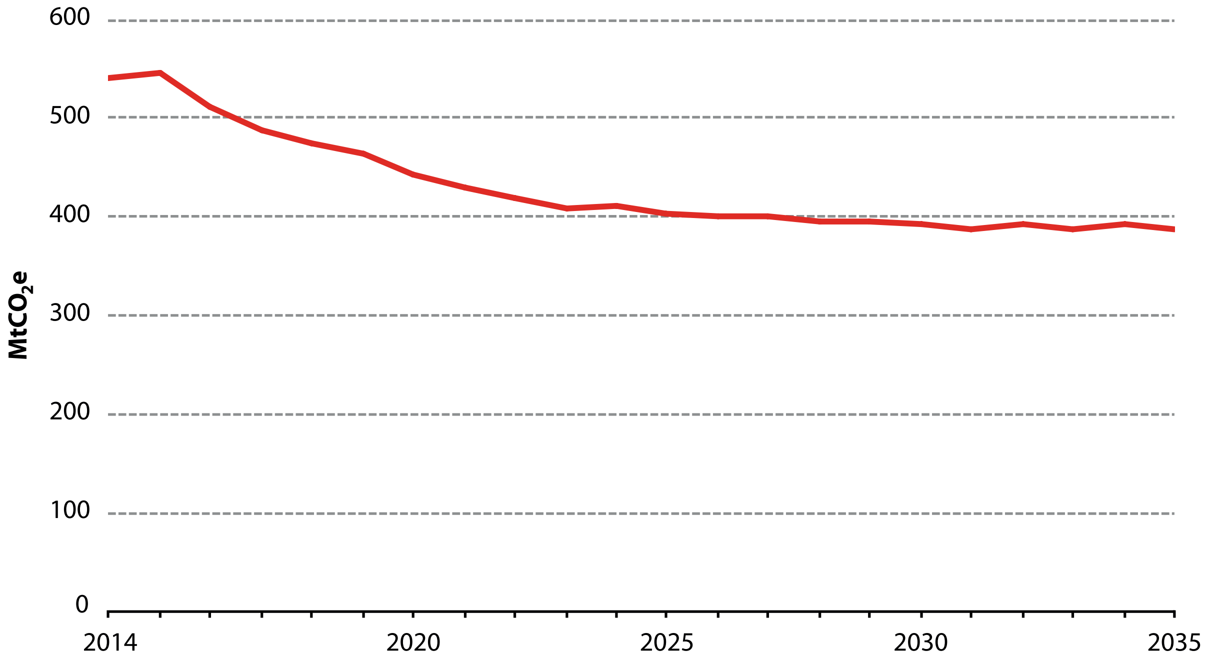
Projected emissions to 2020 – central case

DECC projections allow for the combined impact of current policies (those that are currently implemented or where implementation is underway) and planned policies (those where the Government's intentions have been announced or are still being consulted on). The latest interim projection (October 2015) suggests continued reductions in GHG emissions, by a further 15% between 2014 and 2020:

- Overall, the reduction is driven largely by a very significant reduction in power sector emissions, due in particular to the impact of the 2020 renewables target, and a continued shift away from coal.
- Further significant reductions occur in transport, due to the impact of the EU new car and van CO_2 targets for 2020.

The projection shows UK emissions 45% below 1990 levels in 2020 (Figure 3.4). Projections of emissions in 2020 have varied significantly in the past, reflecting incorporation of more recent data and improvements to the projection methodology (Box 3.1).

Figure 3.4: DECC's emissions projections (2014-2035)



Source: DECC interim projections (October 2015).

Box 3.1: Changes in emissions projections since 2010

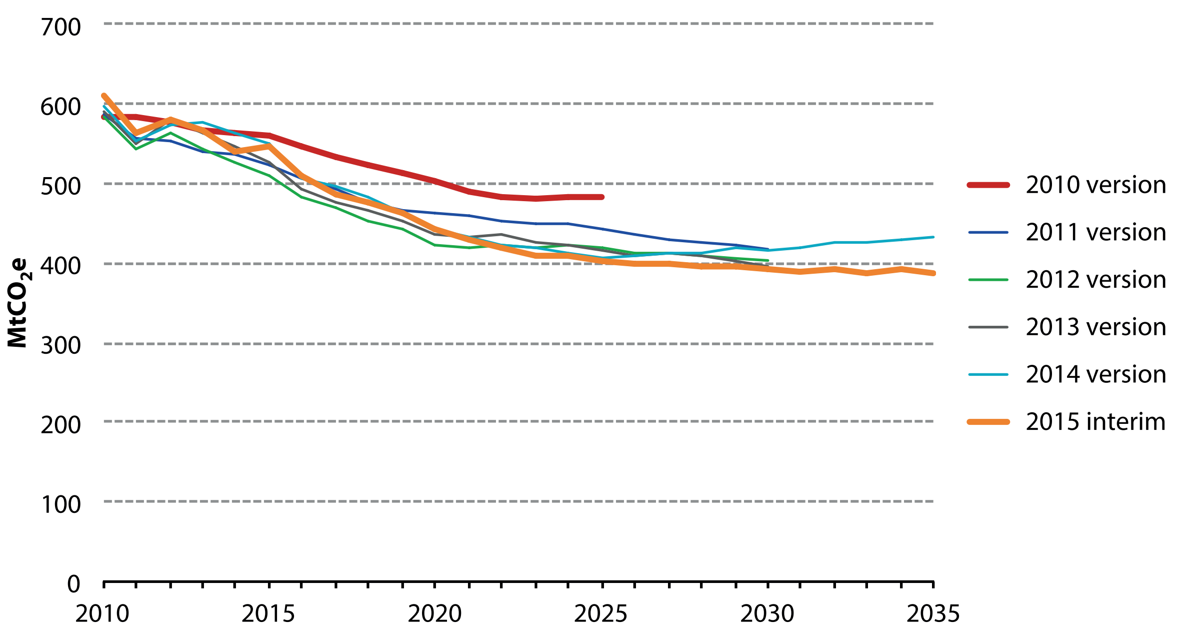
Each year, DECC publishes projections of energy demand, supply and GHG emissions. Since the release of our fourth carbon budget advice in 2010, the projections changed considerably as a result of updates for the latest evidence and methodological improvements (Figure B3.1):

- **2010 projections**. In the year of the fourth carbon budget advice (2010), DECC projected total GHG emissions falling to around 483 $MtCO_2e$ in 2025 (the 2010 projections only go out to 2025).
- **2011 projections**. This release projected significantly lower total GHG emissions, mainly due to the reductions in emissions from power, industry and transport. In the power sector, lower GDP growth together with changes to generation costs and plant efficiencies resulted in lower emissions. Industry emissions decreased primarily due to lower GDP growth assumptions, reduced growth in industrial sub-sectors and higher estimated savings from policy. Projected transport emissions fell because of higher oil prices, revision of the demand equations and revisions in the 2009 UK GHG inventory. In total, 2025 emissions fell to 442 $MtCO_2e$ (a 9% reduction on the 2010 estimate) and 2030 emissions were projected at 418 $MtCO_2e$.
- **2012 projections**. This showed a further fall in projected GHG emissions mainly as a result of reductions in power, transport and industry sectors. In power, a key change in the modelling approach implied a faster decline in coal use. The other main driver was the introduction of Electricity Market Reform (EMR) policies leading to greater support for low carbon technologies. Industry emissions decreased mainly because of lower GDP growth assumptions and combined heat and power projections. Updates in economic assumptions and model changes led to lower transport emissions. Overall, 2030 emissions were projected at 404 $MtCO_2e$, a 3% reduction on the 2011 estimate.

Box 3.1: Changes in emissions projections since 2010

- **2013 projections**. The projection showed slightly higher total GHG emissions by the early 2020s but almost no change by 2030. In industry, refineries emissions increased due to adjustments in the GHG inventory. Residential emissions were higher because of a revision to older supplier obligation schemes. 2030 emissions were projected at 396 $MtCO_2e$, a 2% reduction on the 2012 estimate.
- **2014 projections**. Projected emissions increased slightly due to a revision in the expected impacts of existing policies beyond 2025. Specifically, 2030 emissions were projected at 417 $MtCO_2e$, a 5% increase on the 2013 estimate.
- **2015 interim projections**. DECC published their 2015 projections as this report was sent to print. In this report we use 'interim' emissions projections provided to the Committee in October 2015 and produced on the same basis as the published projections. Revisions to the GHG inventory and emissions projections led to a change in the long-term trend. While the 2014 publication projected emissions to increase from 2025, in the latest projections total GHG emissions are broadly flat in the long-term. Thus, 2030 emissions are projected to be lower (392 $MtCO_2e$), a 6% reduction on the 2014 estimate.

Figure B3.1: DECC Reference projections, 2010-2015 vintages



Source: DECC (2010-2015)*Updated energy and emissions projections, DECC interim projections (October 2015).*
Notes: The 2010 version projected emissions up to 2025 only whilst since 2014, projections go out to 2035.

There is inevitable uncertainty in these projections. We discuss the uncertainty in emissions projections, and its implications for setting and meeting the fifth carbon budget, in Section 3.

DECC's projections assume that current Government policies to reduce emissions deliver in full. In our 2014 and 2015 Progress Reports we noted that a number of these policies are at risk of failing to deliver due to design and delivery problems, or because they are currently unfunded:

- In the non-traded sector (i.e. outside the EU Emissions Trading System) we identified the Agricultural Action Plan, policies to improve the fuel efficiency of HGVs, the Renewable Heat Incentive post-2016, Zero Carbon Homes and the Renewable Transport Fuels Obligation as "at risk" to 2020.
- In the traded sector, we identified fuel switching away from coal as "at risk" to 2020.

Our emissions scenarios are broadly consistent, in terms of ambition, with DECC's 2014 assessment of the impact of current and planned policies. Since then, there has been some weakening of policies, such as the cancellation of Zero Carbon Homes. Delivering our scenario would therefore require strengthening of current and planned policies to ensure they deliver in full.

2. Meeting the 2050 target – what this means for the fifth carbon budget

The 2050 target

The Climate Change Act includes a requirement to reduce 2050 emissions by at least 80% relative to 1990. That follows the Committee's recommendation that emissions for 2050 should be reduced by at least 80% on 1990 levels, covering all sectors *including the UK share of international aviation and international shipping* (IAS)[5]. This implies a level of per capita emissions in 2050, which if replicated globally, would be consistent with a path to limiting global temperature increase to around 2°C.

Accounting complexities mean that the IAS sectors are currently not included formally within the carbon budgets. To ensure consistency with the 2°C goal, emissions from IAS are reflected in the levels of the existing budgets by ensuring these are on the path to meeting the 2050 target with IAS emissions included. This approach has been established over the course of legislating the four previous carbon budgets and the fourth carbon budget review:

- The Committee has recommended budgets on an appropriate path towards a 2050 target that allows room for IAS emissions in achieving an overall 80% reduction. Sensible planning assumptions for IAS emissions (i.e. aviation emissions in 2050 to return to their 2005 level, shipping emissions decline around 35% between 2005 and 2050, as in our Central scenario) imply this would require a reduction of around 85% relative to 1990 for the non-IAS sectors of the economy.
- The Government has followed this approach, both in its own modelling[6], and in legislating the budgets as recommended. In 2012, when reviewing the treatment of IAS emissions, the Government stated that: *"Government reaffirms its overall commitment to the 2050 target and recognises that emissions from international aviation and shipping should be treated the same as emissions from all other sectors, in order to reach our long-term climate goals"*.[7]
- Excluding IAS emissions, UK greenhouse gas emissions were 520 $MtCO_2e$ in 2014, 36% below 1990 levels.

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[5] *Interim advice from the Committee on Climate Change* (2008), available at https://www.theccc.org.uk/publication/letter-interim-advice-from-the-committee-on-climate-change/

[6] For example DECC's 2050 Calculator (https://www.gov.uk/guidance/2050-pathways-analysis) and analysis using the RESOM and ESME models for DECC (2013) *The Future of Heating: Meeting the challenge*, available at: https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge. This approach was recognised in the Government's response to the Committee's 2015 Progress Report.

[7] DECC (2012) *International aviation and shipping emissions and the UK's carbon budgets and 2050 target*. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65686/7334-int-aviation-shipping-emissions-carb-budg.pdf.

Inventory changes

In recent years there have been significant revisions to the UK's emissions inventory, increasing estimated emissions for 1990 and, to a lesser degree, for subsequent years (Box 3.2). This means that an 80% emissions reduction on 1990 levels now implies allowed 2050 emissions, including IAS, of 167 $MtCO_2e$, rather than our earlier estimate of 160 Mt, based on the 2006 inventory. This still implies emissions per capita of just over 2 tonnes, which we estimated was an appropriate level at the time the Climate Change Act was legislated. Using the updated level of allowed emissions in 2050, a further fall of 70% from 2014 is needed in order to meet the 2050 target (Figure 3.5).

Box 3.2: Revisions to the UK emissions inventory

The GHG emissions inventory is reviewed every year. New estimates for historical emissions back to 1990 are produced, based on the latest energy data published in the Digest of UK Energy Statistics (DUKES), as well as any methodological changes or new reporting guidelines from the IPCC.

When we originally recommended the 2050 target in 2008, an 80% reduction on 1990 levels in GHG emissions including international aviation and shipping implied a target of approximately 160 $MtCO_2e$ for 2050. However, improvements in evidence and methodological changes to the inventory mean that the baseline emissions for 1990 have now changed.

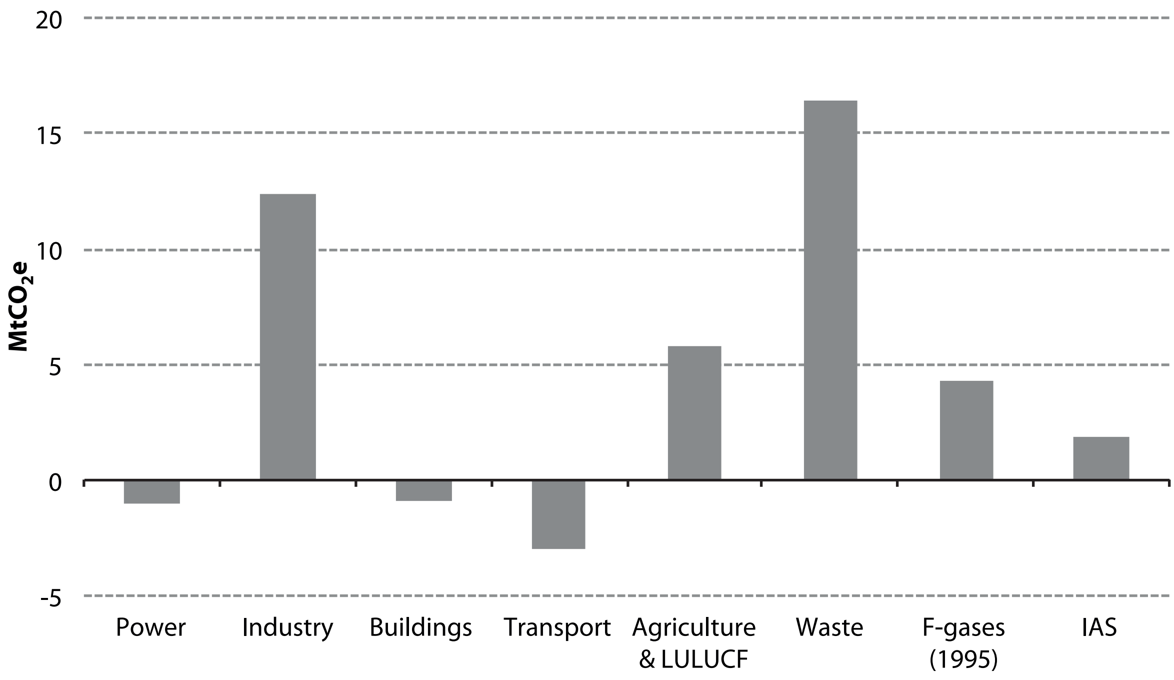
Based on a comparison of the most recent DECC inventory with the 2010 version (the earliest that had an equivalent sectoral breakdown), the largest revisions to estimated GHG emissions in 1990 (Figure B3.2) are:

- **Energy supply and industry**: 1990 emissions were revised upwards by 12 $MtCO_2e$, largely as a result of higher estimates of emissions coming from coal mining (3.5 Mt), exploration, production and transport of oil and gas (1.8 Mt) and other industrial combustion and electricity (4.6 Mt). Some industrial production, such as non-ferrous metal processes, was previously not accounted for, adding a further 2 $MtCO_2e$.
- **Agriculture and LULUCF**: estimates of 1990 emissions increased by around 6 $MtCO_2e$ reflecting new information on the average weights of cattle, manure management practices and UK land areas of cropland on organic soils drained for agricultural purposes.
- **Waste**: 1990 GHG emissions increased by 16.5 $MtCO_2e$, mainly due to changes to estimates of landfill emissions (13 Mt) as new information on the volumes of landfill gas flared at UK sites has been used. In addition, new Defra research estimated the decay rate of biodegradable waste to be slightly higher than previously assessed. Emissions from waste-water handling also rose (3.5 Mt) after the 2012 UNFCCC review concluded that the previous emissions were underestimated.
- **F-gases**: estimates of 1995 emissions are higher by roughly 4 $MtCO_2e$ largely because of the revisions to the emissions from halocarbon production.

Overall, estimates of 1990 GHG emissions including IAS have increased from 798 $MtCO_2e$ in the 2008 inventory, to 802 Mt in the 2010 inventory to the current inventory figure of 837 Mt.

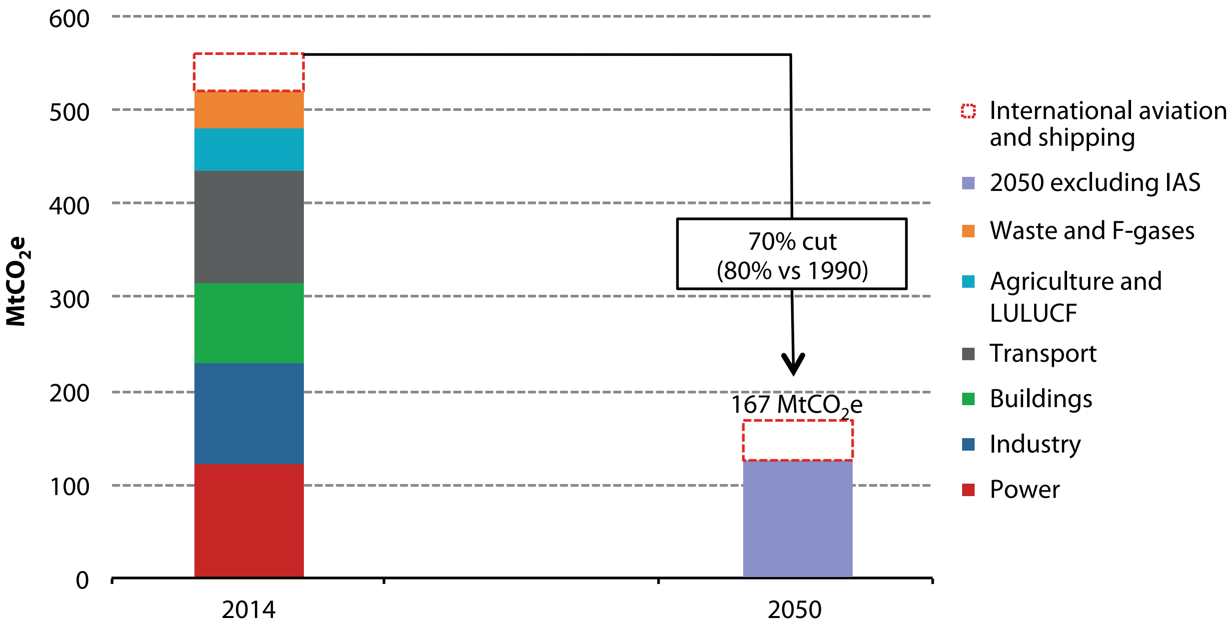
Box 3.2: Revisions to the UK emissions inventory

Figure B3.2: Difference in 1990 GHG emissions estimates between 2010 and 2015 inventories



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; DECC (2010) *Final UK greenhouse gas emissions national statistics: 1990-2008*; CCC analysis.
Notes: F-gases emissions are presented for 1995 which is the year used for those gases, consistent with the Kyoto Protocol.

Figure 3.5: The 2050 challenge



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; DECC (2010) *Final UK greenhouse gas emissions national statistics: 1990-2008*; CCC analysis.
Notes: International aviation and shipping data are for 2013.

As we set out when advising on the 2050 target in 2008, it is sensible to plan now to meet the target without use of emissions trading (Box 3.3). We consider the role of credits in meeting the fifth carbon budget in Chapter 6.

Box 3.3: Potential contribution of trading to meet the 2050 target

The accounting for the 2050 target under the Climate Change Act allows emissions trading to contribute (i.e. the target is set on a 'net' basis). However, as we set out when we recommended the 2050 target, it is not sensible to rely upon being able to purchase emissions credits, given that all countries would need to be pursuing stretching targets and any available credits would be likely to be very expensive.

A more reasonable approach is to plan now to meet the 80% target via domestic effort (i.e. on a 'gross' basis), while retaining the flexibility to use credits as we approach 2050 if they turn out to be available and less costly than domestic action at the margin. This is the basis on which our scenarios to 2050 have been constructed.

Scenarios for meeting the 2050 target

Since the 2050 target was legislated in 2008, the Committee, and others, have produced analysis and modelling on how it can be met, which has been updated as new information emerges (Box 3.4). Different approaches and assumptions have been tested over time.

A number of common themes have emerged from the various approaches[8]:

- **Energy efficiency and behaviour change.** Reducing the level of energy demand through improved efficiency and small changes to consumer behaviour can greatly reduce the cost of meeting the 2050 target. However, it is clear that this alone will not be enough to reduce emissions by 80%, and fuel switching to low-carbon sources will also be needed.
- **Power sector**. Meeting the target is likely to require a power sector with very low emissions intensity in 2050. This is needed to decarbonise existing demands for electricity and to meet new demands in road transport and heat in buildings without increasing emissions (with potential for other applications). Depending on the extent of electrification in transport, heat and other applications, the level of electricity consumption in 2050 could be 50-135% above the level in 2014.
- **Carbon capture and storage (CCS)** is very important in meeting the 2050 target at least cost, given its potential to reduce emissions across heavy industry, the power sector and perhaps with bioenergy, as well as opening up new decarbonisation pathways (e.g. based on hydrogen). Estimates by the Committee[9] and by the Energy Technologies Institute (ETI)[10] indicate that the costs of meeting the UK's 2050 target could almost double without CCS. At the global level the IPCC has estimated that its absence could increase costs by over 100%[11].

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[8] The evidence for these themes and supporting analysis can be found in the accompanying Technical Report.

[9] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping* https://www.theccc.org.uk/archive/aws/IA&S/CCC_IAS_Tech-Rep_2050Target_April2012.pdf

[10] ETI (2015) *Building the UK carbon capture and storage sector by 2030 – Scenarios and actions* http://www.eti.co.uk/wp-content/uploads/2015/03/CCS-Building-the-UK-carbon-capture-and-storage-sector-by-2013.pdf

[11] 138%, IPCC (2014) *Fifth Assessment Report – Synthesis Report*. Available at http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf

- **Bioenergy**. Sustainable bioenergy can play an important role. However, there are limits to the sustainable supply (e.g. this could provide around 10% of primary energy in 2050), so its role must be supplementary to other measures. Bioenergy should be allocated to options where it has the largest impact on reducing emissions. Our analysis indicates that use should preferentially be with CCS and/or displacing coal, with further potential for use where alternative low-carbon options are not available (e.g. aviation). The Committee's estimates of sustainable bioenergy supply suggest that use with CCS would provide an extra emissions reduction of around 20 $MtCO_2e$/year relative to use of the same quantity of bioenergy to displace gas in heat for industry and buildings[12].
- **Industry**. In addition to opportunities for energy efficiency and CCS, industry can be decarbonised through switching heat generation from fossil fuel combustion to use of electricity or combustion of hydrogen from low-carbon sources. There may also be opportunities to reduce emissions through materials efficiency and product substitution, but it is difficult to estimate the extent of these. Given the costs and challenges associated with decarbonising industry, residual emissions might be around 65 $MtCO_2e$ in 2050.
- **Agriculture**. Agriculture emissions can be reduced by changed farming practices (e.g. on-farm efficiencies, improved animal fertility), reduced food waste and adjustment of diet towards less carbon-intensive foods. However, there is a limit to what is likely to be achievable, so residual emissions in 2050 may be around 30 $MtCO_2e$.
- **Aviation**. While UK demand for international aviation is likely to grow considerably, there will be a need to limit emissions. Previous analysis by the Committee concluded that aviation should plan for emissions in 2050 to be no higher than those in 2005. That requires strong efficiency improvements to balance demand growth of about 60%.
- **Buildings and surface transport**. With the developments described above, there may be a small amount of room for residual emissions in buildings and/or surface transport. Where emissions remain should depend on how different low-carbon technologies develop. It is therefore sensible to plan now to keep open the possibility of near-full decarbonisation of both buildings and surface transport by 2050.

These scenarios provide a high-level sense of direction for decarbonisation to 2050. They still leave significant flexibility in the mix of effort between sectors, technologies and the role of behaviour change. Further, they provide the flexibility for new innovation and technologies to emerge.

However, a recurrent and robust feature of these analyses is the importance of action to largely decarbonise the power sector over the period to 2030, and expand capacity thereafter to extend low-carbon electricity into other sectors such as transport and buildings (see Box 3.5 in the following section). We set out different scenarios for a decarbonised electricity supply in 2030 in our report on *Power sector scenarios for the fifth carbon budget*[13]. That report considers in detail the issues of security of supply and affordability associated with this change.

Should efforts to reduce or limit emissions be less successful in one area, more effort will be required elsewhere. For example, if CCS were to be unavailable, it might be necessary to find additional emissions reductions of around 35 $MtCO_2e$ in 2050 from the rest of the economy. Given limited scope to reduce emissions beyond our planning assumptions for international aviation and shipping or from agriculture, this could imply near-full decarbonisation of surface transport and heat in buildings.

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[12] As solid biomass releases a lot of CO_2 on combustion, its use with CCS (e.g. for power generation) to capture most of that CO_2 would lead to a greater emissions reduction than displacing lower-carbon fossil fuels such as natural gas. For a more detailed explanation of this, see CCC (2011) *Bioenergy Review*, available at: https://www.theccc.org.uk/publication/bioenergy-review/

[13] Available at https://www.theccc.org.uk/publication/power-sector-scenarios-for-the-fifth-carbon-budget/

Our scenarios to 2032 therefore keep open the possibility of reducing emissions from heat in buildings and from surface transport to very low levels in 2050.

Our analysis of the costs of decarbonisation is consistent with a range of studies which find costs of meeting the 2050 target of no more than 1-2% of GDP. We assessed these costs most recently in our 2012 report on *The 2050 Target*[14]; updates to the evidence base since then do not alter this estimate significantly.

Box 3.4: Modelling of the 2050 target

Previous analysis of meeting the 2050 target has included use of the MARKAL[15] and Energy Technology Institute (ETI) ESME[16] models, joint DECC-CCC modelling on appropriate use of bioenergy within a decarbonising economy[17], as well as the DECC 2050 Calculator[18]. The Government, academia and industry have engaged in similar modelling exercises. In 2012, we also undertook a bottom-up analysis of how the 2050 target could be met, which involved development of scenarios to look at different balances of effort across the energy system[19].

We have supplemented that work for this report by commissioning analysis by DECC using the new UK TIMES model.

The UK TIMES model (UKTM) is the successor to UK MARKAL, and was originally developed at the UCL Energy Institute.

Like MARKAL, and other energy system models such as the Energy Technology Institute's ESME model, UKTM is a technology-rich model that performs a least-cost optimisation in order to meet energy service demands while meeting specified emissions targets.

Such models generally assume perfect foresight and so provide insights into appropriate strategies as if all important strategic considerations were known.

There are considerable uncertainties over options and their costs and benefits over the timeframe to 2050. The "perfect foresight" approach of these models does not allow a risk-based analysis or effectively taking behavioural factors into account. Therefore it is important to undertake a range of sensitivity tests in order to identify robust insights.

UKTM (or any similar model) does not directly produce an appropriate strategy for meeting the 2050 target. Rather, it provides insights that can be incorporated into a strategic approach to long-term decarbonisation, including full consideration of issues such as deliverability, option creation and robustness to uncertainty. Equally, it is not appropriate to judge different long-term decarbonisation strategies simply in terms of the costs estimated by such a model.

In practice, the Committee's final advice and recommendations draw on wider sources of evidence, expert judgment and analysis.

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[14] CCC (2012) *The 2050 Target*, available at https://www.theccc.org.uk/archive/aws/IA&S/CCC_IAS_Tech-Rep_2050Target_April2012.pdf

[15] UCL (2010) *UK MARKAL Modelling – Examining Decarbonisation Pathways in the 2020s on the Way to Meeting the 2050 Emissions Target*. Available at https://www.theccc.org.uk/publication/the-fourth-carbon-budget-reducing-emissions-through-the-2020s-2/

[16] CCC (2012) *Renewable Energy Review – Technical Annex – Energy system modelling using the Energy Technologies Institute ESME model*. Available at https://www.theccc.org.uk/publication/the-renewable-energy-review/

[17] Redpoint (2012) *Appropriate Uses of Bioenergy*. Available at https://www.theccc.org.uk/publication/bioenergy-review

[18] http://2050-calculator-tool.decc.gov.uk/

[19] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*, https://www.theccc.org.uk/archive/aws/IA&S/CCC_IAS_Tech-Rep_2050Target_April2012.pdf

What the 2050 picture means for the nearer term

In order to reduce emissions by at least 80% by 2050 at lowest overall cost, there is a strong case for steady action to reduce emissions. This gives time and incentives for new technologies to emerge and existing technologies to develop. It allows markets to grow and consumers and businesses to adapt their behaviour over time. Roll-out of low-carbon technologies can be aligned to capital stock turnover and investment can build up steadily while supply chains and skills bases have time to develop.

Having a clear decarbonisation strategy based around known technologies does not mean specifying now a precise mix of technologies that will be used over the next 15 or 35 years. It is important to strike a balance between pursuing solutions that currently appear to be the most promising, while retaining flexibility to alter direction. This is reflected in the set of scenarios we have developed for each sector, outlined in the Technical Report.

Based on what we know now about how to reduce emissions by 80%, a range of actions will be important in the medium term to keep in play alternative ways to meet the 2050 target:

- **Power sector decarbonisation**. Continuing decarbonisation of the power sector to 2030 is crucial to meeting the 2050 target at least-cost (Box 3.5). As well as directly reducing emissions from UK electricity generation, it opens up decarbonisation opportunities for other sectors. To ensure that low-cost options are available to meet growing demand beyond 2030 it is important that less-mature options are developed alongside the roll-out of more mature options.
- **Development of CCS**. Given the importance of CCS in meeting the 2050 target, CCS must make significant progress by 2030. This requires continuing deployment in the power sector over the period to 2030, in order to provide anchor loads for CO_2 infrastructures and reduce risk for projects in both power and industry[20].
- **Infrastructure development**. New infrastructures will be required to support the deployment of low-carbon technologies. As well as CO_2 infrastructure, which is key to commercialisation of CCS, development of heat networks and electric vehicle charging networks will be required, and potentially infrastructure for hydrogen applications. Electricity networks will also need to be strengthened in places, to cope with new demands (e.g. from heat pumps) and increasing generation from low-carbon sources.
- **Market development**. Some of the technologies that will be important for decarbonisation, such as heat pumps and electric vehicles, are available but have yet to be deployed widely in the UK. Developing these markets will take time. Deployment over the next 15 years will be required, such that natural stock turnover after 2030 can deliver the necessary decarbonisation by 2050.
- **Strategic decisions**. While it is important in the near term to create options, there will in some cases be a requirement for Government to choose between different paths. Identification of these decision points, and of the information that will be required to inform them, is an important part of a strategic approach to decarbonisation. Such decisions may include whether and when to develop a widespread hydrogen vehicle refuelling network or how to repurpose the gas grid given changes in demand for gas.

As well as laying the groundwork to meet the 2050 target, these actions will also contribute to emissions reductions in the intervening period. Our scenarios for the fifth carbon budget consist of measures that prepare for 2050 as described above or that reduce emissions at low cost (see section 3).

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[20] Pöyry & Element Energy (2015) *Potential CCS Cost Reduction Mechanisms*, available at https://www.theccc.org.uk/publication/poyry-element-energy2015-potential-ccs-cost-reduction-mechanisms-report; and Gross (2015) *Approaches to cost reduction in carbon capture and storage and offshore wind*, available at https://www.theccc.org.uk/publication/gross-2015-approaches-to-cost-reduction-in-carbon-capture-and-storage-and-offshore-wind

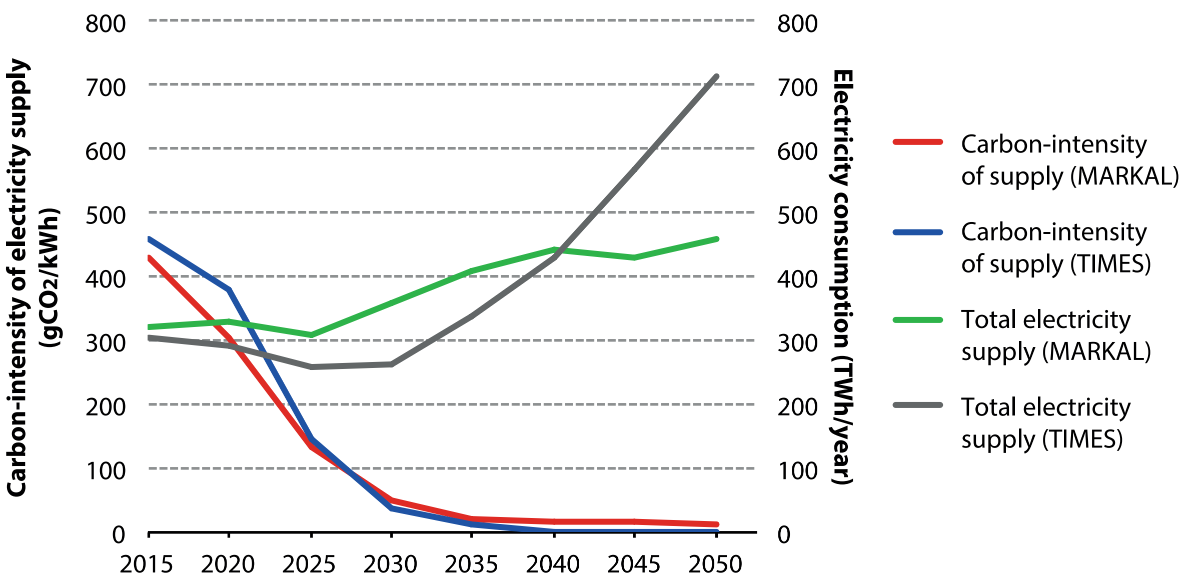
Box 3.5: The rationale for power sector decarbonisation to 2030

The emissions intensity of the UK power sector is currently around 450 gCO_2/kWh. All new generation in recent years has come from low-carbon sources, and the Government has committed to continuing this to 2020. This continued investment, in combination with closures of coal plants, will reduce carbon intensity to 200-250 g/kWh. Further decarbonisation to below 100 g/kWh in 2030 is on the cost-effective path to 2050:

- Our recent report on *Power sector scenarios for the fifth carbon budget*[21] identified that the cost-effective path would be to continue low-carbon investment through the 2020s consistent with reaching below 100g by 2020. This would entail cost-effective deployment of mature low-carbon technologies, commercialisation of key technologies and a rate of low-carbon build consistent with getting to a potentially much larger low-carbon power sector in 2050.
- That is in line with the findings of the 2050 modelling exercises, which reach below 100g in 2030 on the path to close to full decarbonisation by 2050 of a system that could have demand double current levels.

Our power scenarios set out a range of scenarios for low-carbon power sectors in 2030 consistent with this set of considerations.

Figure B3.5: Energy system model trajectories for the power sector (2015-2050)



Source: UCL (2010) *UK MARKAL Modelling – Examining Decarbonisation Pathways in the 2020s on the Way to Meeting the 2050 Emissions Target*; UK TIMES modelling for the CCC by DECC (2015).
Notes: Carbon-intensity calculations exclude the 'negative emissions' benefits of using biomass in conjunction with CCS. While energy system models provide a high-level direction for least-cost decarbonisation, more detailed modelling is required on specific sectors. More detailed modelling of the power sector for our report on *Power sector scenarios for the fifth carbon budget* suggested slightly higher carbon intensity for 2030 than the MARKAL and TIMES results here.

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[21] CCC (2015) *Power sector scenarios for the fifth carbon budget*, available at https://www.theccc.org.uk/publication/power-sector-scenarios-for-the-fifth-carbon-budget

The role of innovation

Innovation will be critical in developing and implementing new low-carbon technologies, and improving the cost and performance of existing ones.

Government involvement is important to ensure limited resources are best allocated across the innovation process to ensure that carbon budgets, the 2050 target and subsequent decarbonisation can be met at acceptable cost. Our 2010 review of low-carbon innovation[22] identified three broad phases of the innovation process:

- **Research and development (R&D)**, involving both basic research and development of specific technologies, culminating in initial demonstration of feasibility.
- **Demonstration**, involving large-scale pre-commercial demonstration of technologies designed to test and improve reliability, improve designs, and establish and reduce operating costs. Technologies currently at this stage include carbon capture and storage (CCS), and hydrogen fuel cell vehicles.
- **Deployment**, leading to technologies considered 'commercially proven' and achieving economies of scale. Technologies within this stage include nuclear power, heat pumps, offshore wind and electric vehicles.

Product development involves progressing through these three phases. Innovation occurs at each phase but has different characteristics and opens up different options. Innovation is not a strictly linear process: experience at the demonstration and deployment phases frequently reveals the need for additional basic R&D to overcome barriers to further progress, while R&D highlights issues that may have to be tackled when it comes to deployment, and demonstration and deployment both involve new learning.

Our assessment is that while R&D is important, it is sensible to plan for meeting the 2050 target largely through currently-known technologies:

- R&D will be required to develop new low-carbon technologies, and to improve the cost and performance of existing ones. Many of the benefits of early stage R&D may accrue in the period beyond 2050 when, according to IPCC, even deeper reductions in emissions may be required to maintain the expected temperature increase below 2°C.
- Deployment of currently-known technologies at scale will be required to ensure the 2050 target can be met at reasonable cost. It will also drive innovation and learning that feeds back into new R&D as well as potentially creating competitive advantages for the companies and countries involved.

Box 3.6 sets out the rationale for extensive deployment of currently-known technologies to meet the 2050 target. This underpins our approach to developing our emissions scenarios, and the inclusion of considerable volumes of offshore wind, CCS, electric vehicles and district heating in our scenarios, as set out in Section 3.

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[22] CCC (2010) *Building a low-carbon economy – the UK's innovation challenge.* Available at https://www.theccc.org.uk/publication/building-a-low-carbon-economy-the-uks-innovation-challenge

Box 3.6: The importance of deployment in the 2020s

Deployment of currently known technologies will be of critical importance to meeting the 2050 target due to the remaining time available, the time frame for developing and scaling up new technologies, risks and uncertainty over new technologies, the role of deployment in the innovation process and the need for supporting infrastructure and supply chains:

- **Time available to meet the 2050 target**. Asset lives of 15-30 years require early deployment of the technologies needed to meet the 2050 target. To effectively decarbonise power, transport and heat generation by 2050, it will be necessary to decarbonise all new investment by 2020 for power (with the exception of back-up and balancing plant), 2035 for transport, and 2035 for heat.
- **Time frame to reach deployment at scale**. The development of new technologies, and their deployment at scale, takes time. A recent report by the UK Energy Research Centre (UKERC) found that it can take several decades for new technological innovations to reach commercial maturity (covered further below).
- **Risk and uncertainty of early-stage technologies**. Each phase of innovation carries different risks of failure. Total risk is highest for technologies at the R&D stage, and lowest at the deployment stage (when earlier risks have been eliminated). We therefore have a reasonable degree of confidence that later-stage technologies – e.g. offshore wind, electric vehicles and heat pumps – can be deployed at sufficient scale to meet the 2050 target, given a sensible deployment strategy, supplemented by monitoring and evaluation of costs and technical performance, and measures to address financial and non-financial barriers.
- **Role of deployment in the innovation process**. Deployment of a new technology at scale provides manufacturers, installers and developers with the experience to successfully identify remaining barriers to commercialisation, so that these can be addressed through product redesign, and if necessary, further R&D to improve the product or reduce its cost. It is far from clear that currently unknown technologies will face lower costs than currently known technologies, and will not therefore require the same level of deployment support.
- **Requirement for supporting infrastructure, supply chains and developed markets.** Energy technologies require supporting infrastructure to operate, extensive supply chains to deploy at scale, and developed markets to ensure demand is sufficient for the level of deployment. Infrastructure, supply chains and markets all take time to develop. Early deployment of currently known technologies will help ensure infrastructure, supply chains and markets are in place by the time the technologies need to be deployed at scale in the mid-2030s.

The UK Energy Research Centre (UKERC) recently carried out a review of available evidence for the time new technological innovations take to reach commercial maturity. This covered the innovation timescales of both energy and non-energy technologies, supplemented by five energy-specific case studies.

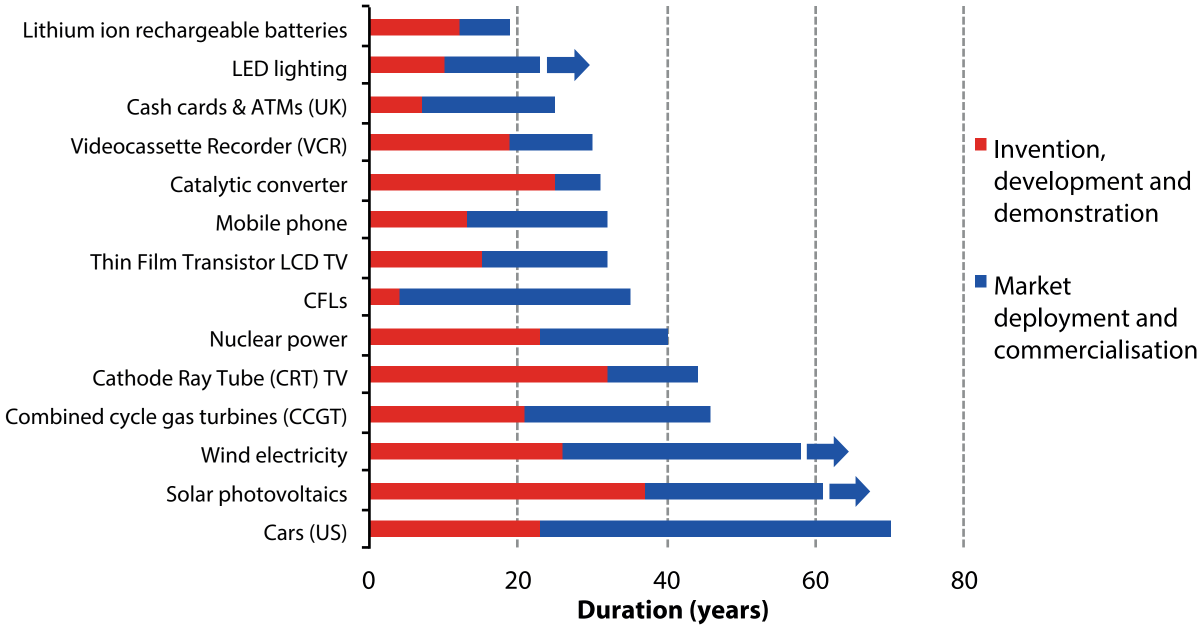
Across the 14 innovations considered, the review examined total time taken from invention to commercialisation, as well as the duration of two broad phases: a first phase of invention, development and demonstration, and a second phase of market deployment and commercialisation:

- The average time taken from invention to commercialisation was 39 years. The shortest time to commercialisation was 19 years (lithium-ion rechargeable battery for consumer electronics), and the longest was 70 years (the car) (Figure B3.6).

Box 3.6: The importance of deployment in the 2020s

- The average time taken for the invention, development and demonstration phase was 19 years. The shortest time to demonstration was four years (compact fluorescent light bulb), and the longest was 37 years (solar PV).
- The average time taken for the market deployment and commercialisation phase was similar, at 20 years. The shortest time to commercialisation was 6 years (catalytic converter), and the longest was 47 years (the car).
- There is considerable variation between the innovations in terms of how quickly they reached market and became commercialised. It is difficult to identify which factors affect the time frames of the two phases; however, the following observations can be made:
  - The average time taken from invention to commercialisation is significantly longer than average for energy generation technologies (48 years), due to a longer market deployment and commercialisation phase.
  - The physical scale of the technology affects the time taken from invention to commercialisation. The overall speed of innovation was significantly lower for large-scale electricity generation technologies than products which are for personal use.
  - The time taken from invention to commercialisation tended to be significantly shorter for products providing the same service as existing products, though this may not be a general finding due to possible outliers such as the car and cathode-ray tube TV, new innovations with relatively long time frames.

Figure B3.6: Time taken for development and commercialisation of a range of innovations



Source: UKERC (2015) *Innovation timelines from invention to maturity: A review of the evidence on the time taken for new technologies to reach widespread commercialisation.*

3. Scenarios for the fifth carbon budget

Alongside the high-level energy system modelling to 2050, we have refreshed our bottom-up scenarios for the fifth carbon budget, based on an analysis of what is possible and meets the criteria in the Climate Change Act in each sector of the economy.

(i) Our approach to building scenarios

We have developed a set of scenarios for reducing UK GHG emissions across the sectors of the economy. In developing our scenarios we have considered:

- The relative cost-effectiveness of different approaches to reducing emissions in the period to 2050. Specifically, the scenarios include measures that are available at lower cost than the Government's published carbon values (Box 3.7).
- The wider criteria set out in the Act, including impacts on affordability and competitiveness (Chapter 4).
- The need to ensure that measures required to meet the 2050 target are available to be deployed when needed, through demonstration and deployment of key technologies, development of markets, and deployment of supporting infrastructure. The scale of the reduction needed to meet the 2050 target is such that a high level of ambition and significant policy intervention will be required across all the emitting sectors.
- The feasibility of deploying particular solutions. This has included consideration of barriers to deployment and measures that can be taken to address these barriers, supply chain constraints, and rates of stock turnover.
- Actions to which the Government is already committed, largely occurring in the period to 2020 (e.g. standards for new car gCO_2/km).

The **Central Scenario** represents our best assessment of the technologies and behaviours required over the fifth carbon budget period to meet the 2050 target cost-effectively, while meeting the other criteria in the Act.

There is inevitable uncertainty over the rates at which technologies will become available, their future costs and the scale of behaviour change likely to occur. Our scenarios are not prescriptive: it may be possible to meet carbon budgets with lower deployment of some options, provided the increase in emissions is offset by higher deployment of others. The scenarios are also not exhaustive: it is possible that some options that are not currently included in our scenarios become more cost-effective than we currently envisage. The scenarios allow the Committee to determine whether the overall budget is deliverable within the statutory duties placed on it by the Climate Change Act and discussed in Chapter 1.

As considered earlier, there are many uncertainties over the possible emissions path over the period to 2030 and beyond. These include macro drivers (the level of future economic activity, fossil fuel prices, population), the evolution of cost and performance of options to reduce GHG emissions, consumer acceptance of these options, and the extent of behavioural change people are prepared to make. Our scenarios take a conservative approach to these uncertainties: they assume demand for energy services grows in line with historical experience, and that there is relatively limited scope for radical behaviour change over the near-to-medium term. This approach minimises the risks of a fifth carbon budget set at our recommended level being too tight and excessively costly or otherwise infeasible.

Our scenarios explicitly recognise uncertainty in two ways:

- In addition to the Central Scenario, we develop Barriers and Max scenarios in each sector. The **Barriers Scenario** represents unfavourable conditions for key measures (technological barriers, failure to achieve cost reductions, or market barriers). The **Max Scenario** represents maximum feasible deployment of key measures. This demonstrates that there is flexibility in how a given carbon budget could be met with varying degrees of effort across sectors.
- We also develop one or more **Alternative** scenarios in each sector, representing deployment of different measures to those in Barriers, Central and Max. For example, one of the Alternative scenarios in the Buildings sector involves greater levels of district heating and lower take-up of heat pumps than the Central scenario; one of the Alternative scenarios in the transport sector involves widespread take up of hydrogen technologies, rather than battery electric vehicles. This demonstrates some robustness within sectors to uncertainty over the types of abatement options that will ultimately prove to be better-performing and cost-effective.

Box 3.7: A target-consistent value of carbon and market expectations for carbon prices

Target-consistent carbon value

- The Government's carbon values for policy appraisal are designed to be consistent with action required under the Climate Change Act. They reflect estimates in the literature and modelled scenarios and have been peer reviewed by an expert panel. The modelling work includes a top-down global sectoral model for the world energy system under low, central and high projections for global technology costs, fossil fuel prices and global energy demand. The model is used to calculate carbon costs consistent with international action to limit the average increase in global surface temperatures to 2°C above pre-industrial levels.
- In a central case the carbon values reach £78/tCO_2e in 2030, growing steadily to £220/t in 2050. Low and high values are 50% below and above the central level. We have previously concluded that these values are in line with estimates in the wider literature for the costs of limiting warming to 2°C, where these do not rely on over-optimistic assumptions for the availability of sustainable bioenergy.
- The UK's 2050 target is aligned to this level of effort globally, and is likely to require actions at the margin that have a similar carbon cost[1].
- The annual rate of increase in the Government carbon values is around 5%. Using this trajectory for carbon values as a guide to low-carbon investment would therefore support a steady increase in effort over time.

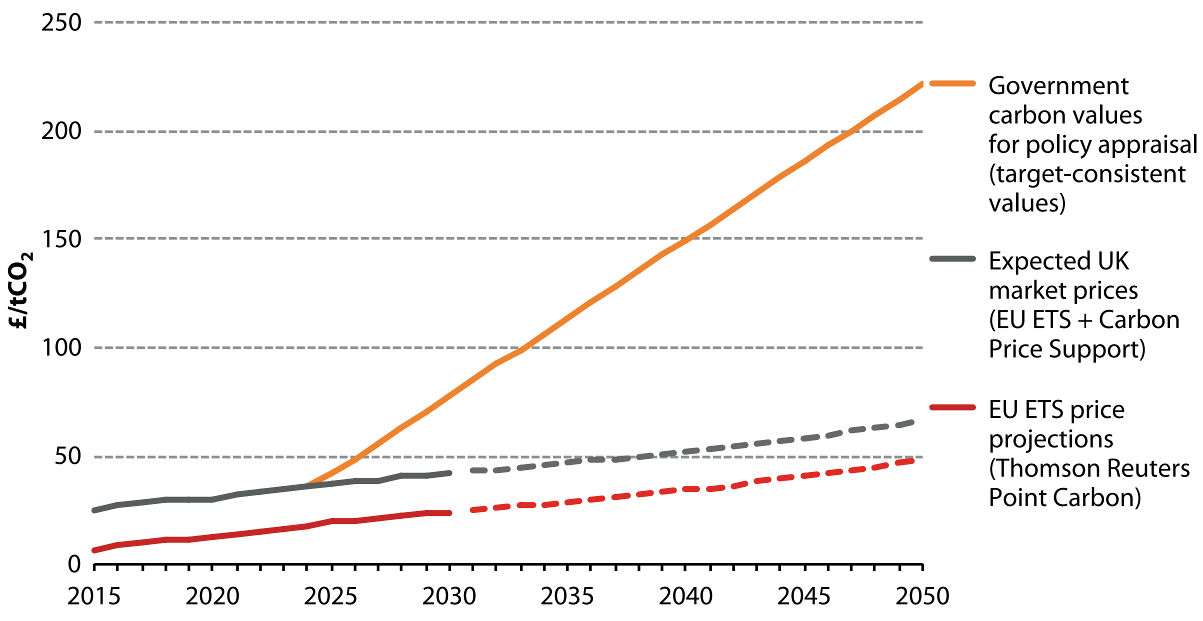
We use the target-consistent carbon value to assess whether low-carbon investments represent good value. Figure B3.7 shows the trajectory of carbon values we consider out to 2050.

Expected market carbon price

- The actual carbon price in the market is expected to be lower than the target-consistent carbon values above. Independent forecasters project a carbon price in the EU Emissions Trading System of £24/tCO_2e in 2030. Although this will be topped up in the UK, with the Government's carbon values as the formal target trajectory, the additional UK carbon price support has been frozen at £18/t. That implies a total market price of £42/t in 2030.
- If the world were to agree action to reduce emissions consistent with a 2°C target and deliver this through an efficient carbon market, then in theory market carbon prices would rise to a level in line with the target-consistent carbon values.

Box 3.7: A target-consistent value of carbon and market expectations for carbon prices

Figure B3.7: Target-consistent carbon values and market prices (2015-2050)



Source: DECC (2009) *Carbon Valuation in UK Policy Appraisal*; DECC (2014) *Updated short-term traded carbon values used for UK policy appraisal*; PointCarbon Thomson Reuters (2015); projected beyond 2030 at 3.5% p.a.
Notes: Expected market prices projected in 2020s and beyond assuming CPS frozen at £18/tCO_2.

Source: DECC (2009) *Carbon Valuation in UK Policy Appraisal: A Revised Approach*; DECC (2014) *Updated short term carbon values for UK policy appraisal*; CCC (2012) *The 2050 target*; Thomson Reuters Point Carbon (June 2015) and Aurora Energy Research (2015) each project a price of £24/tonne in 2030.
Notes: 1) For example, a carbon price at this level was needed to construct scenarios that could meet the 2050 target in CCC (2012) *The 2050 target*.

(ii) Sectoral scenario composition

The sectoral scenarios are discussed in detail in the accompanying Technical Report. They comprise the set of measures that it appears sensible to plan now to deploy, given our current understanding of decarbonisation options in each sector.

To stay on track to the 2050 target, markets for low-carbon heating systems and ultra-low emission vehicles must develop significantly in the 2020s. The Central Scenario requires continuing efficiency improvement across the economy, but also an extension of the shift to low-carbon fuel sources beyond the power sector. Similar emissions reductions could be achieved using a different low-carbon technology mix, as demonstrated by our Alternative scenarios. In summary:

- In **Power**, the carbon intensity of generation decreases from around 450 gCO_2/kWh in 2014 to 200-250 g/kWh in 2020, and to below 100 g/kWh in 2030. This reduction could be delivered by a range of different mixes of low-carbon generation (i.e. renewables, nuclear and CCS), reaching a total share of around 75% of generation by 2030. It is important that the low-carbon portfolio includes roll-out in the 2020s of offshore wind and CCS given their long-term importance and the role of UK deployment in driving down costs (see our supporting report on Power Sector Scenarios). Improvements to energy efficiency (e.g. increased use of LED lighting and more efficient appliances) will support progress in the power sector. The demand side also has an important role in increasing the flexibility of the power system, alongside interconnection, storage and flexible back-up capacity.

- In **Industry**, there is improved energy management and process control, use of more energy efficient plant and equipment, waste heat recovery, use of bioenergy in space and process heat, and development of a carbon capture and storage (CCS) cluster allowing use of CCS in the iron and steel and chemicals sectors. Hydrogen could provide an alternative to CCS depending how technologies develop. The Alternative scenario involves the use of hydrogen instead of CCS.
- In **Buildings**, deployment of low-carbon heat increases so that heat pumps and heat networks from low-carbon sources provide heat for around 13% of homes and over half of business demand; insulation increases (including a further around 1.5 million solid walls and 2 million cavity walls in the 2020s), and there is more use of heating controls and efficient lights and appliances. Alternatively, low-carbon heat could be provided via hydrogen added to the gas grid or using hybrid heat pumps, which include a gas boiler to top-up heat supply on the coldest days. The Alternative scenarios involve either (i) conversion of a proportion of the gas grid to hydrogen use, with use of hydrogen boilers to generate heat in residential, commercial and public buildings; (ii) hybrid heat pumps[23] in place of a mix of conventional heat pumps or gas boilers in residential buildings; or (iii) greater deployment of heat networks, in place of a proportion of heat pumps in residential, public and commercial buildings.
- In **Transport**, efficiency of conventional vehicles continues to improve in the 2020s (e.g. conventional car emissions fall from 125 gCO_2/km in 2014 to 102g/km in 2020 then 86g/km in 2030), on a test-cycle basis; we allow for 'real world' emissions in our scenarios alongside deployment of electric vehicles across cars, vans and smaller HGVs (e.g. the combination of plug-in hybrids and battery electric vehicles reach 9% of new car and van sales in 2020 and around 60% in 2030). We include hydrogen buses (reaching 25% of sales in 2030), with the possibility of a bigger contribution from hydrogen for other vehicles types. On the demand side we assume some behavioural change results in modest reductions in total distance travelled and more fuel-efficient travel. The Alternative scenarios involve either (i) hydrogen transport technologies achieving widespread deployment across all vehicle types; (ii) use of LNG to fuel HGVs with only modest emissions savings; or (iii) a greater role for demand reduction compensating for barriers to electric vehicle deployment.
- In **Agriculture**, there is increased take-up of crops and soils measures that mainly target the reduction of N_2O through improved fertiliser use efficiency (e.g. use of cover crops and improved manure management practices); livestock measures targeting diets, health, and breeding that reduce methane; waste and manure management, including anaerobic digestion and improvements in the fuel efficiency of stationary machinery.
- In **Waste and F-gases**, five main biodegradable waste streams are fully diverted away from landfill across the UK by 2025, and F-gases are replaced by low-carbon alternatives in refrigeration, air conditioning and other uses by 2030.

The impact of the Central Scenario on abatement by sector and residual emissions is set out in Figure 3.6. Sectors covered by the EU Emissions Trading System (the 'traded' sector - power and energy-intensive industry) are shown in Figure 3.7. Those sectors outside the EU ETS (the 'non-traded' sector - transport, heating in buildings, agriculture) are shown in Figure 3.8.

As noted above, we have also developed Barriers and Max scenarios as one way to help understand whether recommendations properly incorporate future uncertainty. It is likely that some areas will prove more difficult than suggested in the Central Scenario (e.g. costs may not fall as quickly as anticipated) and other areas will prove easier (e.g. new innovation will make it easier to achieve the

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[23] Hybrid heat pumps are heating systems that use a combination of a heat pump and a gas boiler; the heat pump generally provides the heat required, but supplemented by the gas boiler at peak times (i.e. on the coldest winter days).

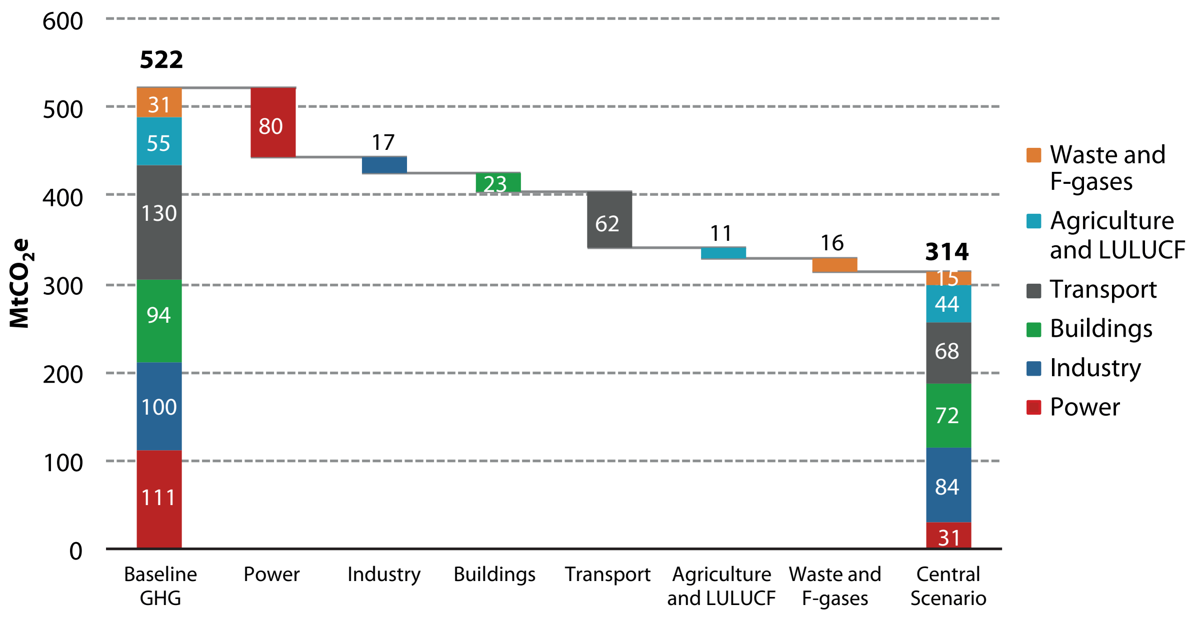
maximum potential). The types of additional barriers or new measures considered in these scenarios are summarised in Table 3.1. Details for each sector are set out in the Technical Report.

Table 3.1: Composition of Barriers and Max sectoral scenario

Sector	Barriers Scenario	Max Scenario
Power	Further delays or failure to roll out nuclear or CCS	Greater deployment of low-carbon generation as costs fall more quickly than anticipated
Industry	Lower uptake of energy efficiency and failure to deploy CCS	Greater electrification in industry and wider adoption of CCS
Buildings	Lower levels of deployment of heat pumps and fewer energy efficiency measures	Greater deployment of low-carbon heat and energy efficiency options
Transport	Reduced uptake of low emissions vehicles	Greater change in travel behaviour, and better alignment of real-world emissions with test cycle
Agriculture	Slow introduction of measures to manage soils and crops, failure to reduce emissions from vehicles	Greater uptake of alternative diets for animals, new crops and more efficient vehicles
Waste and F-gases	More limited diversion of biodegradable waste streams from landfill with less of UK participating in such programmes	No further abatement beyond the Central Scenario due to limited evidence

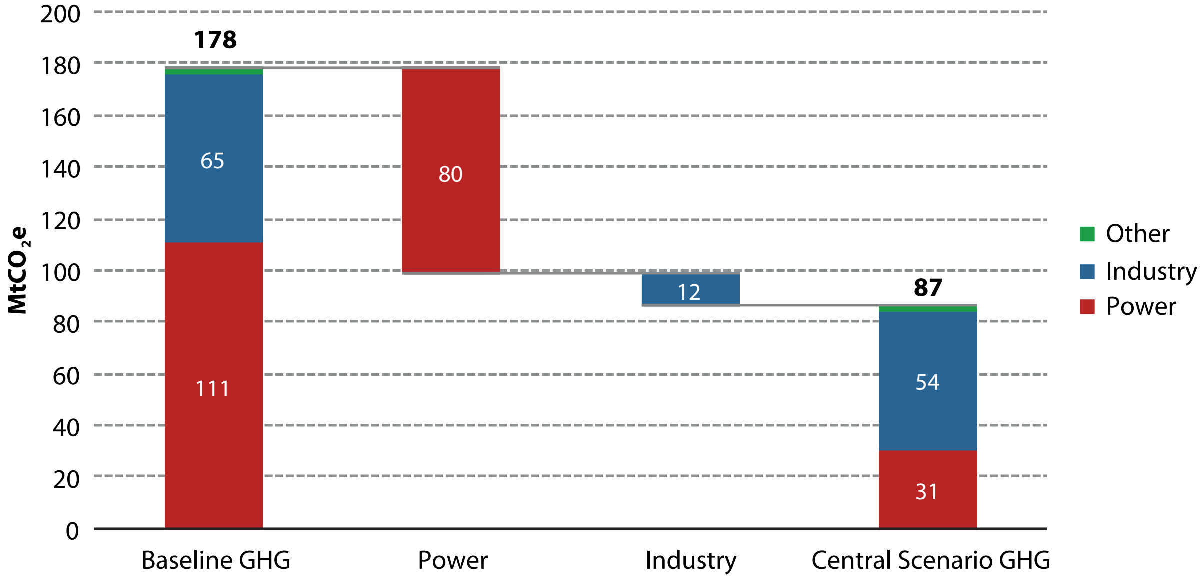
Source: CCC analysis.

Figure 3.6: Abatement in the Central Scenario (total emissions, 2030)



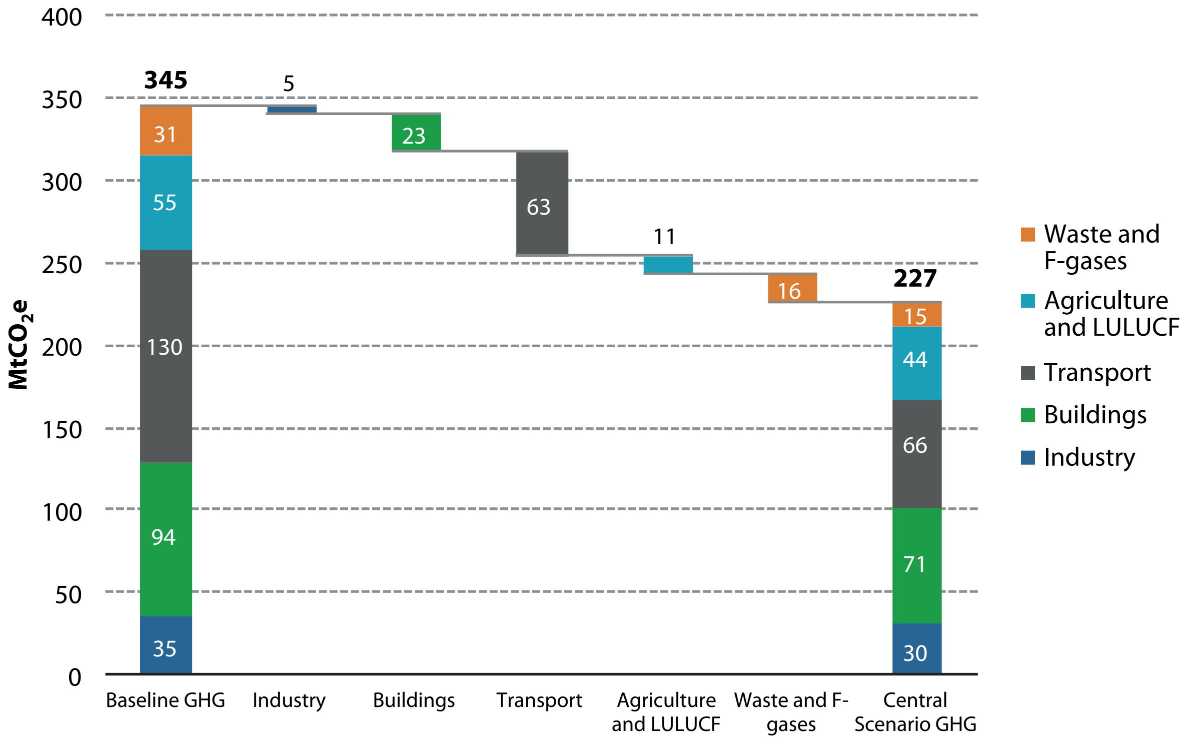
Source: CCC analysis.
Note: The Baseline is a projection of GHG emissions in the absence of absence of further effort to reduce them. Baseline GHG emissions are drawn from Government models and our own modelling at the sector level.

Figure 3.7: Abatement in the Central Scenario (traded sector, 2030)



Source: CCC analysis.
Note: The Baseline is a projection of GHG emissions in the absence of absence of further effort to reduce them. Baseline GHG emissions are drawn from Government models and our own modelling at the sector level. Other includes traded emissions in buildings and transport sectors.

Figure 3.8: Abatement in the Central Scenario (non-traded sector, 2030)



Source: CCC analysis.
Note: The Baseline is a projection of GHG emissions in the absence of absence of further effort to reduce them. Baseline GHG emissions are drawn from Government models and our own modelling at the sector level.

(iii) Economy-wide scenarios

Our central estimate of the emissions path under the Central Scenario implies territorial UK emissions decreasing to 314 $MtCO_2e$ in 2030 (Figure 3.9). This is 61% below 1990 levels, and compares to 61% and 63% reductions in our central 2030 scenarios for the Fourth Carbon Budget, as set out in our original advice in 2010 and our Review in 2013.

The estimated emissions path is subject to considerable uncertainty around macro drivers and their impact on GHG emissions (Box 3.8).

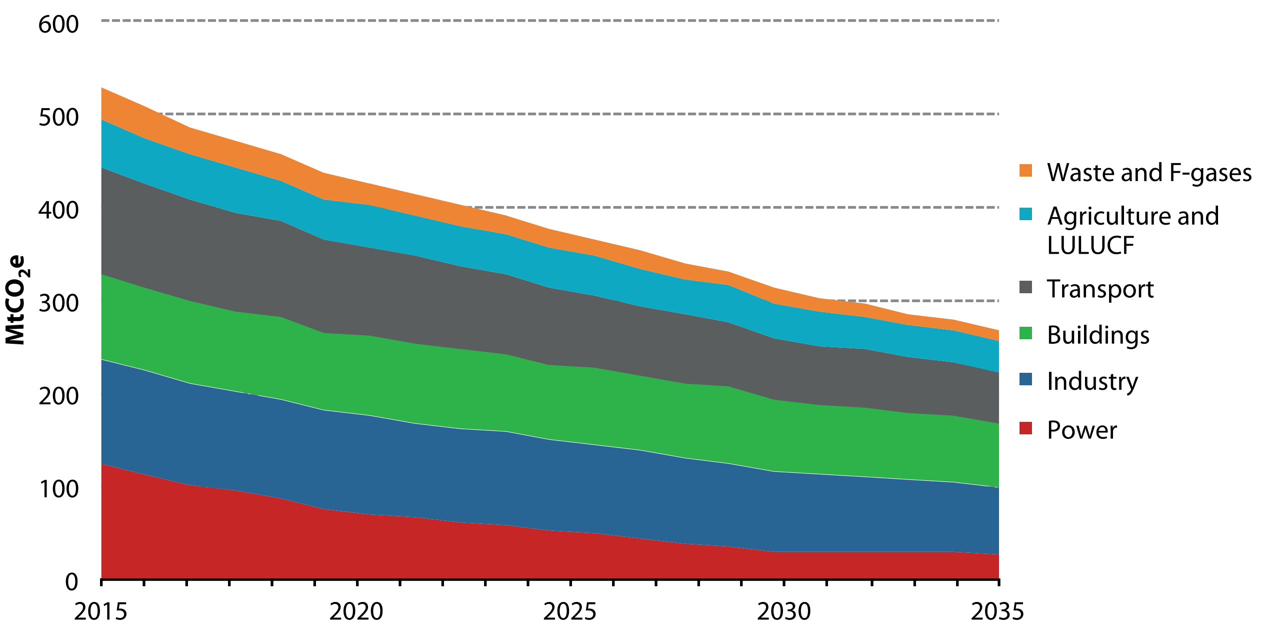
In addition, barriers to deployment of some measures might increase GHG emissions above the Central Scenario emissions path. Should macro drivers or barriers to deployment push emissions upwards, greater levels of emissions reductions consistent with the Max scenarios could compensate for any increase (Figure 3.10).

A combination of all the Max or all the Barriers scenarios would imply total GHG emissions in 2030 of 274 $MtCO_2e$ or 359 $MtCO_2e$ (Figure 3.11), equivalent to 56% or 66% below 1990 levels, respectively.

Under the Central scenario emissions decrease on average around 13 $MtCO_2e$ (3%) per annum between 2014 to 2030, and a further 9 Mt per annum to meet the 2050 target (Figure 3.12). For the non-traded sector (i.e. outside the EU ETS), emissions decrease on average around 6 $MtCO_2e$ (2%) per annum between 2014 and 2030.

We set out the implications of these scenarios for the various criteria in the Climate Change Act in the next chapter and the role of the devolved administrations in Chapter 5.

Figure 3.9: Central Scenario emissions (2015-2035)



Source: CCC analysis.

Box 3.8: Emissions projections and sources of uncertainties identified by Cambridge Econometrics

Emissions projections are inherently uncertain. In addition to the deliverability of measures, and the success of policy instruments to implement those measures, additional uncertainties include: variation in macro drivers of energy demand (population, income, energy prices); the impacts of macro drivers on fuel consumption and GHG emissions; and changes to patterns of energy use that may already be underway but are difficult to identify in the historical data.

We commissioned Cambridge Econometrics (CE) to quantify additional uncertainties in emissions projections[24]. The project identified a range of uncertainties and assessed their potential impact on the emissions path:

- CE developed an alternative emissions projection to DECC's baseline projection (i.e. assuming no policy to reduce GHG emissions) using econometric modelling. For the sectors covered, CE's projection was 4% lower than DECC's in 2035 (though it was higher for some sectors, and significantly lower for others). This variation highlights the impact that different model specification can have on emissions projections. This finding is consistent with the impact of changes to the specification of the DECC model over time: across projections published between 2010 and 2014, DECC's central projection for 2020 has varied by an average of 2%, and by as much as 3% in a single year, due to differences in model specification.
- CE carried out a literature review to identify possible emerging trends in energy consumption that are difficult to identify in a longer period of historical data, and future changes to energy consumption that may be expected to occur, and assessed the likelihood that these current trends or future changes might reasonably be expected to impact the future emissions path. The review identified a range of possible changes to energy demand in the residential sector (the composition of the future housing stock, the use and purchase of appliances, stabilisation of desired room temperatures and demographic factors), industry (the structural composition of industry), and road transport (saturation of road transport demand and improved logistics in the freight sector). CE estimate that the uncertainty range for the impact of these factors is a -13.5% to +4.5% variation in GHG emissions in 2035.
- A comparison of the most recent eight publications of the Digest of UK Energy Statistics (DUKES) identified the scale of revisions to outturn fuel consumption data. Because there is a relationship between current and historical consumption and expected future consumption, any revision to outturn fuel consumption would affect the expected level of future consumption. CE found that data revisions can be significant for coal and bioenergy and waste, but are likely to be small for gas and petroleum. This finding is consistent with the variation in DECC's emissions projections published between 2010 and 2014: due to changes to the UK emissions inventory, DECC's central projection for 2020 has varied by up to 1% in a single year.
- Fuel consumption is affected by a range of factors outside the scope of a forecasting model. CE estimate that the 95% confidence interval for the impact of these factors is a ±6% variation in GHG emissions in 2035; however, the 95% confidence interval for a variation over a 5-year carbon budget period would be expected to be smaller than this.

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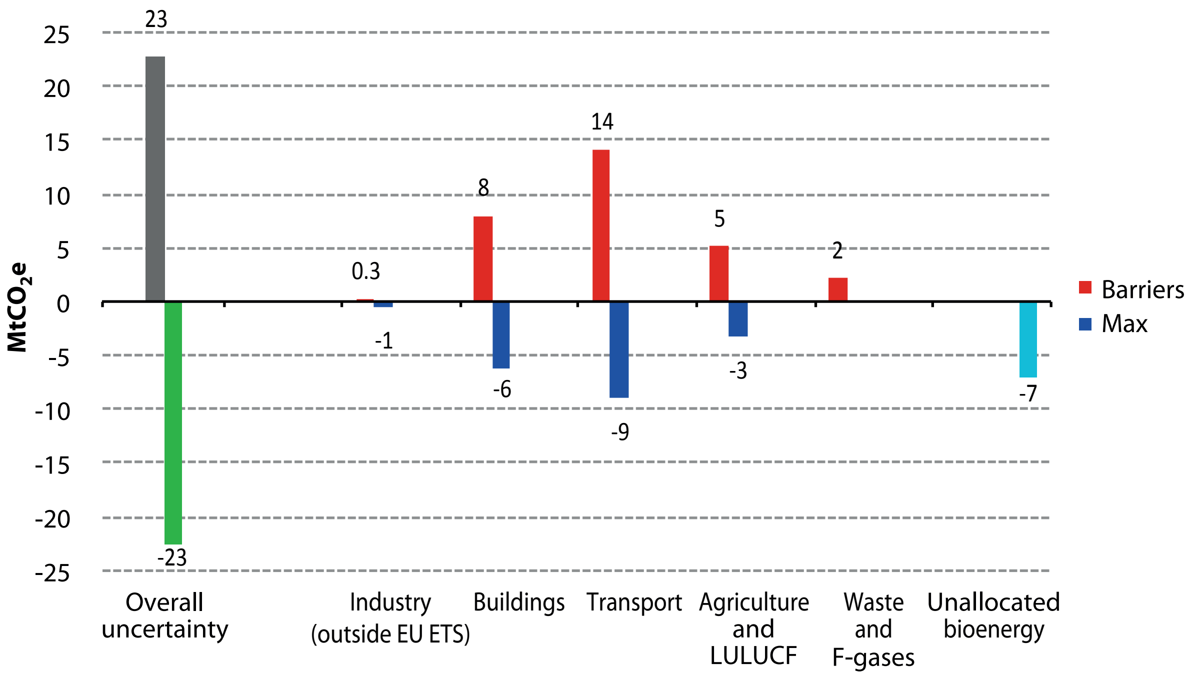
[24] Cambridge Econometrics (2015) *Quantifying Uncertainty in Baseline Emissions Projections*. Available on our website, www.theccc.org.uk

Box 3.8: Emissions projections and sources of uncertainties identified by Cambridge Econometrics

- Variation in macro drivers of energy demand (economic activity, energy prices, external air temperature) would be expected to affect fuel consumption and GHG emissions. CE carried out a Monte-Carlo analysis which found that the 95% confidence interval for the impact of these factors ranges from a -6% to a +7% variation in GHG emissions in 2035 (-8% to +10% in the non-traded sector). DECC estimate a slightly wider uncertainty range of -9 to +8% for the fourth carbon budget period.

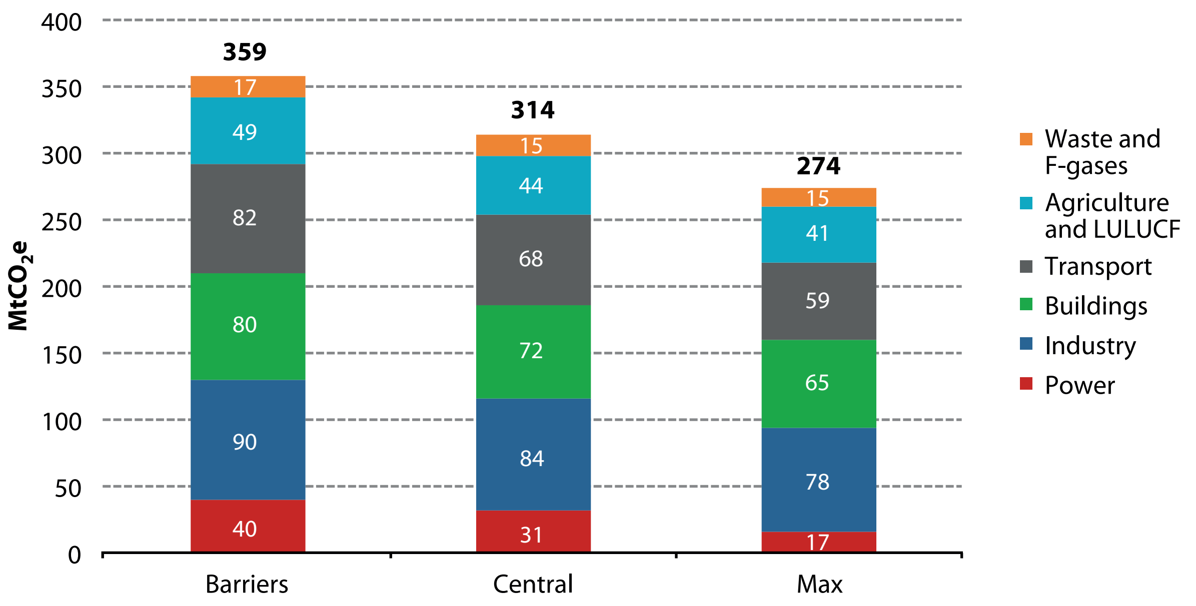
While it is not possible to provide a statistically robust uncertainty range incorporating all the above factors, for illustrative purposes in Figure 3.10 we include a range for overall uncertainty that is up to 10% higher or lower than our central estimates.

Figure 3.10: Impact of uncertainties on 2030 emissions



Source: CCC analysis.
Note: Our scenarios do not use the entire sustainable bioenergy resource estimated to be available to the UK. Further details are given in Chapter 1 of the Technical Report.

Figure 3.11: Total emissions under Barriers, Central and Max scenarios in 2030



Source: CCC analysis.

4. Further progress required from 2033 to 2050

The Central Scenario outlined in the preceding section is designed on the basis of cost-effective emissions reduction to 2032 on the way to meeting the 2050 target. It is not intended to be prescriptive, but is designed to ensure the Committee can satisfy itself that the recommended budget is achievable while meeting the various conditions set out by the Act. In that sense they provide our best assessment now of how to reduce emissions in a cost-effective way in the medium term and prepare for longer-term reductions.

Beyond the fifth carbon budget period, continued emissions reductions will be required at a similar rate across the economy (i.e. an average of around 9 $MtCO_2e$ per year) to the progress embodied in our Central scenario, but with emphasis shifting from power sector decarbonisation towards faster emissions reduction in transport and buildings.

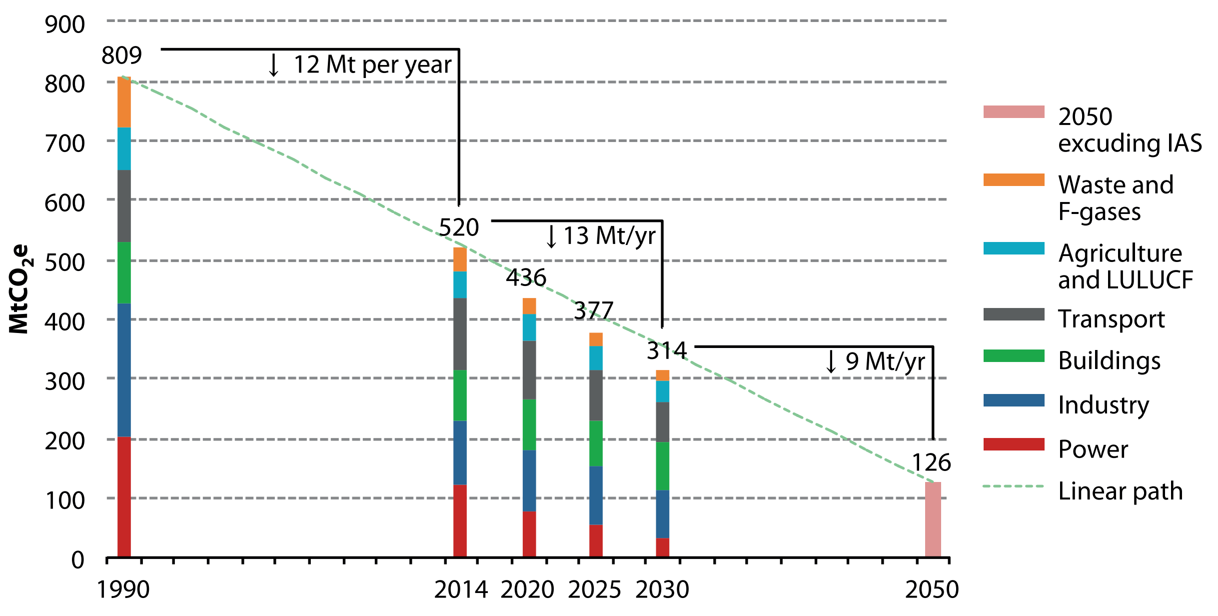
The shape of the emissions path under our scenarios is determined by the set of sector-specific paths, which reflect the different considerations in each case. Our current best assessment of the whole economy cost-effective path to 2050 works out fairly close to a linear reduction in emissions (Figure 3.12).

The Central scenario is designed to keep in play the possibility of emissions reductions in individual sectors towards the ambitious end of the contribution that may be required to meet the overall 2050 target. As set out in section 2, this is appropriate, given that is reasonable to expect that some sectors – although we do not yet know which – could fall short of the level of decarbonisation for which we are currently aiming.

The rate of emissions reduction required after 2032 in the non-traded sector (i.e. outside the EU ETS) will depend on progress in decarbonising the traded sector and limiting emissions from international aviation and shipping (IAS). While the rate of reduction in the non-traded sector embodied in our Central Scenario to 2030 may be similar to that required thereafter, it is also possible that a considerably greater rate of reduction proves necessary (Figure 3.13).

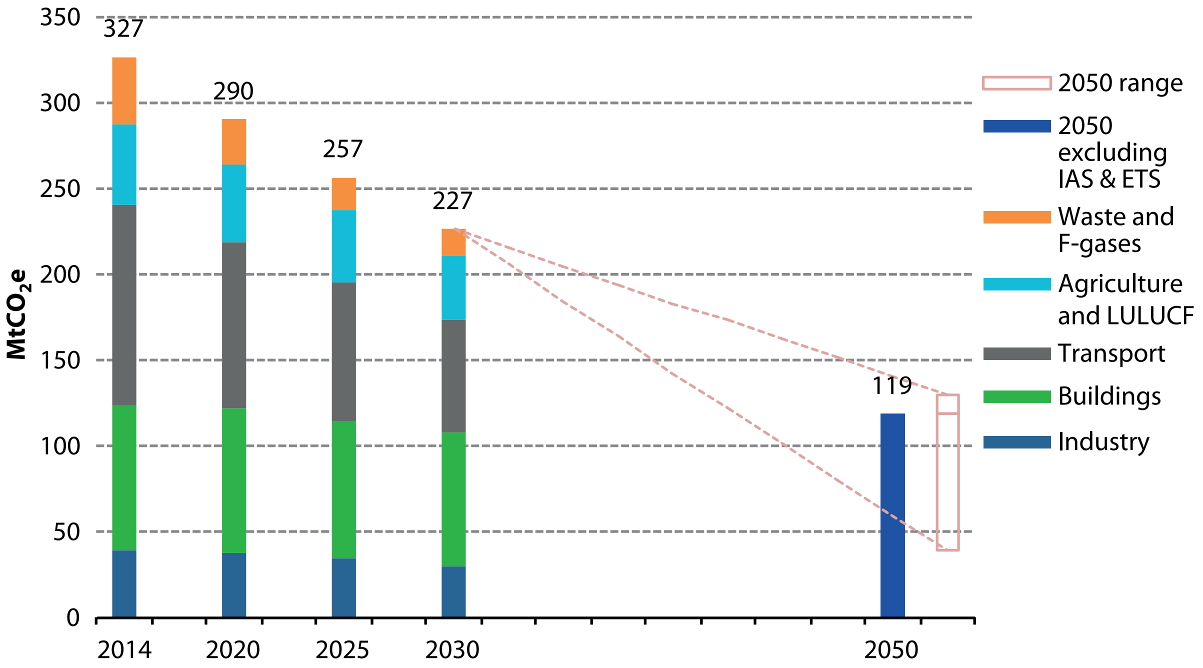
Our approach keeps in play a range of different ways of meeting the 2050 target. A lower level of deployment of measures to prepare for meeting the 2050 target would imply greater risks to, or greater costs of, meeting the 2050 target.

Figure 3.12: Emissions reductions in the Central Scenario and to 2050



Source: CCC analysis.

Figure 3.13: Range of rate of emissions reduction required 2030-50 for non-traded sector cost-effective path compared to 2014-2030



Source: CCC analysis.
Notes: Non-traded sector (NTS) emissions in 2050 based on the CCC's best estimate of their share of emissions in meeting the 2050 target allowing for emissions from international aviation and shipping (IAS) and sectors covered by the EU ETS.. The high end of the range for NTS emissions in 2050 allows for extra emissions due to lower IAS emissions (as in the Max scenarios); the low end of the range allows less emissions due to higher IAS emissions (as in the Barriers scenarios) and the absence of CCS, which lowers abatement in industry and from bioenergy.