Committee on Climate Change

UK climate action following the Paris Agreement

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Contents

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Executive Summary

The Paris Agreement marks a significant positive step in global action to tackle climate change. This report considers the domestic actions the UK Government should take as part of a fair contribution to the aims of the Agreement. Our conclusions are as follows:

- **Do not set new UK emissions targets now.** The UK already has stretching targets to reduce greenhouse gas emissions. Achieving them will be a positive contribution to global climate action. In line with the Paris Agreement, the Government has indicated it intends at some point to set a UK target for reducing domestic emissions to net zero. We have concluded it is too early to do so now, but setting such a target should be kept under review. The five-yearly cycle of pledges and reviews created by the Paris Agreement provides regular opportunities to consider increasing UK ambition.
- **Vigorously pursue the measures required to deliver on existing UK commitments and maintain flexibility to go further.** The most important contribution the Government can make now to the Paris Agreement is publishing a robust plan to meet the UK carbon budgets and delivering policies in line with the plan. Meeting the carbon budgets will require economy-wide improvements to efficiency, decarbonisation of electricity and scaling up of markets for zero-emission vehicles and heating. Current policies, at best, will deliver about half the required reduction in emissions. Acting with urgency to close this policy gap would reduce long-term costs and keep open options for the future. If all measures deliver fully and emissions are reduced further, this would help support the aim in the Paris Agreement of pursuing efforts to limit global temperature rise to 1.5°C.
- **Set out a strategy for developing options to remove greenhouse gases from the air**. Even with full deployment of known low-carbon measures some UK emissions will remain, especially from aviation, agriculture and parts of industry. Greenhouse gas removal options (e.g. afforestation, carbon-storing materials, bioenergy with carbon capture and storage, and direct air capture and storage) will be required alongside widespread decarbonisation in order to reach net zero emissions. Success requires a globally co-ordinated effort across the full chain from basic research to market readiness, reflecting the differing levels of development of removal options. A strategy for deployment at scale by 2050 should start now given the timescales inherent in bringing new technologies to market.

We agree with the Government's intention to set a new target in future that reflects the global need to reach net zero emissions. However, to be credible it needs to be evidence-based, accompanied by strong policies to deliver existing targets and a strategy to develop greenhouse gas removals. Early action will allow the UK to fulfil its commitment under the Paris Agreement and position it to take competitive advantage in the global shift to a zero-carbon world.

The rest of this summary is set out in four sections:

1. UK and international ambition
2. Net zero emissions
3. Strategies for hard-to-treat sectors and greenhouse gas removals
4. Implications for UK policy priorities in the nearer-term

1. UK and international ambition

In December 2015 the UK, under the UN negotiations and alongside over 190 other countries, drafted the Paris Agreement to tackle climate change. It will enter into force by the end of 2016 having been ratified by the US, China, India, Brazil, the EU and others.

The Agreement describes a higher level of global ambition than the one that formed the basis of the UK's existing emissions reduction targets:

- The UK's current long-term target is a reduction in greenhouse gas emissions of at least 80% by the year 2050, relative to 1990 levels. This 2050 target was derived as a contribution to a global emissions path aimed at keeping global average temperature to around 2°C above pre-industrial levels.
- The Paris Agreement aims to limit warming to well below 2°C and to pursue efforts to limit it to 1.5°C. To achieve this aim, the Agreement additionally sets a target for net zero global emissions in the second half of this century.

Alongside the Agreement nearly all parties have submitted pledges of action to 2030. Current pledges fall short of a path to meet either the stated temperature aim of the Paris Agreement or the implicit aim behind the UK target. However, the Agreement includes a process for taking stock of progress and increasing action around the world:

- Pledges by parties in total imply annual global emissions in 2030 of 56 billion tonnes of carbon dioxide equivalent ($GtCO_2e$) whereas the parties to the Agreement agreed the need to reduce annual emissions to 40 $GtCO_2e$ to be on a path to below 2°C.
- The Agreement creates a 'ratchet' mechanism of pledges and reviews to facilitate parties increasing their ambition towards the temperature target. A UN dialogue to take stock of current pledges will take place in 2018. Starting in 2020 parties will provide new pledges every five years, with stocktakes of the pledges occurring every five years from 2023.
- Parties are also asked to publish mid-century, long-term low greenhouse gas emission development strategies by 2020.

We welcome the Government's commitment to ratifying the Paris Agreement by the end of the year. The clear intention of the Agreement is that effort should increase over time. While relatively ambitious, the UK's current emissions targets are not aimed at limiting global temperature to as low a level as in the Agreement, nor do they stretch as far into the future.

2. Net zero emissions

Global temperature rise is a function largely of cumulative carbon dioxide emissions over time, meaning carbon dioxide emissions will need to fall to net zero in order to stabilise temperature. Some other greenhouse gas emissions may not need to fall to zero but will require very deep reductions in order to reach the temperature aims in the Paris Agreement:

- Global temperature rise depends primarily on cumulative emissions of CO_2 and other very long-lived greenhouse gases (e.g. nitrous oxide and some F-gases). Temperature limits will therefore only be met if emissions of these gases reach net zero. Other, shorter-lived gases (e.g. methane) drive temperature by their rate of emission. The lower the emission rates, the greater the available cumulative budget for the very long-lived gases.

- Emissions pathways indicate that CO_2 emissions will need to reach net zero by the 2050s-70s, along with deep reductions of all other greenhouse gases, in order to stay below 2°C. To stay close to 1.5°C CO_2 emissions would need to reach net zero by the 2040s (Table 1).
- The timescales above assume global emissions start to fall from 2020. If reductions are delayed further, subsequent reductions will need to be faster and net zero emissions will need to be reached sooner to satisfy the cumulative CO_2 budget.
- Furthermore, the timescales above assume global net CO_2 emissions can go net negative later in the century through removals of billions of tonnes of CO_2 per year from the air (Box 1). This would imply that total emissions of greenhouse gases (CO_2 plus non-CO_2 emissions measured as CO_2-equivalent) fall to net zero before 2100. If such future removals are not feasible, CO_2 emissions would need to reach net zero about a decade earlier.

Table 1. Timescales for reaching global net zero emissions consistent with Paris Agreement aims

Level of ambition	**Decade of global net zero emissions**	
	Carbon dioxide only	**All greenhouse gases**
Return to 1.5°C	2040s	2060s-2080s
Below 2°C	2050s-2070s	2080s-2090s

Notes: Timescales are based on cost-optimal pathways from integrated global economy-climate models. All pathways assume global action is limited before 2020 and CO_2 emissions can go net negative before 2100. "Below 2°C" pathways have at least a 66% likelihood of avoiding 2°C altogether, while "Return to 1.5°C" pathways have at least a 50% likelihood of reaching 1.5°C in 2100 after earlier temperature overshoot. No model paths are currently published that remain below 1.5°C at all times. "All greenhouse gases" denotes the basket of Kyoto gases (including CO_2) summed as CO_2-equivalent using the standard 100-year Global Warming Potential metric.

Box 1. Greenhouse gas removals

Greenhouse gas removal (GGR) technologies are ways to reduce the level of carbon dioxide and other greenhouse gases in the air. We already include three such options in our UK scenarios to 2050: bioenergy with carbon capture and storage, afforestation and wood in construction. The full range of potential GGR options is wide and diverse, including management of soils and habitats, biochar, direct air capture and storage, carbon-storing cements and plastics, enhanced mineral weathering and methods for storing carbon in the oceans.

Some GGR options are already well-understood and deployed at scale, such as afforestation and wood in construction. Others are at much earlier demonstration stages, such as bioenergy with carbon capture and storage and direct air capture. The overall costs, effectiveness and feasibility of GGR options are highly uncertain. In addition, options have a variety of potential co-benefits (such as energy generation or improved crop yields) and risks (such as competition with food production) to consider when deciding which may be the best options to deploy at scale.

GGR globally and in the UK will be central to realising the Paris aim of balancing greenhouse gas sources and sinks from human activities, given the difficulty of removing all sources.

There is no single agreed way to define fair contributions of effort between nations. However, it is hard to envisage the UK continuing as a net emitter for longer than the rest of the world:

- The UK's existing long-term target is based on the judgment that it should be no more than an average emitter in per person terms by 2050 on a global 2°C path. On this rationale the UK would need to reach net zero emissions no later than the world as a whole (Table 1).
- Other methods for defining a fair UK contribution out to 2050 on a 2°C path nearly all point to more ambitious action than the existing targets. They would therefore suggest the UK reaching net zero before the world as a whole. Currently, however, few of these methods have been calculated specifically for the timing of net zero emissions or for a 1.5°C path.
- Emissions trading and other forms of international assistance are important ways for the UK to contribute in addition to domestic action (e.g. the UK has already committed £5.8 billion to the International Climate Fund). In the long run, if all countries are taking stringent action, it is unclear whether reductions elsewhere will be cheaper or more expensive than domestic reductions. However, future markets could be a key source of flexibility in meeting a net zero target, especially if removal technologies are scaled up successfully around the world.

We currently have no scenarios for how the UK can achieve net zero domestic emissions. Alongside widespread efficiency improvements and deployment of zero-carbon energy sources, net zero would require greenhouse gas removals of over 100 $MtCO_2e$ per year (UK emissions were around 500 $MtCO_2e$ per year in 2015):

- The UK's 2050 target to reduce emissions at least 80% from 1990 (i.e. to around 160 $MtCO_2e$ per year) is challenging but can be met in various ways using currently known technologies. Scenarios generally involve deep reductions in emissions from power, heating and transport, where zero-carbon options already exist. More challenging sectors (especially agriculture, aviation and industry) are currently not expected to reach zero emissions on this timescale.
- A full and successful roll-out of all options identified in our published scenarios to 2050 would lead to greenhouse gas emissions just over 90% lower than 1990, and CO_2 emissions close to zero.
- These options include greenhouse gas removals from afforestation, bioenergy with carbon capture and storage (BECCS) and wood in construction. Together they remove up to 70 $MtCO_2$ per year within the limits to sustainable bioenergy supply we have identified.
- Achieving net zero emissions of all greenhouse gases on these timescales would require a combination of further greenhouse gas removals and further breakthroughs in hard-to-treat sectors, going beyond those already in our scenarios. Without further breakthroughs in emissions sources, UK removals would need to be over 100 $MtCO_2e$ per year.

Reaching net zero emissions will be a global necessity in order to limit climate change. Achieving it on the timescales necessary to meet the aims of the Paris Agreement will be very challenging for all nations. Given current uncertainties around domestic feasibility, inclusion of non-CO_2 emissions and ambition of other countries to reach zero, it makes sense at this point to remain flexible on how best to reflect the aim of global net zero emissions in a UK target. Addressing these uncertainties will help in setting a robust target which provides the right incentives.

3. Strategies for hard-to-treat sectors and greenhouse gas removals

Even with full deployment of known low-carbon technologies and behaviours some UK emissions will remain, especially from hard-to-treat sectors: aviation, agriculture and parts of industry. Reaching net zero (and possibly net negative) emissions will require technologies to remove greenhouse gases. The UK should pursue a strategy to develop options in both hard-to-treat sectors and greenhouse gas removals, domestically and in collaboration with wider global efforts (for instance Mission Innovation and the Breakthrough Energy Coalition).

A diverse range of potential removal technologies exists. Currently they face low levels of funding and policy support, without an overall national or international strategy to develop them. Such a strategy should include the following components:

- **Support for research, development and demonstration** to help clarify whether options deliver genuine long-term greenhouse gas removal and to address technical, environmental and social challenges. Examples include improving measurement of land carbon, assessing impacts over the lifecycle of bioenergy crops and biochar, and testing of direct air capture processes.
- **Support for deployment** by removing barriers and providing incentives for options that are technically more mature. Targeted deployment can help in bringing down costs and understanding more about impacts. Examples for deployment include carbon capture and storage infrastructure, sustainable bioenergy crops, afforestation and wood in construction.
- **Integration into policy and accounting frameworks** so that removals count equally with reduction of emissions. The lack of long-term policy commitment is a key barrier to development. Schemes such as the EU Emissions Trading System (ETS) and the Common Agricultural Policy (CAP) could be structured to reward removals but currently are not.

The current challenges to removal technologies at scale mean they are not a substitute for widespread deployment of zero-emission technologies:

- All removal technologies have requirements in terms of land, energy and other resources. Achieving removal levels of over 100 $MtCO_2e$ per year in the UK will be very stretching.
- Reducing residual sources of emissions to close to 100 $MtCO_2e$ per year would require stretching options in hard-to-treat sectors, such as substantial biofuel use in aircraft and reduced red meat consumption in diets.

Finding ways to further reduce residual emissions from aviation, agriculture and industry is therefore an innovation priority. Options could, for example, include support for new technologies, products and innovation in each of these areas and shifting demand to lower-emissions alternatives (e.g. increased re-use of products and materials, and further shifts towards virtual conferencing in place of international travel).

Given the very low levels of funding and policy support for removal technologies at present, there is potential for UK efforts to have a significant international impact and to secure a UK leadership position in this area.

4. Implications for UK policy priorities in the nearer term

Current policy in the UK is not enough to deliver the existing carbon budgets that Parliament has set. The Committee's assessment in our 2016 Progress Report was that current policies would at best deliver around half of the emissions reductions required to 2030, with no current policies to address the other half. This carbon policy gap must be closed to meet the existing carbon budgets, and to prepare for the 2050 target and net zero emissions in the longer term.

The existing carbon budgets are designed to prepare for the UK's 2050 target in the lowest cost way as a contribution to a global path aimed at keeping global average temperature to around 2°C. Global paths to keep close to 1.5°C, at the upper end of the ambition in the Paris Agreement, imply UK reductions of at least 90% below 1990 levels by 2050 and potentially more ambitious efforts over the timescale of existing carbon budgets.

However, we recommend the Government does not alter the level of existing carbon budgets or the 2050 target now. They are already stretching and relatively ambitious compared to pledges from other countries. Meeting them cost-effectively will require deployment to begin at scale by 2030 for some key measures that enable net zero emissions (e.g. carbon capture and storage, electric vehicles, low-carbon heat). In theory these measures could allow deeper reductions by 2050 (on the order of 90% below 1990 levels) if action were ramped up quickly.

The priority for now should be robust near-term action to close the gap to existing targets and open up options to reach net zero emissions:

- The Government should publish a robust plan of measures to meet the legislated UK carbon budgets, and deliver policies in line with the plan.
- If all measures deliver fully and emissions are reduced further, this would help support the aim in the Paris Agreement of pursuing efforts to limit global temperature rise to 1.5°C.
- The Government should additionally develop strategies for greenhouse gas removal technologies and reducing emissions from the hardest-to-treat sectors (aviation, agriculture and parts of industry).

There will be several opportunities to revisit the UK's targets in future as low-carbon technologies and options for greenhouse gas removals are developed, and as more is learnt about ambition in other countries and potential global paths to well below 2°C and 1.5°C:

- 2018: the Intergovernmental Panel on Climate Change (IPCC) will publish a Special Report on 1.5°C, and there will be an international dialogue to take stock of national actions.
- 2020: the Committee will provide its advice on the UK's sixth carbon budget, including a review of progress to date, and nations will publish mid-century greenhouse gas development plans.
- 2023: the first formal global stocktake of submitted pledges will take place.

We will advise on whether to set a new long-term target, or to tighten UK carbon budgets, as and when these events or any others give rise to significant developments.

Further analysis underpinning these recommendations is set out in the four chapters of this report:

1. Current UK ambition and the Paris Agreement
2. Implications of Paris ambition for emissions in 2050 and beyond
3. Feasibility of the UK taking more ambitious domestic action
4. Considerations in setting UK policy to reflect Paris ambition

Chapter 1: Current UK ambition and the Paris Agreement

Key messages

This chapter summarises the level of ambition in limiting climate change that underpins the UK's existing emissions targets, and the level of ambition agreed by nations (including the UK) at the international negotiations in Paris in December 2015.

Our key messages are:

- The UK's current long-term target is a reduction in greenhouse gas emissions of at least 80% by the year 2050, relative to 1990 levels. This 2050 target was derived as a contribution to a global emissions path aimed at keeping global average temperature to around 2°C above pre-industrial levels.
- The Paris Agreement aims to limit warming to well below 2°C and to pursue efforts to limit it to 1.5°C. This is more ambitious than both the ambition underpinning the UK 2050 target and previous international agreements.
- The Paris Agreement additionally sets a new long-term target for net zero global emissions ("a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases") in the second half of this century.
- If the world follows a pathway with a 66% likelihood of staying below 2°C then the likelihood of staying below 1.5°C would be low (around 20%). Limiting warming to 1.5°C would help avoid some key significant negative impacts from climate change, but not all.
- Current pledges of action by nations to 2030 fall short of both the stated temperature aim of the Paris Agreement and the implicit aim behind the UK target. However, the Agreement includes a process for taking stock of progress and increasing action around the world.

1. The UK 2050 emissions target and associated warming

The Climate Change Act (2008) sets the framework for UK efforts to reduce emissions. Written into the Act is a limit for UK emissions in 2050: they should be at least 80% below the level in 1990. This limit was designed as a contribution to halving global greenhouse gas emissions by 2050, broadly consistent with keeping global average temperature rise close to 2°C above pre-industrial levels and keeping the chance of an extreme 4°C warming to very low levels:[1]

- The Climate Change Act was passed in 2008, containing the 2050 target of at least an 80% reduction in emissions below 1990 levels based on advice from the Committee that year.
- We based our advice on a proposed global objective to keep central estimates of global temperature in 2100 close to 2°C above pre-industrial levels (i.e. a risk of exceeding 2°C of around 50%), and keep the probability of a 4°C rise to very low levels (e.g. 1%).
- Pathways we analysed that met these temperature goals showed global emissions peaking before 2020 and then falling thereafter to 2100, such that they are in the region of 20-24 billion tonnes of CO_2-equivalent ($GtCO_2e$) by 2050 (emissions in 2010 were 49 $GtCO_2e$).
- We stated that it was difficult to envisage a global climate deal which allows the UK to emit much more per person than the global average in the long run. The 2050 target of at least an 80% cut below UK emissions in 1990 follows from applying this per person average (i.e. 2.1-2.6 tCO_2e per person) to the UK in 2050, accounting for expected population growth.

[1] CCC (2008) *Building a low-carbon economy - the UK's contribution to tackling climate change*

The UK 2050 target is potentially consistent with a wide range of global temperature outcomes:

- Temperature depends principally on cumulative emissions of long-lived greenhouse gases (especially carbon dioxide) over time. Hence nearer-term reductions below the assumed global emissions path will lower warming, as would deeper reductions after 2050.
- Warming depends on global greenhouse gas emissions, and the UK currently contributes around 1% of the global total per year. Other nations may not reach the same level of emissions per person in 2050. To the extent their emissions are different, total global emissions, and hence warming, will be different.

The IPCC suggests a lower temperature could be achieved for the level of global emissions we assumed in 2050. This relies on the option of reaching net negative global CO_2 emissions after 2050, which was not included in our scenarios. We do not yet know if such cuts will be feasible:

- The most recent IPCC assessment, drawing on a wider range of more detailed evidence than our 2008 report, concluded that paths consistent with at least a 66% chance of staying below 2°C would have global emissions in 2050 of 15-29 $GtCO_2e$. Hence the global level of 20-24 billion tonnes underpinning the UK 2050 target could be consistent with a lower central estimate of temperature than we assumed (i.e. below 2°C).
- This difference (and the large range in the IPCC scenarios) is mainly because many pathways used by the IPCC include the option of large-scale greenhouse gas removal, especially after 2050. For instance, IPCC scenarios average 610 $GtCO_2$ removed from the air during the century using bioenergy with carbon capture and storage (BECCS), with some scenarios as high as 1320 $GtCO_2$. The models generating these scenarios have only rudimentary constraints on BECCS deployment. We discuss the challenges and opportunities for emissions removals in Chapter 3.
- There is uncertainty over the maximum level of greenhouse gas removal that should be planned for, with some evidence suggesting tighter limits on BECCS. For instance, total removals by BECCS could be no more than about 480 $GtCO_2$ after accounting for the land-use emissions from growing bioenergy crops.[2] Other social and technical factors may well limit BECCS further.

In summary, the UK 2050 target was set to align to around a 50% likelihood of limiting temperature increase to 2°C, but could be consistent with around a 66% likelihood. This higher probability depends on other countries following a similar level of ambition to 2050 (e.g. to reach 2.1-2.6 tCO_2e per person) and large emissions removals beyond 2050.

2. How the 2050 target guides near-term action

The 2050 target guides the setting of carbon budgets (five-year limits to UK emissions). These are legislated to reach the 2050 limit cost-effectively and meet other criteria set out in the Act:

- There are five carbon budgets currently set in legislation. The first, covering the period 2008-12, was met successfully. The fifth carbon budget covers 2028-32 and is equivalent to a 57% reduction below 1990 levels (Table 1.1). Emissions in 2015 were 38% below 1990 levels.

[2] Wiltshire et al. (2015) *Planetary limits to BECCS negative emissions*, AVOID 2 WPD.2a Report 1

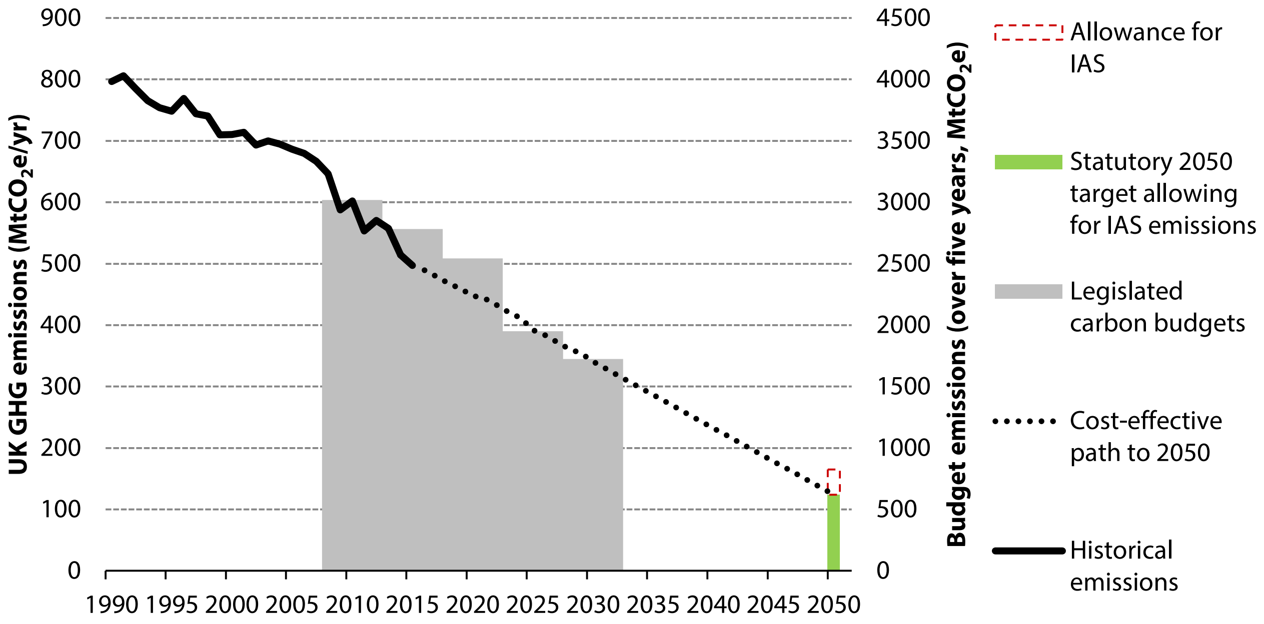
- Carbon budgets must be set with a view to meeting the 2050 target, accounting for factors such as economic and social circumstances, energy security, competitiveness, international circumstances and differences across the devolved administrations.

Table 1.1. Currently legislated UK carbon budgets

Carbon budget (years)	Emissions limit ($MtCO_2e$)	Equivalent reduction vs. 1990
1 (2008-12)	3,018	26%
2 (2013-17)	2,782	32%
3 (2018-22)	2,544	38%
4 (2023-27)	1,950	52%
5 (2028-32)	1,725	57%

Figure 1.1 sets out our best estimate of the cost-effective path to the 2050 target, which underpins the carbon budgets. Overall the path is broadly linear to 2050, although this involves action that is more front-loaded in some sectors and more back-loaded in others.

Figure 1.1. UK carbon budgets and the cost-effective path to the 2050 target

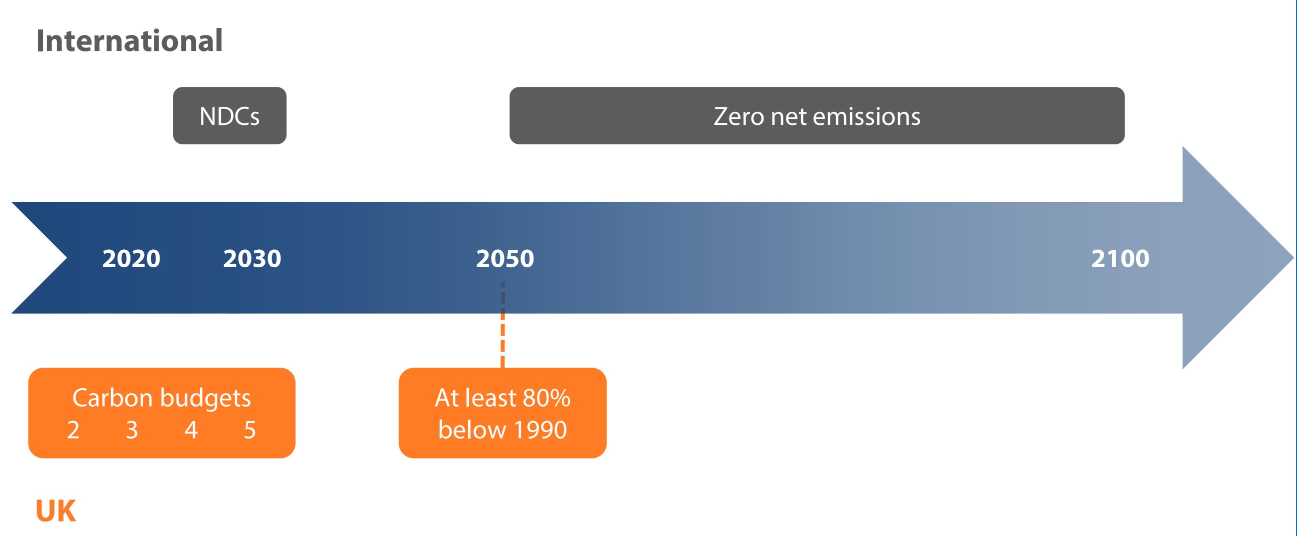


Source: CCC calculations.
Notes: Historical emissions are on a 'gross' basis (i.e. actual emissions). Carbon budgets are on the current budget accounting basis, excluding international aviation and shipping (IAS), but allowing for IAS in the 2050 target.

3. The Paris Agreement

While the UK and other countries have set domestic legislation, international negotiations on climate change have been ongoing. The Paris Agreement, reached at the end of 2015, is the first truly global effort to reduce emissions. It also sets more ambitious limits to warming than previously agreed, and a new long-term aim for global emissions (Figure 1.2). Pledges of action by nations to 2030, however, are not yet in line with that ambition.

Figure 1.2. Timeline of international and UK emissions targets under the Paris Agreement and the Climate Change Act



Notes: NDCs = Nationally Determined Contributions (i.e. pledges of action from parties to the Paris Agreement).

International negotiations on climate change are governed through the United Nations Framework Convention on Climate Change (UNFCCC, Box 1.1). In 2008, when the UK legislated the Climate Change Act, there was neither a UNFCCC-agreed, quantitative goal for limiting climate change, nor a universal effort to reduce emissions.

The Paris Agreement marks a number of new developments in international climate policy, including commitments to reduce emissions from around the world, a more ambitious aim for limiting temperature, and an aim to reach net zero global emissions this century:[3]

- The overarching aim of the Paris Agreement is to hold the increase in global temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit it to 1.5°C. There has been relatively little work to date to quantify climate impacts at 1.5°C. Overall, they are expected to be lower than at 2°C, but still substantial in places (Box 1.2).
- To achieve this temperature limit, it sets the aim of balancing "anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (i.e. a 100%reduction in net global emissions by 2050-2100).

[3] FCCC/CP/2015/L.9/Rev.1, http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Note the Paris Agreement addresses goals beside long-term ambition, such as adaptation and finance, which are not the focus of this report.

Box 1.1. Past milestones in the UNFCCC process

The UNFCCC took effect in 1994, and currently 196 countries plus the EU are party to it.

The overarching goal of the UNFCCC is to "prevent dangerous anthropogenic interference with the climate system… within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner."

The Kyoto Protocol, agreed in 1997, set quantitative limits to emissions but only for industrialised nations. The UK for instance was set a target of a 12.5% reduction by 2008-12 (within an EU-wide target of 8%) which it met.

The "dangerous" level to be prevented was not formally quantified until the Cancun Agreements in 2010. Here the aim was to hold the increase in global temperature below 2°C above pre-industrial levels, requiring deep cuts in global greenhouse gas emissions. In addition, the Agreement recognised the need to consider strengthening this goal to 1.5°C.

Source: United Nations Framework Convention on Climate Change, http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf; FCCC/CP/1997/7/Add.1, http://unfccc.int/resource/docs/cop3/07a01.pdf; FCCC/CP/2010/7/Add.1, http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf.

Box 1.2. Global climate impacts at 1.5°C compared to 2°C and higher temperatures

Studies directly comparing climate impacts at 1.5°C to those at other temperatures are only just starting to emerge in response to the Paris Agreement.

We commissioned the AVOID2 consortium to quantify potential global-scale impacts across a range of sectors at 1.5°C as well as 2°C, 3°C and 4°C above pre-industrial levels in 2100. Wide ranges of impacts are found at each temperature level due to the differences in future regional climates projected by climate models. Even for moderate warming, the upper ends of the ranges point to the possibility of very substantial damages. For most indicators, as expected, impacts are less in a 1.5°C world than in a 2°C world, but the change in impact with temperature varies across sectors:

- Little difference is projected between 1.5°C and 2°C in terms of total land area suitable for crop growing. In both cases around 15-30% of global land becomes more suitable while around 20-45% becomes less so. At higher levels of warming greater areas become less suitable while fewer areas become more suitable.
- Numbers of people affected by coastal flooding are projected to rise, even assuming defences continue to improve with rising population and wealth. The central estimates of numbers affected in 2100 at 2°C, 3°C and 4°C are a factor of three, eight and 13 higher than at 1.5°C, respectively.
- Exposure to extreme heat stress also rises exponentially. While very extreme stress (defined as risk of death even for healthy people at rest) is eliminated below 2°C, the number of people exposed to extreme stress (when those conducting heavy labour are at risk) is almost doubled above current levels at 1.5°C, and almost trebled at 4°C.
- At 4°C around 50-65% of plant and amphibian species, and around 25-40% of bird and mammal species, are expected to lose at least half of their suitable climatic range. At 1.5°C these are reduced to roughly 10-20% and 5-15% respectively. Notably coral reefs are essentially all expected to be subject to annual bleaching (and hence loss) beyond 2°C, while at 1.5°C some of them will be at lower risk (Schleussner et al., 2016).

Box 1.2. Global climate impacts at 1.5°C compared to 2°C and higher temperatures

These estimates are incomplete. They only consider a subset of potential impacts (excluding supply chains, finance and security, for instance); are based on models which may not capture potentially important nonlinear shifts in climate (Schellnhuber et al., 2016); and do not consider the compound effects of impacts occurring together. But they indicate the variety of expected impacts and the wide range of estimates, including the possibility of substantial damages, even for moderate warming.

Source: Arnell et al. (2016) *The global impacts of climate change under a 1.5°C pathway: supplement to assessment of impacts under 2, 3 and 4°C pathways*, AVOID 2; Schleussner et al. (2016) *Differential climate impacts for policy-relevant limits to global warming:the case of 1.5°C and 2°C*, Earth System Dynamics; Schellnhuber et al. (2016) *Why the right climate target was agreed in Paris*, Nature Climate Change.

- Each party is asked to make a national pledge to contribute to emissions reduction, reflecting "common but differentiated responsibilities and respective capabilities, in the light of different national circumstances."
- Nearly all parties made pledges, either to 2025 or 2030. For example, the EU (on behalf of the UK and the other EU nations) pledged to reduce its emissions by at least 40% below 1990 levels by 2030. In total these pledges now cover over 99% of global territorial emissions (i.e. excluding the 2% of emissions from international aviation and shipping, which are the subject of separate negotiations[4]).

In order to assess global emissions paths, we interpret the temperature aims in the Paris Agreement to range from (at minimum) a 66% likelihood of staying below 2°C, to (at maximum) a 50% likelihood of staying below 1.5°C:

- Previous international statements referred to the aim of staying below 2°C, without stating explicitly what likelihood of exceeding 2°C is acceptable.
- In practice, many studies have taken this to mean at least a 66% likelihood of staying below 2°C, given the spread in uncertainty in how the climate system responds to emissions. Others have also considered at least a 50% likelihood,[5] closer to the original logic underpinning the UK 2050 target.
- A similar judgment will be required about the likelihood consistent with the Paris Agreement of staying "well below 2°C". Given the interpretation of "below 2°C", it is hard to see this meaning less than a 66% likelihood of 2°C.
- Pathways with a 66% likelihood of staying below 2°C have a 50% likelihood of staying below 1.8°C and a roughly 20% likelihood of staying below 1.5°C, based on current estimates of the range of climate-system uncertainty. Conversely, pathways with a 50% likelihood of staying below 1.5°C have about an 80% likelihood of staying below 2°C.[6]

[4] Negotiations on shipping emissions take place under the International Maritime Organization (IMO) while those on aviation emissions take place under the International Civil Aviation Organization (ICAO)
[5] UNEP (2015) *The emissions gap report 2015*
[6] Schleussner et al. (2016) *Science and policy characteristics of the Paris Agreement temperature goal*, Nature Climate Change

- Very few published studies have looked at global pathways with more than a 50% likelihood of staying below 1.5°C (see Chapter 2). These are considered extremely ambitious. We therefore interpret this as the upper limit of Paris ambition.

Current pledges of action to 2030 do not together add up to a credible pathway to achieve either 2°C or more ambitious temperature aims. Recognising this, the Paris Agreement creates a "ratchet" mechanism designed to encourage greater action over time:

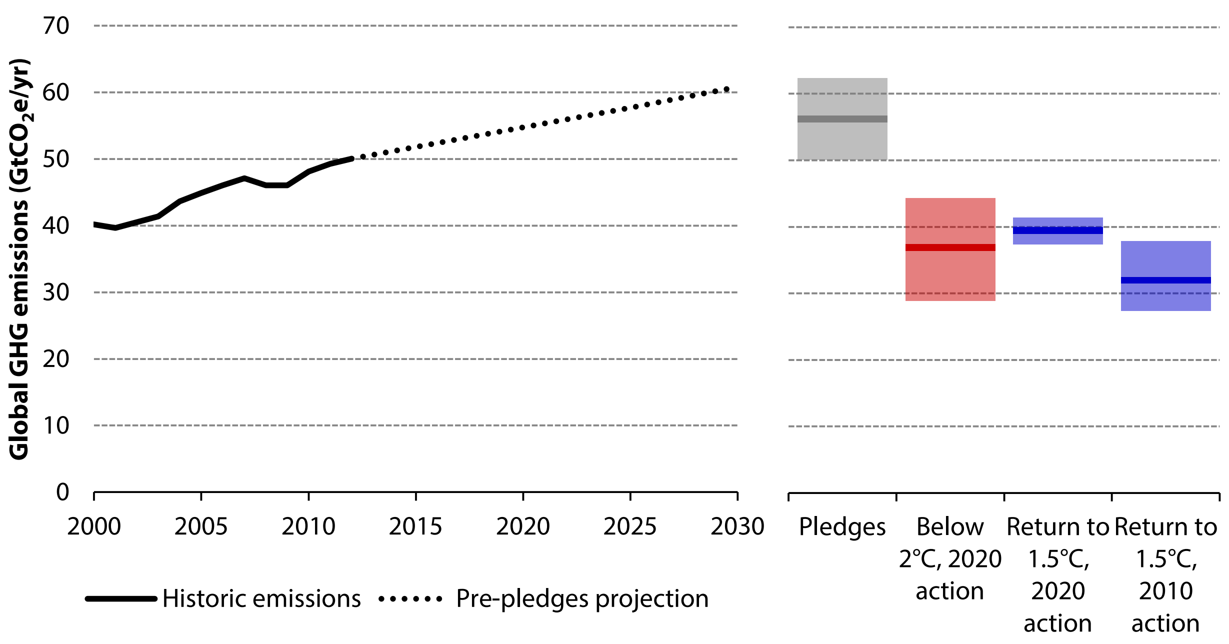
- The pledges indicate a wide range of ambition from different nations. The UK currently participates in the negotiations as part of the EU, which submitted a pledge to reduce EU-wide emissions to 40% below 1990 levels by 2030.
- In aggregate, achievement of the pledges would lower emissions compared to previous expectations, but they would still grow from current levels to around 56 $GtCO_2e$ in 2030. Such a path is not consistent with cost-effective paths in the literature to 2°C or below (Figure 1.3).
- Parties to the Paris Agreement recognised 40 $GtCO_2e$ in 2030 as the global emissions level consistent with a path below 2°C.
- The parties did not specify an emissions level consistent with 1.5°C. Instead they asked the Intergovernmental Panel on Climate Change (IPCC) to provide information on pathways consistent with 1.5°C in a Special Report due in 2018.
- The Agreement sets a five-yearly 'ratchet' system to review pledges, starting in 2023, with the intention that their ambition will rise over time in a nationally-determined manner. Ahead of this, nations agreed to a "facilitative dialogue" in 2018 to take stock of the current pledges.

The Agreement will come into force on 6 November 2016:

- To enter into force the Agreement required at least 55 countries accounting for at least 55% of global greenhouse gas emissions to formally ratify it.
- This condition was met on 5 October 2016, with major emitters including the US, China, India, Brazil and the EU all ratifying the Agreement. Additional countries are expected to ratify over the coming months.
- The UK Government has not yet ratified the Agreement but has announced its intention to do so before the end of 2016.

The rest of this report considers what the Paris Agreement should mean for the UK's long-term ambition to reduce emissions and the policies to meet it.

Figure 1.3. Projected global emissions to 2030 before the Paris process (left), emissions in 2030 projected with pledges and cost-effective paths consistent with the Paris Agreement aims (right)



Source: UNFCCC (2016) *Updated synthesis report on the aggregate effect of INDCs.*
Notes: 2030 ranges are provided for cost-optimal paths to at least a 66% likelihood of staying below 2°C or at least a 50% likelihood of returning to 1.5°C in 2100 after previous overshoot. Two variants are shown for 1.5°C - one assuming co-ordinated action starts in 2020, one assuming it started in 2010 - to show the effect of delayed action. Shaded regions in 2030 denote the full scenario ranges while lines denote the median.

Chapter 2: Implications of Paris ambition for emissions in 2050 and beyond

Key messages

This chapter examines the available information on global emissions paths consistent with the Paris aims, and their implications for UK long-term targets.

Our key messages are:

- Global temperature over the 21st Century is a function largely of cumulative emissions of CO_2 (and other very long-lived greenhouse gases) over time. Other, shorter-lived gases such as methane drive temperature by their rate of emission. A lower temperature limit entails a smaller global carbon budget and hence an earlier deadline for reaching zero net CO_2 emissions.
- In order to meet the temperature limits of the Paris Agreement, global net greenhouse gas emissions will need to reach zero before 2100.
  - For cost-effective paths to at least a 66% likelihood of staying below 2°C, integrated climate-economy models show net global CO_2 emissions reaching net zero by the 2050s-70s and net global greenhouse gas emissions by the 2080s-90s.
  - Several models find 1.5°C technically infeasible. At best, some can return to 1.5°C with at least a 50% likelihood after earlier overshoot. In these cases net global CO_2 emissions reach zero by the 2040s and net global greenhouse gas emissions by the 2060s-80s.
- These paths assume greenhouse gas removal technologies will be deployed and can reach a scale large enough to push global emissions net negative. If this is not achieved, net emissions would need to reach zero around a decade sooner.
- Based on the rationale underpinning the current 2050 target the UK would need to reach net zero emissions no later than the rest of the world. Furthermore, pathways that return to 1.5°C would imply a UK reduction of at least 86-96% below 1990 levels by 2050.

1. Long-term global pathways

The global carbon budget and zero net CO_2 emissions

CO_2 accumulates in the air over very long timescales, meaning that global temperature rise is a function largely of cumulative CO_2 emissions over time. There is a cumulative CO_2 emissions budget consistent with staying below any given temperature. Once that limit is reached, CO_2 emissions must be reduced to zero or warming will continue.

Global CO_2 budgets consistent with different temperature limits are available from the IPCC, based on the current best understanding of the sensitivity of the climate to emissions and assumptions over future emissions for other gases:

- Table 2.1 shows the global CO_2 budgets provided by the IPCC, consistent with a 50% likelihood of staying below 1.5°C and 66% likelihood of staying below 2°C (the range of temperature ambition in the Paris Agreement). The budget from 2015 for at least a 66% likelihood of 2°C is 590-1240 billion tonnes of CO_2 ($GtCO_2$) and for at least a 50% likelihood of 1.5°C is 390-440 $GtCO_2$.
- The range within each CO_2 budget reflects uncertainty in scenarios of non-CO_2 emissions which also cause climate change. Non-CO_2 emissions do not fall to zero in these scenarios, but reducing them plays a critical role. Deeper reductions allow a higher carbon budget.

- These budgets can be used to infer simple, indicative timescales for reaching net zero global CO_2 emissions. If global emissions are reduced starting now on a linear path to zero, the budgets imply zero would need to be reached in the 2030s for a 50% likelihood of 1.5°C and the 2040s to 2070s for a 66% likelihood of 2°C.
- Delays to emissions reductions will hasten the deadline for zero emissions, making the credibility of meeting the global CO_2 budgets very questionable. For example, if global emissions remain flat the entire CO_2 budget for 2°C would be used up in 15 to 30 years, after which time emissions would need to be eliminated immediately.

While the IPCC has only given a global CO_2 emissions budget, it is likely that the link between peak temperature and cumulative emissions also applies to other very long-lived greenhouse gases such as some F-gases (which remain in the air on timescales of hundreds to thousands of years) and, arguably, nitrous oxide (120 years). For shorter-lived greenhouse gases such as methane (12 years) and some other F-gases, it is primarily the rate of emissions that affects global temperature.[7]

The question of which gases need to be reduced to net zero is a key current uncertainty, which we return to in our discussion of policy targets in Chapter 4.

Table 2.1. Global CO_2 emissions budgets to stay within temperature limits

Global temperature limit	Global CO_2 budget from 2015 ($GtCO_2$)
1.5°C (50% likelihood)	390-440
2°C (66% likelihood)	590-1240

Source: IPCC AR5 Synthesis Report.

Economic modelling of long-term global pathways

Integrated models of the economy and climate provide more detailed, multi-gas information on the global cost-optimal path to limit warming (Box 2.1).

They indicate that the most cost-effective route (given limited action already locked in to 2020) may involve CO_2 emissions falling below net zero. Along with deep reductions in non-CO_2 emissions, the sum of all greenhouse gases (aggregated on a standard CO_2-equivalent basis) reaches net zero before 2100. This is in line with the Paris Agreement aim of balancing sources and sinks of all greenhouse gases, not just CO_2, in the second half of the century. Pathways towards 1.5°C require deeper and earlier reductions than paths to 2°C:

- A range of published model studies (with constrained action before 2020) show global CO_2 emissions reaching net zero during 2055-75 for at least a 66% likelihood of 2°C, while total greenhouse gas emissions fall to net zero during 2080-90.

[7] Smith et al. (2012) *Equivalence of greenhouse-gas emissions for peak temperature limits*, Nature Climate Change

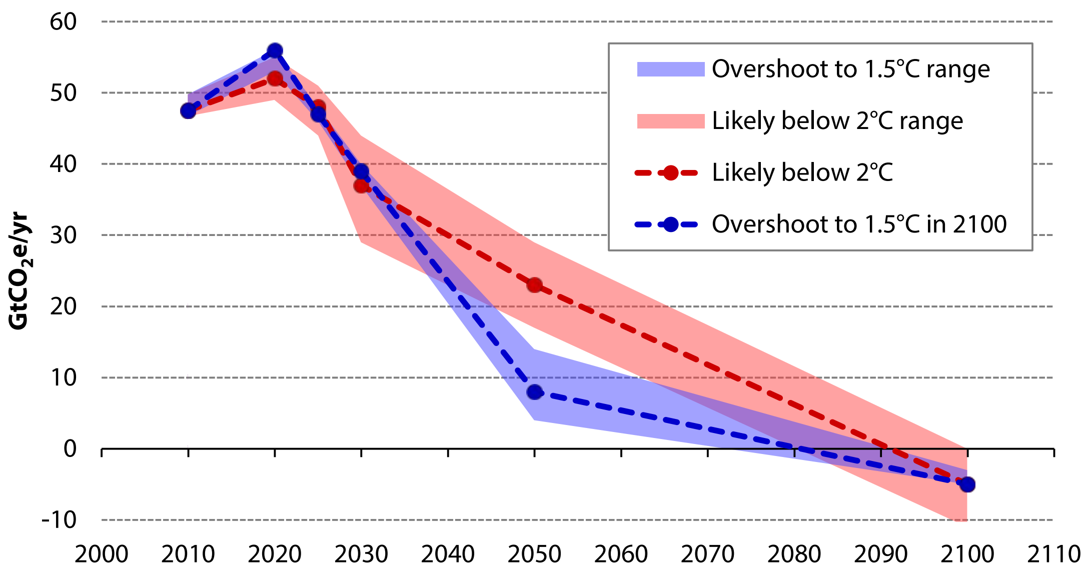
Box 2.1. Integrated global economy-climate modelling

Several research centres around the world have developed Integrated Assessment Models (IAMs) to simulate the future global economy and climate change. They project technologies, costs and resulting emissions over time under specific assumptions. Many of the conclusions in IPCC and UN reports regarding emissions levels consistent with temperature targets derive from these models.

The different models vary widely in scope, detail and numerical methods. They all involve simplifications such as assuming perfect co-ordination between countries (e.g. initiating and responding to a single carbon price), rudimentary constraints on land use, and minimal changes through innovation and behaviour change. While they are the most sophisticated models available, care should therefore be taken in judging the feasibility of different futures on the basis of their results.

In this report we use the pathways considered in the most recent UNEP Emissions Gap report, all of which are constrained by limited action to 2020 (reflecting current pledges) before finding the most cost-effective path to meet temperature limits (Figure B2.1). Further details on the differences these IAMs find between 2°C and 1.5°C paths is given in Table 2.2.

Figure B2.1. Global greenhouse gas emissions paths (aggregated into CO_2-equivalent) consistent with at least a 66% likelihood of 2°C, and pathways with a 50% likelihood of 1.5°C after overshoot



Source: UNEP (2015) *The Emissions Gap Report 2015.*
Notes: Different sets of models contribute to the two ranges of pathways. The two models contributing to the 1.5°C overshoot pathways on average project higher near-term emissions than the three contributing to the below 2°C pathways (one model is common to both sets). This causes the 1.5°C overshoot pathways to have higher emissions in 2020. All models indicate that swifter reductions before 2020 would be more cost-effective; for instance, 1.5°C overshoot pathways which assume co-ordinated action could have begun back in 2010 show emissions in 2030 of around 27-38 $GtCO_2e$.

- No model paths are currently published which reach at least a 50% likelihood of 1.5°C without previously overshooting to higher temperatures. For the two models that achieve this, net CO_2 emissions reach zero during 2045-50 and net greenhouse gas emissions during 2060-80.
- Global greenhouse gas emissions in 2050 are 17-29 $GtCO_2e$ for at least a 66% likelihood of 2°C (equivalent to 1.8-3.0 tCO_2e per person). They are 4-14 $GtCO_2e$ for pathways overshooting then returning to a 50% likelihood of 1.5°C (equivalent to 0.4-1.4 tCO_2e per person).

These timescales for reaching net zero CO_2 assume significant CO_2 removals in the long run:

- These pathways employ large-scale removals of greenhouse gases such that net CO_2 emissions turn negative before the end of the century. This allows a delay in reaching zero at the expense of a temporary overshoot of the global CO_2 budget (and temperature).
- In all these scenarios CO_2 removal is scaled up from the 2020s through a combination of bioenergy with carbon capture and storage (BECCS) and afforestation.
- Scenarios assume 14-22 $GtCO_2$/yr removals in 2100, requiring 150-300 EJ/yr of bioenergy. For comparison there is high agreement among experts in a technical potential of 100 EJ/yr sustainable bioenergy, moderate agreement up to 300 EJ/yr and low agreement above 300 EJ/yr.[8] For our UK scenarios (Chapter 3) we assume a sustainable global bioenergy resource of up to around 110 EJ/yr, based on our 2011 Bioenergy Review.[9]

To the extent these removals cannot be achieved (by BECCS and afforestation or other removal methods, see Chapter 3) emissions would have to reach net zero sooner than in these scenarios.

2. The difference in global action between 1.5°C and 2°C

The Paris Agreement aim of pursuing efforts to limit warming to 1.5°C recognises that some risks from climate change are severe, even below 2°C. There are, however, barriers to increasing effort further, when global pledges are not currently on a credible path to 2°C and the rise in global temperature since the late 19th Century is already above 1°C.

Integrated models able to produce pathways returning to 1.5°C by 2100 show there are several differences to 2°C pathways. These include a smaller, lower window of emissions in 2030, more rapid scale-up of CO_2 removals, greater efforts to manage energy demand and higher overall mitigation costs (Table 2.2).

These models and wider considerations point to 1.5°C being an extremely challenging goal. Indeed, staying below 2°C remains very challenging:

- 76 scenarios included in the latest IPCC assessment (AR5) were able to stay below 2°C with at least 66% likelihood, coming from 5 different integrated models.
- For 1.5°C only one study has been published, after IPCC AR5, involving integrated models. It found just two different integrated models able to meet the limit, and only then after overshooting to higher temperature before returning down in 2100.[10]

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[8] Creutzig et al. (2014) *Bioenergy and climate change mitigation: an assessment*, GCB Bioenergy
[9] CCC (2011) *Bioenergy Review*
[10] Rogelj et al. (2015) *Energy system transformations for limiting end-of-century warming to below 1.5°C*, Nature Climate Change

Table 2.2. Key characteristics of 1.5°C scenarios and comparison with 2°C scenarios	
Key 1.5°C characteristic	**Explanation**
Global CO_2 reductions below net zero	1.5°C scenarios reach net zero carbon emissions globally by mid-century, 10-20 years earlier than scenarios consistent with 2°C, and show net negative emissions in the 2050–2100 period, which are not required for 2°C scenarios if reductions start before 2020.
Additional greenhouse gas (GHG) reductions from CO_2.	The mitigation potential of non-CO_2 GHGs is often already exhausted by mitigation action for keeping warming to below 2°C. Therefore, additional reductions in 1.5°C scenarios are mainly from CO_2.
Rapid and profound near-term decarbonisation of energy supply.	1.5°C scenarios require a decarbonisation of energy supply more rapid and profound than in 2°C scenarios. Early CO_2 reductions in 1.5°C scenarios are achieved through early reductions in the power sector.
Greater mitigation efforts on the demand side.	By mid-century, mitigation efforts in industry, buildings and transport sectors lead to significantly lower emissions from these sectors.
Greater energy efficiency improvements.	Energy efficiency plays a critical role in both 2°C and 1.5°C scenarios. It is crucial to 1.5°C scenarios, most of which project energy use per unit of GDP decreasing at a faster pace than historically observed. This decrease comes from dedicated energy efficiency policies as well as substantial climate-policy-induced demand reductions, which are greater in 1.5°C than in 2°C scenarios.
Higher mitigation costs.	Aggregated long-term mitigation costs are higher, for example up to two times when comparing corresponding 1.5°C and 2°C scenario pairs. The effect on near-term costs is greater.
Deeper emission reductions by 2030.	The window for delay that keeps the option open to limit warming to 1.5°C by 2100 is narrower than for 2°C scenarios. For emissions in 2030 consistent with current pledges, some 2°C scenarios are available but none are currently available for 1. 5°C. Diverting investments to low-carbon technologies in the coming decade is therefore critical.

Source: Adapted from Rogelj et al. (2015) *Energy system transformations for limiting end-of-century warming to below 1.5°C*, Nature Climate Change; UNFCCC (2016) *Updated synthesis report on the aggregate effect of INDCs*.

- Scenarios to reach either 2°C or 1.5°C require increased efforts to 2030. This was recognised by the parties to the Paris Agreement, who identified the need to reduce emissions to 40 $GtCO_2e$/yr in 2030, rather than the expected level from existing pledges of 56 $GtCO_2e$/yr. Emissions would need to continue falling after 2030, with a 1.5°C goal implying much faster rates of reduction (Figure B2.1).
- Some experts already state that 2°C is no longer feasible in reality because model scenarios are too optimistic about global co-operation and technology availability.[11]

We therefore consider the goal of pursuing efforts to 1.5°C as implying a desire to strengthen and potentially to overachieve on efforts towards 2°C. One further option is to explore more radical forms of geoengineering that could play a role in moderating climate change in addition to reducing greenhouse gas levels (Box 2.2).

Box 2.2. Solar geoengineering

Various ways have been proposed to limit warming by deliberately altering the amount of sunlight absorbed by the climate system. These methods are commonly referred to as "geoengineering" (with the term sometimes used to include greenhouse gas removal methods as well).

Solar geoengineering proposals include:

- Spraying reflective particles into the upper atmosphere (stratospheric aerosols). This process occurs naturally during very large volcanic eruptions, such as Mt. Pinatubo in 1991.
- Enhancing the reflectivity of clouds by spraying particles which encourage a greater number of smaller cloud droplets.
- Enhancing the reflectivity of land surfaces, for instance whitening roofs or planting brighter crops.

Early studies suggest stratospheric aerosols may have the potential to offset a substantial amount of global temperature rise, and at lower cost than some emissions reductions. There are however many unknowns and potential risks:

- No form of solar geoengineering addresses the problem of ocean acidification which, alongside climate change, is a direct impact of CO_2 emissions.
- Studies point to wider environmental impacts. Stratospheric aerosols can cause ozone depletion. Solar geoengineering alters regional patterns of temperature and rainfall (although they may still be closer to pre-industrial patterns in a geoengineered world than in an unmitigated greenhouse gas world). The complexity of the climate means other, currently unknown impacts are likely.
- Stratospheric aerosols have lifetimes on the order of weeks, meaning they would need to be continually replenished. If spraying was ramped up and then suddenly stopped (e.g. due to a technical fault or social unrest) then the climate would warm rapidly.
- Public awareness of geoengineering options is low, but surveys suggest it is seen as more ethically fraught than reducing emissions and removing greenhouse gases from the air. Some are favourable towards incremental, accountable research; few towards full-scale deployment.

Source: Integrated Assessment of Geoengineering Proposals project iagp.ac.uk; National Academy of Sciences (2015) *Climate intervention: reflecting sunlight to cool Earth*.

[11] Victor & Kennel (2014) *Ditch the 2°C warming goal*, Nature Climate Change

3. The UK contribution

The Paris Agreement does not allocate specific emissions targets to nations. Instead, parties are required to make voluntary pledges reflecting their "common but differentiated responsibilities and respective capabilities, in the light of different national circumstances". In this section we look at different ways to estimate a UK contribution within the global paths to meet the Paris aims.

The UK 2050 target is based on the judgment that average emissions of greenhouse gases per person should be no more than the global average by then. This is because it will be hard to find other nations much below the average, especially in a world of substantially-declining emissions. On this rationale, UK greenhouse gas emissions would reach zero no later than the world as a whole (i.e. 2060-90). For the upper end of Paris ambition, the 2050 target would need to be at least 86-96% below 1990 levels (Table 2.3).

Table 2.3. UK emissions in 2050 and time to reach net zero emissions for paths consistent with the range of ambition implied by the Paris Agreement, assuming UK emissions per person equal the global average (the basis of the current UK 2050 target)

	Below 2°C	**Return to 1.5°C**
UK 2050 GHG emissions (below 1990)	71-83%	86-96%
Year to reach zero UK GHG emissions	2080-90	2060-80
Year to reach zero UK CO_2 emissions	2055-75	2045-50

Source: CCC calculations based on UNEP (2015) *The emissions gap report 2015*
Notes: For paths below 2°C, IPCC AR5 gave a 2050 range for global emissions which implies UK emissions 73-87% below 1990. The range here differs because it considers only paths that start reductions after 2020 (and hence pass through higher emissions in 2050 before heavier reliance on greenhouse gas removals later in the century).

In considering any new UK long-term target there are alternative approaches to assessing a fair UK contribution:

- One consideration is the share of domestic emissions reductions between nations that minimises global costs. It is currently unclear whether a global least-cost strategy would be for UK domestic emissions to reach zero sooner or later than the world as a whole:
  - Of the sectors which are hard to reduce to zero emissions, the UK has a low share of emissions from agriculture relative to the rest of the world, an average share from industry and a high share from aviation.
  - Regarding potential for greenhouse gas removals the UK has access to large potential stores to sequester CO_2, but relatively little land for growing bioenergy or deploying other land-based options (see Chapter 3).
  - Integrated climate economy models suggest Europe – and by implication the UK – would reach zero net emissions later than the world as a whole on a globally-cost effective

path.[12] However, these paths also involve Europe having higher emissions per person in 2050, which is at odds with existing 2050 commitments both in the UK and Europe.

- Other methods of defining a fair UK share emphasise different aspects of responsibility and capability relative to other nations (Box 2.3). Relatively little information is available on how these methods apply to the timing of zero emissions, or achieving 1.5°C. But nearly all methods would point to more ambitious UK action than current targets:
  - Analysis for the fifth carbon budget[13] looked at several alternative methods and found that paths to at least a 66% likelihood below 2°C imply a range for UK emissions in 2030 of 59-80% below 1990 levels (c.f. the fifth carbon budget at 57%).
  - Similar analysis is unavailable for 1.5°C pathways or for timescales to reach zero, but they would imply the UK should reach net zero before the world overall. For example, dividing the global cumulative emissions budget remaining from 2011 by the UK share of global population implies the UK reaching net zero CO_2 by around 2030-55 for a 66% likelihood of 2°C, and by around 2025-30 for a 50% likelihood of 1.5°C.
  - These methods do not aim to define the path of domestic emissions, but rather an allocation to be met through a combination of domestic action and wider international assistance (trading of emissions, financing of climate projects, etc.). An efficient way of meeting these allocations could be for the UK to reach net zero at the same time or later than others, but with significant levels of effective support flowing to other countries.

[12] Data from the LIMITS project, https://tntcat.iiasa.ac.at/LIMITSPUBLICDB/dsd?Action=htmlpage&page=about
[13] CCC (2015) *The scientific and international context for the fifth carbon budget*.

Box 2.3. Alternative methods of defining a UK share

Several methods for defining a nation's fair contribution have been proposed. Importantly, these methods give a notional allocation of emissions that can be met through a combination of domestic action and wider international assistance (trading of emissions credits, financing of climate projects, etc.). They are therefore different in concept to the cost-effective path of domestic emissions alone.

In our fifth carbon budget advice we looked at the implications of these methods for the UK contribution in 2030. We found an indicative 59-80% cut below 1990 levels for a least-cost global pathway broadly consistent with the lowest end of ambition in the Paris Agreement:

- We assessed the implications of different methods for a UK emissions allocation in 2030, assuming global emissions in 2030 of 42 $GtCO_2e$/yr (chosen at the time to be within the range for a 66% likelihood of 2°C).
- Results ranged from 59% below 1990 levels (on the basis of convergence to equal emissions per person by 2050) to 80% (on the basis of equal per person shares of the global cumulative emissions budget during 1990-2050).
- Considering the domestic UK reduction under a global least-cost path (i.e. without accounting for the UK's wider international responsibility and capability) gave a 53% reduction below 1990 levels.
- Other literature suggests even higher cuts for the UK.

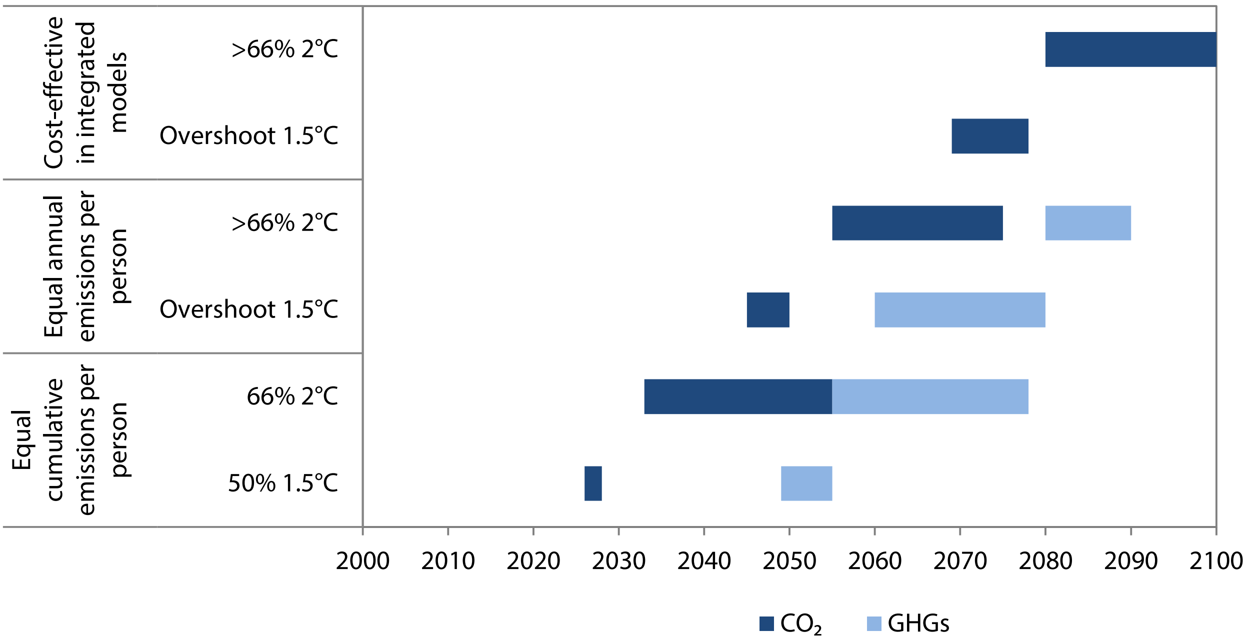
Little information is currently published on how these estimates change when looking beyond 2030 to a net zero-emission world, or a 1.5°C limit. But using a similar method based on equal per person shares of the global cumulative emissions budget (indicative of the more ambitious end of the range) we estimate UK CO_2 emissions would need to reach zero by 2025-55:

- We use the 'equity' method in Raupach at al. (multiplying the cumulative CO_2 budgets in Table 2.1 by the projected UK fraction of global population when the world reaches 9 billion people) to derive UK budgets from 2015 of 4,000-9,200 $MtCO_2$ for a 66% likelihood of 2°C, and 2,400-2,800 $MtCO_2$ for a 50% likelihood of 1.5°C.
- A linear path from 2014 (when UK emissions where 462 $MtCO_2$/yr including international aviation and shipping) implies reaching net zero CO_2 emissions by 2033-55 for 2°C and 2026-8 for 1.5°C.
- As discussed earlier in the chapter, there would be some (limited) scope for delay if net negative emissions can be achieved afterwards.
- For all greenhouse gas emissions, this method gives indicative net zero years of 2055-2078 for 2°C and 2049-55 for 1.5°C. These numbers are indicative, however, as the link between peak temperature and cumulative emissions is less robust for all greenhouse gases than for CO_2 only.

Source: Höhne et al. (2013) *Regional GHG reduction targets based on effort sharing: a comparison of studies*, Climate Policy; https://www.mitigation-contributions.org/; https://calculator.climateequityreference.org/; CCC (2015) *The scientific and international context for the fifth carbon budget*; Raupach et al. (2014) *Sharing a quota on cumulative carbon emissions*, Nature Climate Change; UN world population prospects, 2015 revision.

In summary, currently available information indicates a range of timescales by which the UK should aim for zero net emissions, depending on the range of global paths implied by Paris ambition and the method of judging a fair UK contribution (Figure 2.1). On the logic underpinning the existing 2050 target, net UK CO_2 emissions should be zero by 2045-65 and net greenhouse gas emissions should be zero by 2060-90.

Figure 2.1. Comparison of timings to reach zero UK emissions under different allocation methods, assuming linear reductions to zero



Source: CCC calculations based on sources listed in chapter. Data on the cost-effective path in integrated models for overshoot 1.5°C scenarios provided by Joeri Rogelj, personal communication.
Notes: Dark bars show the range of timings for CO_2 emissions only, while light bars show timings for the Kyoto basket of greenhouse gases. The "cost-effective in integrated models" bars indicate the timing of reaching net zero domestic CO_2 emissions for the EU27 (including the UK); the EU27 does not reach net zero greenhouse gases before these scenarios end in 2100.

Chapter 3: Feasibility of the UK taking more ambitious domestic action

Key messages

This chapter considers long-term scenarios for domestic actions to reduce UK emissions, and looks at the implications of the Paris aims for action beyond 2050 and/or raising effort before 2050.

Our key messages are:

- The UK 2050 target to reduce emissions at least 80% from 1990 levels (i.e. less than around 160 $MtCO_2e$/yr) is challenging and requires significant action across the economy, but can be met in various ways using currently known technologies.
- A full and successful roll-out of all options in our published scenarios to 2050 would lead to net UK greenhouse gas emissions of about 60 $MtCO_2e$/yr (i.e. just over 90% lower than 1990 levels) and net CO_2 emissions close to zero. This level of emissions reductions could be achieved by around 2070 on a path through an 80% reduction in 2050.
- Achieving net zero domestic emissions of all greenhouse gases would require a combination of further breakthroughs in hard-to-reduce sectors (agriculture, aviation and some industry) and greenhouse gas removal technologies beyond those already in our scenarios (afforestation, wood in construction and bioenergy with carbon capture and storage).
- The aim of the Paris Agreement to balance sources and sinks of greenhouse gases implies the need for a globally coordinated strategy to develop and deploy greenhouse gas removal options. Such options are not a substitute for widespread decarbonisation, given current estimates of the potential scale for greenhouse gas removal both globally and in the UK.

1. Recap of CCC scenarios to 2050

The current UK long-term target implies UK emissions should be around 160 $MtCO_2e$/yr or less in 2050. The CCC has developed a range of scenarios to 2050, but not beyond.

Our approach to scenarios for meeting the 2050 target recognises uncertainties in costs and availability of different options. Rather than defining a single central scenario we have identified a set of building blocks across sectors that can stack up in different ways, allowing the possible lack of delivery in one sector to be compensated by more delivery in others:

- For each sector (power, buildings, surface transport, industry, non-CO_2 and aviation & shipping) we have developed three scenarios, "Barriers", "Central" and "Max", representing different levels of success in deploying low-emissions options.
  - **Central** represents our best assessment of the technologies and behaviours required to meet targets cost-effectively while meeting the other criteria in the Climate Change Act.
  - **Barriers** represents less favourable conditions for key measures (technological barriers, failure to achieve cost reductions, or market barriers).
  - **Max** represents higher deployment towards the maximum limits that are likely to be feasible, acceptable and sustainable.

- Our fifth carbon budget scenarios were designed such that levels of deployment by 2030 would keep open the option of achieving Max levels of deployment by 2050 (although this would require a significant ramp-up of effort).[14]

These scenarios, alongside others by Government and independent groups,[15] confirm that the 2050 target is challenging but achievable, and share a number of common themes:

- **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 achieve deep emissions reductions, and fuel switching to low-carbon sources will also be needed.
- **Rapid electricity decarbonisation and electrification**. Meeting the target is likely to require a power sector with very low emissions in 2050. This is needed to decarbonise existing demands for electricity and to meet new demands in road transport and heat in buildings (and potentially other applications) without increasing emissions. The level of electricity consumption in 2050 could be 50% to 135% above the level in 2014.
- **Carbon capture and storage (CCS)** is very important given its potential to reduce emissions across heavy industry and the power sector, open up new decarbonisation pathways (e.g. based on hydrogen) and remove CO_2 when coupled to bioenergy. Estimates by the Committee[16] and by the ETI[17] indicate that the costs of meeting the UK's 2050 target could almost double without CCS.
- **Bioenergy**. Sustainable bioenergy can play an important role reducing emissions where alternative options are very limited. However, there are limits to the sustainable supply so its role must be targeted at options where it has the largest impact on emissions. Our analysis indicates that use should preferentially be as wood in construction or with CCS and/or displacing coal, with further potential for use where alternative low-carbon options are not available (e.g. aviation).
- **Infrastructure development**. New infrastructures will be required to support 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 and increasing generation from low-carbon sources.

Significant action is needed across the economy to meet the 2050 target (no more than around 160 $MtCO_2e$/yr). However, there is some flexibility in the precise mix of effort between sectors, technologies and behaviours:

- The target could be reached for instance with a combination of Barriers in industry, Max in transport and Central in other sectors alongside significant greenhouse gas removals (e.g. from bioenergy with CCS - see section 3). Alternatively it could be reached by Barriers in

[14] CCC (2015) *Sectoral scenarios for the fifth carbon budget.*

[15] HM Government (2011) *The Carbon Plan: Delivering our low carbon future*; UKERC (2013) *The UK energy system in 2050: Comparing low-carbon, resilient scenarios*; ETI (2015) *Targets, technologies, infrastructure and investments – preparing the UK for the energy transition*; Pye et al. (2015) *Pathways to deep decarbonization in the United Kingdom.*

[16] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping.*

[17] ETI (2015) *Building the UK carbon capture and storage sector by 2030 – Scenarios and actions.*

transport and power coupled to Max in non-CO_2, Central in others and greenhouse gas removals.

- The target could be met without greenhouse gas removals provided there is high delivery in all other areas and that bioenergy is targeted to applications without low-carbon alternatives.
- The flexibility to meet the target in different ways is valuable because of the significant challenge to achieve deep reductions in all areas, the risk of under-delivery and the uncertainty over exactly what levels will be achievable.

In theory, realising all the options would result in domestic UK emissions 66% below 1990 levels by 2030, and just over 90% by 2050, within the range of a 2050 target aligned closer to a 1.5°C temperature target:

- Our fifth carbon budget Max scenarios to 2030 reach direct domestic emissions of 66% below 1990 levels.[18]
- Achieving all of the options in the Max scenarios would result in net economy-wide emissions of around 64 $MtCO_2e$/yr in 2050 (i.e. 92% below 1990 levels) including the UK share of international aviation and shipping.
- This is within the range of 86-96% suggested by the most ambitious paths available from global climate-economy models (which keep a 50% likelihood of 1.5°C in 2100 after overshooting) based on the logic used to define the current UK long-term target (equal annual emissions per person by 2050).

Table 3.1 sets out brief descriptions of our Max, Central and Barriers scenarios for each sector, and the level of emissions these imply. They are illustrative given the significant uncertainties in demand and technologies to 2050. Alternative low-carbon options may prove more effective or cheaper, whilst other sources of emissions could emerge. The scenarios are intended to give a useful sense of how the 2050 target could be met, given what we know now.

[18] CCC (2015) *Sectoral scenarios for the fifth carbon budget.* 66% should be compared to a reduction of 61% in direct emissions under the Central scenarios (the fifth carbon budget is equivalent to 57% because it accounts for UK allowances under the EU Emissions Trading System as well as direct emissions).

Table 3.1. Summary of CCC Barriers, Central and Max scenarios and resulting annual emissions of greenhouse gases in 2050

	Max	Central	Barriers
Power	Full decarbonisation. Peaks met by low-carbon storage and H_2. **3 $MtCO_2e$**	Full decarbonisation. Peaks met by low-carbon storage and some gas. **6 $MtCO_2e$**	Limited decarbonisation. Peaks met by low-carbon storage and some gas. **25 $MtCO_2e$**
Heat in buildings	Domestic: demand met by heat pumps or H_2 (70%), heat networks (10%), electric heating (5%) and gas (10%). Non-domestic: demand met by heat pumps (35%), heat networks (25%) and gas (40%). **4 $MtCO_2e$**	Domestic: demand met by heat pumps or H_2 (60%), heat networks (10%), electric heating (5%) and gas (25%). Non-domestic: demand met by heat pumps (50%), heat networks (45%) and gas (5%). **19 $MtCO_2e$**	Domestic: demand met by heat pumps or H_2 (20%), heat networks (5%), electric heating (5%) and gas (75%). Non-domestic: demand met by heat pumps (35%), heat networks (55%) and gas (5%). **67 $MtCO_2e$**
Surface transport	100% of cars and vans are EVs. 95% of buses low-carbon (half H_2, half EV). 50% of HGVs use H_2, 40% are EVs. **5 $MtCO_2e$**	93% of cars and vans are EVs. 95% of buses low-carbon (half H_2, half EV). 40% of HGVs use H_2, 25% EVs. **19 $MtCO_2e$**	70% of cars and vans are EVs. 90% of buses low-carbon (half H_2, half EV). 20% of HGVs use H_2, 25% EVs. **42 $MtCO_2e$**
Industry	Full '2050 Roadmaps' deployment with wider deployment of CCS and electrification where possible. No emissions from energy supply. **32 $MtCO_2e$**	Further deployment of cost-effective options in '2050 Roadmaps' including CCS in industrial clusters. **61 $MtCO_2e$**	Deployment of options in '2050 Roadmaps' including some application of CCS in iron & steel, chemicals and cement sectors. **74 $MtCO_2e$**
Non-CO_2	All on-farm measures deployed to full technical potential. Near-zero landfill emissions. Diet shift away from red meat, F-gas ban. **47 $MtCO_2e$**	All on-farm measures deployed up to 85-90% of technical potential. Near-zero landfill emissions. No diet shift or F-gas ban. **57 $MtCO_2e$**	All on-farm measures deployed to around 45% of technical potential. Near-zero landfill emissions. No diet shift or F-gas ban. **60 $MtCO_2e$**

Table 3.1. Summary of CCC Barriers, Central and Max scenarios and resulting annual emissions of greenhouse gases in 2050

	Max	Central	Barriers
Aviation & shipping	Aviation: emissions 15% lower than 2005 levels Shipping: full take-up of technological and operational measures; further increases in ship size and use - still limited - of biofuels and LNG. **40 $MtCO_2e$**	Aviation: emissions around 2005 levels. Shipping: speed reductions and increases in the average size of unitised container ships; limited use of biofuels and LNG. **46 $MtCO_2e$**	Aviation: emissions not capped, increasing to 40% above 2005 levels. Shipping: improvements reflecting IMO's Energy Efficiency Design Index but limited further abatement. **63 $MtCO_2e$**
Land use, land use change and forestry	Woodland creation averaging 30,000ha/yr. Agro-forestry on 2.3% of agricultural land. **-16 $MtCO_2e$**	Woodland creation averaging 15,000ha/yr. Agro-forestry on 1.6% of agricultural land. **-8 $MtCO_2e$**	Woodland creation averaging 2,500ha/yr. Agro-forestry on 1.2% of agricultural land. **-2 $MtCO_2e$**
Biomass with carbon capture and storage (BECCS)	50 TWh/yr (8%) of power generation. Includes estimated lifecycle emissions. **-47 $MtCO_2e$**	50 TWh/yr (8%) of power generation. Includes estimated lifecycle emissions. **-47 $MtCO_2e$**	-
Wood in construction	**-4 $MtCO_2e$**	-	-
TOTAL ($MtCO_2e$)	**64**	**154**	**328**
SOURCES ($MtCO_2e$)	**131**	**209**	**330**
SINKS ($MtCO_2e$)	**-67**	**-55**	**-2**

Source: CCC calculations.
Notes: Numbers may not sum exactly due to rounding. H_2 = hydrogen, EV = electric vehicle, HGV = heavy goods vehicle, LNG = liquified natural gas.

2. Scope for further emissions reduction

To the extent not all options in our scenarios are achieved by 2050 they may still be achievable afterwards. In addition there is scope for some further reductions from transport, buildings and industry due to stock turnover. However, even if they are delivered there are remaining activities for which we do not currently see a complete decoupling of emissions, namely aviation, agriculture (methane and nitrous oxide emissions) and some industrial processes.

Continued savings beyond 2050

Continued deployment of low-carbon measures beyond 2050, replacing higher-carbon stock (e.g. vehicles, power generators and heating systems), would save a further 12 $MtCO_2e$/yr below our Max scenario:

- **Vehicles.** If electric and hydrogen vehicles were to continue displacing fossil-fuelled engines at the rate envisaged in our scenarios to 2050, total vehicle emissions would reduce to near zero by 2055-60. Alongside this, motorcycles, construction vehicles and aircraft support vehicles could be fully decarbonised.
- **Buildings.** Increased displacement of fossil-fuelled heating by heat pumps, district heating and low-carbon hydrogen has the potential to reduce emissions in buildings to zero. If continued beyond 2050 at the rate envisaged in our scenarios, this transition would complete by 2055-70. There could be a more sudden change away from the use of gas for heating, if it became uneconomic to maintain the gas grid.
- **Refining.** Our scenarios envisage a decline in UK refining output to 2050, reflecting a lower need for refined fuels as transport and heating are electrified or switched to hydrogen. Beyond 2050 we expect refining output and refining emissions to continue towards zero.

Together these stock turnovers would imply emissions that are close to zero from power generation, transport, buildings and much of industry.

Remaining emissions

It is less clear how to avoid emissions in other sectors, in particular from agriculture, aviation and some parts of industry. These sectors make up around 100 $MtCO_2e$/yr of residual emissions in our Max scenario in 2050 (Figure 3.1):

- **Aviation** contributes a remaining 35 $MtCO_2$/yr. We assume a maximum of 1.5% annual improvements in fuel efficiency and10% take-up of biofuels. Further emissions reduction would require breakthroughs in advanced low-carbon fuels, alternative propulsion methods (e.g. LNG, hydrogen, nuclear, solar, hybrid planes) or greater shifts in consumer demand away from jet aircraft to alternatives.

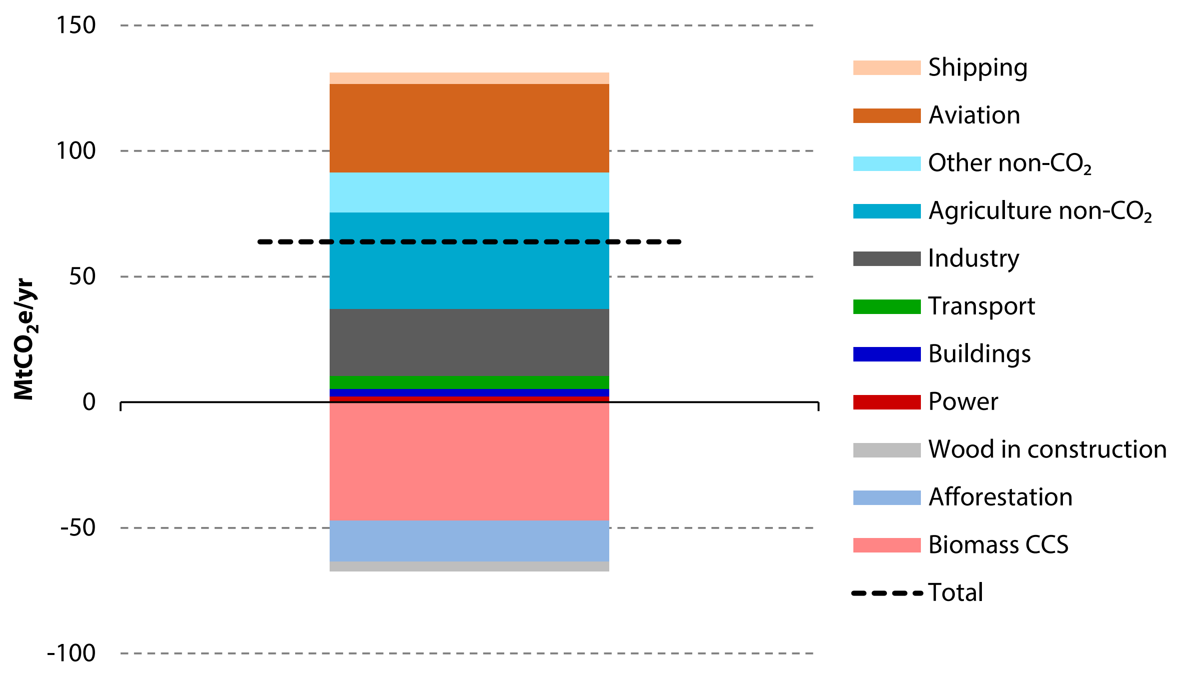
- **Agriculture** contributes a remaining 38 $MtCO_{2e}$/yr. Our scenarios envisage that agriculture continues to make up around 60% of non-CO_2 emissions in 2050, mainly from livestock (23 $MtCO_2e$/yr of methane) and fertilisation of soils (14 $MtCO_2e$/yr of nitrous oxide). Lower emissions beyond 2050 may be possible through increased diet change, food waste reduction, breakthroughs in genetically modified livestock, novel crops and precision livestock farming, though we have not made a quantitative assessment of the savings that these measures may be able to deliver.
- **Industry** (excluding refining) contributes a remaining 27 $MtCO_2e$/yr. These are largely from fuel combustion, process emissions and residual CCS emissions[19] from manufacturing (such as iron & steel, food & drink), water management and construction sectors. There may be scope to reduce fuel combustion emissions through further electrification or the use of

[19] Although CCS can significantly reduce emissions from applications where there are few low-carbon alternatives, we assume it only captures up to 90% of emissions.

hydrogen, however process and CCS emissions will be harder to decarbonise. Structural shifts such as demand for industrial products moving to less carbon-intensive products and increased reuse of products and materials may further reduce emissions in this sector.

In total we envisage a minimum of about 120 $MtCO_2e$/yr emissions across the economy (of which 65 Mt/yr is CO_2) coming from aviation, agriculture and industry as well smaller contributions from CCS, surface transport, shipping and waste. Breakthrough innovations or changes in demand could drive emissions down further in the hard-to-reduce sectors. But successful new technologies typically take 30-40 years to develop from invention to mass deployment,[20] suggesting that even if there are breakthroughs in coming years there will still be a significant level of emissions in 2050 and probably for some time beyond.

Figure 3.1. Residual UK greenhouse gas emissions in 2050 under Max deployment across all sectors



Source: CCC calculations.

[20] UKERC (2015) *A review of the evidence on the time taken for new technologies to reach widespread commercialisation.*

3. Greenhouse gas removal technologies

Greenhouse gas removal (GGR) technologies are options to actively remove CO_2 and other greenhouse gases from the air. Three such options (BECCS, forestry and wood in construction) are included in our scenarios. Developing and deploying GGR options globally and in the UK will be central to realising the Paris ambition of a balance between greenhouse gas sources and sinks, given the difficulty of removing all sources.

Characterising removal options

The range of GGR options is diverse (Table 3.2). Some of them are already well understood, but many are at an early stage of development meaning their costs, effectiveness, feasibility and wider impacts are highly uncertain (Figure 3.2):

- Specific GGR technologies range from afforestation to ocean liming, direct air capture and storage, and alternative forms of cement.
- Estimated financial costs range from negligible to hundreds of dollars per tonne of CO_2 removed. Similarly, their technical potential to remove greenhouse gases varies over two orders of magnitude. Estimates come from a wide range of different methods and may exclude additional costs from infrastructure, transport, etc.
- Implementation would involve different skills and sectors of the economy. Some have co-benefits: for instance, restoration of habitats can improve biodiversity and ecosystem services such as water management; biochar and BECCS can provide power and heat; ocean liming helps mitigate the impacts of ocean acidification from CO_2 emissions.
- Several GGR options have wider potential impacts on people and the environment. Some of these are direct and local, such as changes to soil chemistry from biochar. Others are systemic risks that may occur under large-scale deployment, such as food and ecosystem effects from bioenergy used with CCS. Some of these impacts would be addressed by existing regulation, although general governance principles for GGR technologies have been proposed as well.[21]

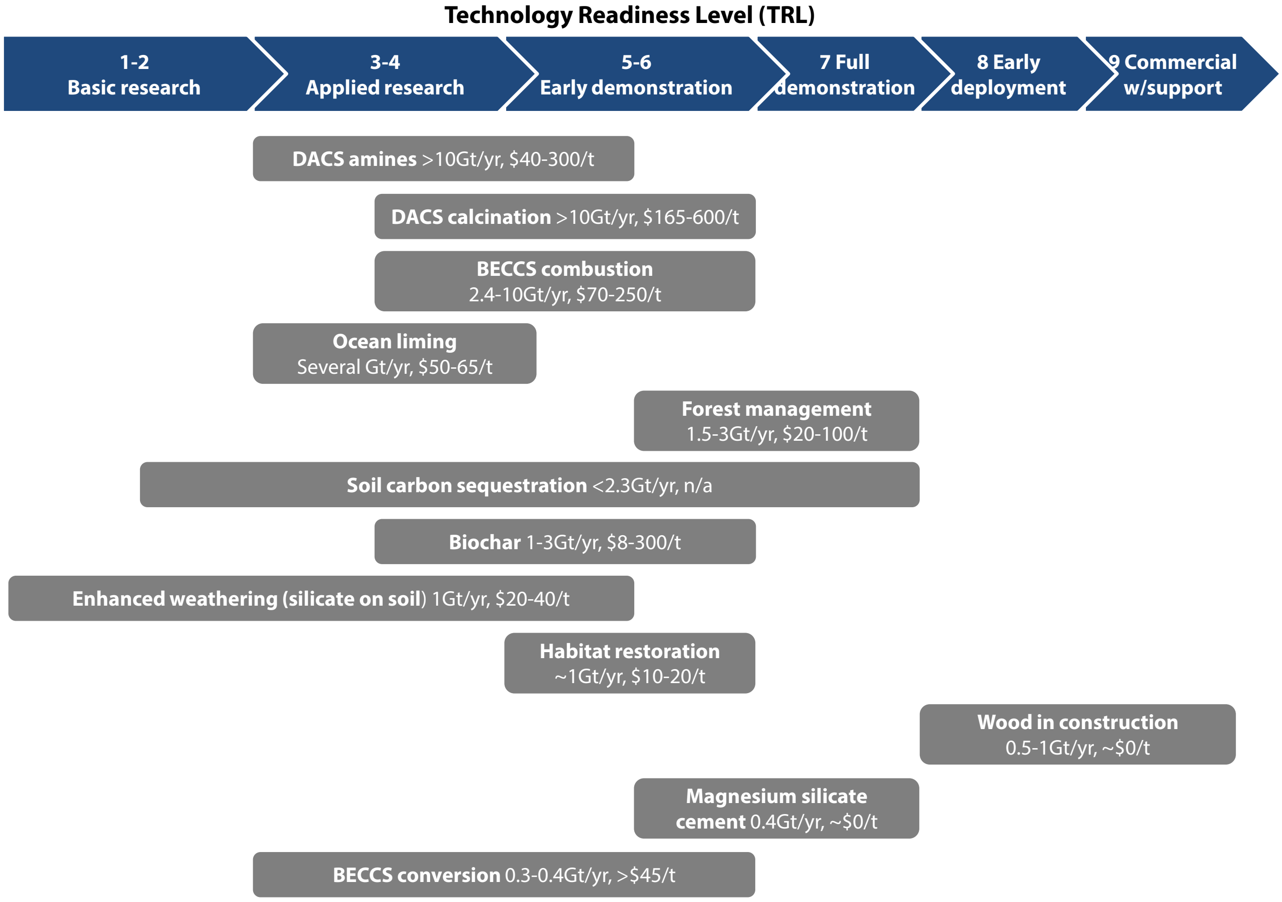
[21] House of Commons Science and Technology Committee (2010) *The regulation of geoengineering*

Table 3.2. Example greenhouse gas removal technologies

Name	Description
DACS (amines)	Branched frames supporting amines ("artificial trees"), capturing CO_2 from air which is recovered by washing in a vacuum and then stored.
DACS (calcination)	Wet scrubbing systems using calcium or sodium cycling, capturing CO_2 from air which is recovered by calcining and then stored.
BECCS (combustion)	Combusting biomass to provide energy, with the CO_2 released from the organic matter captured and then stored.
Ocean liming	Adding calcium hydroxide bicarbonate to surface waters, enhancing the natural process of ocean CO_2 uptake. (Also proposed is ocean fertilisation, adding nutrients such as iron to increase growth of marine organisms to take up CO_2. But most studies agree this poses more risks at scale than benefits.)
Forest management	Planting forests, or enhancing management of existing forests, with the trees taking up additional CO_2.
Soil carbon management	Restoring degraded soils using methods such as "no-till" agriculture, manures and composts, increasing the organic matter content.
Biochar	Adding partially-combusted organic matter (char) to soil, thereby (in principle) returning the CO_2 locked up in the organic matter to the soil. Biofuels can be a by-product of biochar production.
Enhanced weathering (rocks on soil)	Adding crushed silicate rocks to soils, enhancing the natural process of CO_2 capture by these rocks, with potential co-benefits in soil nutrients.
Habitat restoration	Restoring and rewetting habitats such as peatlands, tidal salt marshes and mangroves, so they store more CO_2 in the form of dead organic matter.
Wood in construction	Using harvested timber in buildings and other long-lived constructions, thus storing the absorbed CO_2 in the built environment. Common in some other countries (e.g. over 80% of Finnish housing stock is built from wood).
Magnesium cement	Cement containing magnesium oxide instead of carbonate, absorbing CO_2 in the process of setting.
BECCS (conversion)	Capturing and storing the CO_2 released by organic matter during the process of converting biomass into other forms of biofuel.

Source: Adapted from McLaren (2012) *A comparative global assessment of potential negative emissions technologies*, Process Safety and Environmental Protection; National Academy of Sciences (2015) *Climate intervention: carbon dioxide removal and reliable sequestration*.
Notes: DACS = direct air capture and storage, BECCS = bioenergy with carbon capture and storage.

Figure 3.2. Indicative estimates of Technology Readiness Levels (TRLs), technical potential and costs of greenhouse gas removal technologies



Source: Adapted from McLaren (2012) *A comparative global assessment of potential negative emissions technologies*, Process Safety and Environmental Protection

Notes: Alongside the name of the technology, each box gives estimates of their global technical potential (in billion tonnes of CO_2 removed per year) and cost (in US dollars per tonne of CO_2 removed). These estimates are based on a range of literature and subject to large uncertainties. Technologies are listed in descending order of technical potential.

UK potential

Deployment of GGR options is subject to key uncertainties. In broad terms, GGR using biological systems faces uncertainty over the wider impacts (positive and negative) on the environment, as well as how much carbon they sequester and for how long. GGR using chemical processes faces uncertainty over technical hurdles and costs:

- Lack of deployment and, in some cases, lack of basic research is a principal reason for the large uncertainties around GGR options. Some demonstration projects and research programmes are underway around the world. UK research councils, the Met Office and BEIS recently announced funds of up to £8.3 million for fundamental GGR research over

four years.[22] However, global funding for research, development and demonstration in general is currently very low.[23]

- Monitoring and verifying the carbon stored in biological systems is more difficult than for emissions from fuels. The carbon passes through a range of complex chemical and biological processes, and may re-emerge in the air. Nevertheless, existing policies at UK, EU and UN level for monitoring and verifying removals could be applied and refined for GGR options.[24]

Our UK scenarios to 2050 include up to 67 MtCO_2/yr removals from three GGR options: afforestation, BECCS and wood in construction.

- We assume a maximum 30,000 ha/yr of planting trees and wood crops, resulting in up to 16 MtCO_2/yr removal.
- BECCS could become capable of reducing emissions at a comparable cost to other technologies in the 2030s. This would require the Government to implement an effective new approach to CCS development[25] and development of sustainable bioenergy supplies without locking these into alternative uses. Our scenarios include up to 47 MtCO_2/yr removed by BECCS while generating energy. This assumes a combination of domestically-grown biomass (0.5EJ primary energy in 2050) and imports (0.2EJ) reflecting the UK share of a potential global market in sustainable biomass.
- We assume increased use of wood in place of other construction materials, resulting in 4 MtCO_2/yr removal.

Given the early stage of development, any estimate of technical potential across the greenhouse gas removal technologies is highly uncertain. Current, tentative estimates suggest that GGR options could have enough technical potential to offset the residual UK emissions after all other reduction options are deployed:

- One estimate has suggested a total technical potential up to 280 MtCO_2/yr removals in the UK[26] while another focussed on land-based GGR options (excluding marine-based options and direct air capture and storage) estimates 40-180 MtCO_2/yr.[27]
- The UK has a high potential for storing CO_2 in geological formations, which is necessary for BECCS and direct air capture and storage. Estimates predict a total UK storage resource of around 78 GtCO_2, or 100 MtCO_2/yr for nearly 800 years.[28] However, using the same CCS infrastructure for fossil fuels would reduce the overall storage capacity for these GGR options.

[22] http://www.nerc.ac.uk/research/funded/programmes/ggr/news/ao-ggr/
[23] Centre for Carbon Removal (2016) *Philanthropy beyond carbon neutrality : How near-term grants to carbon removal can make long-term climate goals a reality*
[24] For example European Parliament and Council Directive 2009/31/EC EU CCS on geological storage of carbon dioxide, and IPCC (2006) *Guidelines for national greenhouse gas inventories vol 4: agriculture, forestry and other land use*
[25] CCC (2016) *A strategic approach to Carbon Capture and Storage*, Letter to DECC Secretary of State
[26] McLaren (2011) *Negatonnes – an initial assessment for the potential of negative emission techniques to contribute safely and fairly to meeting carbon budgets in the 21st Century*
[27] Smith et al. (in press) *Preliminary assessment of the potential for, and limitations to, terrestrial negative emission technologies in the UK*, Environmental Science: Processes & Impacts
[28] ETI (2016) *Progressing development of the UK's strategic carbon dioxide storage resource*

The amount of greenhouse gas removal that options deliver in reality may well be smaller due to social and technical barriers, and how biomass is prioritised. GGR options are therefore a complement to the reduction of greenhouse gas emissions, not a substitute:

- Current estimates of technical potential are close to the scale of remaining emissions sources in our most ambitious UK scenarios to 2050, indicating the requirement for greenhouse gas removals will be stretching.
- Technologies in reality only rarely fulfil estimates of their technical potential. Limiting factors include unforeseen costs and technical issues, wider impacts and public attitudes.
- Biochar, BECCS, afforestation and use of wood in construction all draw on a shared, limited land and biomass resource. BECCS and construction, in which the biomass is harvested and the carbon locked up on a long-term basis, give the greatest removal per unit biomass. However, the potentially large, local benefits (unrelated to climate) from the other methods mean that a mix of options is likely to be deployed.[29]
- Soil carbon management and some other biological options build carbon stores up to a new equilibrium over time, after which continued deployment simply maintains that equilibrium. If deployment stops, some carbon is re-released. Therefore their deployment will not be able to offset emissions from fossil fuels indefinitely.

The aim of the Paris Agreement to balance sources and sinks of greenhouse gases implies the need for a globally coordinated strategy to develop and deploy greenhouse gas removal options. Removal options will be needed to reach zero net emissions in the UK, given the sources of emissions remaining for the foreseeable future. We return to the question of what a high-level strategy for developing greenhouse gas removals might look like in Chapter 4.

[29] Further detailed analysis of UK biochar in particular can be found in Shackley & Sohi (eds) (2010) *An assessment of the benefits and issues associated with the application of biochar to soil*, which suggests a UK potential of 4-20 $MtCO_2$/yr in 2020.

Chapter 4: Considerations in setting UK policy to reflect Paris ambition

Key messages

This chapter draws on the evidence of the previous chapters to set out the factors that should be considered in setting any new long-term target, plus the implications for policies over the next couple of decades (i.e. the time horizon of the Government's upcoming plan to meet carbon budgets).

Our key messages are:

- Current policy in the UK is not enough to deliver the existing carbon budgets that Parliament has set. This policy gap must be closed to meet the existing carbon budgets, and to prepare for the 2050 target and net zero emissions in the longer term.
- The expectation should be that the UK will set a new long-term target to reflect the need to reach net zero emissions globally. However, this should not be set now. Further evidence is needed on national feasibility, inclusion of non-CO_2 greenhouse gases and emissions accounting in order to set a credible target that provides the right incentives.
- The priority for now should be robust near-term action to close the gap to existing targets and open up options to reach net zero emissions:
  - The Government should publish a robust plan of measures to meet the legislated UK carbon budgets, and deliver policies in line with the plan.
  - If all measures deliver fully and emissions are reduced further, this would help support the aim in the Paris Agreement of pursuing efforts to limit global temperature rise to 1.5°C.
  - The Government should additionally develop strategies for greenhouse gas removal technologies and reducing emissions from the hardest-to-treat sectors (aviation, agriculture and parts of industry).
- Both the Paris Agreement and the UK's carbon budget process provide several decision points over the next decade for reassessing UK targets. We will revisit our conclusions on a net zero target for the UK, and the possibility of tightening existing targets, as and when these events or any others give rise to significant developments.

1. Introduction

Chapter 1 compared the Paris Agreement and the UK's existing targets. The Agreement aims to limit global temperature rise to well below 2°C and to pursue efforts to limit it to 1.5°C. To achieve this it sets a new aim for global emissions: to reach net zero in the second half of the century. However, pledges of action to 2030 currently add up to a path to well over 2°C. The UK's 2050 target to reduce emissions to at least 80% below 1990 levels was designed to contribute to a global effort to stay close to 2°C (although it could be consistent with less than 2°C if greenhouse gas removals can reach very large scales later in the century).

Chapter 2 showed that global net CO_2 emissions would need to reach net zero by the 2050s-70s, along with deep reductions of all other greenhouse gases, in order to stay below 2°C. To stay close to 1.5°C CO_2 emissions would need to reach net zero by the 2040s. Based on the same rationale as the existing 2050 target, the UK would aim to reach net zero no later than the rest of the world. Other methods for defining a fair contribution suggest even more ambitious UK effort (although not necessarily to be delivered all through domestic action).

Chapter 3 showed that fully deploying all options in our scenarios (including some greenhouse gas removals) would bring domestic emissions down to just over 90% below 1990 levels by 2050 and net CO_2 emissions close to zero. Even with full deployment, the options in our scenarios are not able to reach zero net emissions of all greenhouse gases. Net zero may be possible with breakthrough reductions in hard-to-reduce sectors and if a range of further

greenhouse gas removal technologies can be deployed. But little is currently known about many of these technologies and their true potential.

Given that set of circumstances we have considered four questions regarding the implications of the Paris Agreement, which are addressed in this chapter:

- Should the UK set a new target for reaching net zero emissions?
- Should the UK change existing targets?
- When should decisions on the UK's targets be revisited?
- What should the UK's domestic policies prioritise in the near term?

2. Setting a UK net-zero emission target

It is clear that reaching zero net global emissions of carbon dioxide is a necessary element of limiting global temperature rise. Reductions in emissions of methane and other, shorter-lived greenhouse gases will also help to reduce warming. For the ambitious global temperature limits in the Paris Agreement, carbon dioxide emissions need to reach net zero within three to six decades, and removal may be required on a sufficient scale to make total greenhouse gas emissions net zero before 2100.

The Government has stated it is not a case of if, but when, they will set a net-zero emission target.[30] We agree with this assessment: the expectation should be that the UK will need a new target to drive action beyond the current 2050 target. Some other jurisdictions around the world have set - or are considering - net-zero targets following the Paris Agreement (Box 4.1).

There are challenges, however, in identifying pathways to reach net zero emissions in the UK and in designing a UK target for net zero. These challenges need to be considered in setting any zero-emission policy target, so that future uncertainty can be managed and the risk of perverse outcomes minimised:

- **Timescale and feasibility**. The critical element of a net zero target is the timescale. While a "top-down" timescale can be inferred from global emissions pathways, we do not currently have detailed "bottom-up" national scenarios of the technologies and behaviours that the UK should deploy to play its part in a zero-emissions world. Particularly uncertain is the scope for deploying greenhouse gas removal technologies in the coming decades, which will be needed nationally and globally to offset remaining sources of emissions.
- **Inclusion of other greenhouse gases.** While the Paris Agreement set the aim of net zero greenhouse gas emissions in order to limit global temperature, the IPCC has only drawn an explicit link between temperature and net zero emissions of carbon dioxide. A target for carbon dioxide alone may be simpler and less difficult to achieve (emissions of methane and nitrous oxide are among the hard-to-treat sectors we have identified). Nevertheless, current targets already include non-CO_2 greenhouse gases and deep reductions in these emissions are required alongside CO_2 in order to meet the Paris aims.
- **Emissions accounting and trading.** Current emissions accounting towards the 2050 target includes a combination of UK territorial emissions and some possible trading of international

[30] Hansard HC Deb vol 607 col 725 (14 March 2016)

Box 4.1 New net-zero emissions targets following the Paris Agreement

To date, at least two nations and one US state have publicly moved to legislate a more ambitious long-term target in light of the Paris Agreement:

- Sweden already had a target to reach net zero emissions by 2050, supported analytically by a cross-government roadmap. It is now in the process of bringing this forward to 2045. The target does not include Sweden's share of international transport, and allows up to 15% of the reduction to come from international emissions credits.
- The Norwegian Parliament has agreed to aim for zero greenhouse gas emissions by 2030. Currently there is little analysis of how Norway can reach this target through domestic action; a previous report by the Norwegian Environment Agency outlines a route to a 40% reduction by 2030, and it is expected that net zero emissions will be met in large part through emissions credits.
- A bill was proposed in New York State to reduce greenhouse gas emissions sources to zero by the year 2050, with a target of at least a 50% reduction below 1990 levels by 2030. It was passed by the General Assembly but also requires passing by the state Senate in order to become law.

The European Commission has announced it does not intend to change its policies or targets to 2030 in light of the Paris Agreement. However, extrapolation of its current emissions caps (which fall linearly over time) implies EU-wide emissions would reach net zero in the early 2060s:

- The EU has an existing goal of an 80-95% reduction below 1990 levels by 2050. Relevant to this goal will be the mid-century low greenhouse-gas plan for communication to the UNFCCC by 2020, for which the Commission has committed to preparing an in-depth economic and social analysis.
- Current EU policy implies an annual decline rate for emissions in the Emissions Trading System (ETS) of 48 $MtCO_2e$/yr after 2020 and of 59 $MtCO_2e$/yr for non-ETS emissions. Extrapolating these rates implies net zero emissions in 2062.

Stepping up these decline rates will be necessary in order for the EU to pass through 80-95% reductions by 2050. Assuming the decline rate increases after 2030 to pass though 80%, if this decline were to continue after 2050, net zero would be reached in 2060. If 2050 ambition increases to pass through 90%, net zero would be reached in the early 2050s.

Source: European Commission COM(2016) 110 final; Swedish Environmental Protection Agency (2012) *Basis for a roadmap for a Sweden without climate emissions in 2050*, http://www.naturvardsverket.se/fardplan2050; Norwegian Environment Agency (2015) *Climate mitigation measures and emission trajectories up to 2030*, http://www.miljodirektoratet.no/Documents/publikasjoner/M418/M418.pdf; New York State Assembly Bill No. A10342, http://assembly.state.ny.us/leg/?default_fld=&leg_video=&bn=A10342&term=2015&Summary=Y.

emissions credits. The UK has a wider carbon footprint from its consumption, which is also monitored by the Government.[31] It is important to continue this monitoring in order to understand the carbon intensity of trade and assess the full impact of policies.[32] Furthermore, the potential role of future emissions trading in a net zero target is not yet clear. It remains our view that UK targets should focus on domestic effort while promoting effective, efficient markets and globally co-ordinated emission reduction:

– The Paris Agreement makes provision for a new market mechanism for trading emissions credit between countries, as well as non-market approaches to co-operation. The details of these schemes are to be worked out in negotiations over the coming years.

[31] Defra (2016) *UK's carbon footprint 1997-2013.*

[32] CCC (2013) *Reducing the UK's carbon footprint and managing competitiveness risks.*

- We have previously stated that the UK should aim to reach its 2050 target through domestic action, given that international credits may be very expensive in a world of low emissions.
- If removal options are scaled up successfully there may be greater scope for trading in 2050 and beyond. The relative cost of removals will likely vary around the world, depending on different national resources such as land and geological stores.
- It may be cheaper for the UK to buy credits from other countries than to reach zero emissions domestically. On the other hand, the UK's access to large geological storage sites for CO_2 may mean it is well-placed to sell removals to other countries.

- **Signalling to decision makers and stakeholders**. The main advantages in setting a UK net zero target would be the signal internationally of support for ambitious climate action, and domestically of the need for complete decarbonisation beyond 2050. That could help support key zero-carbon options (including in the heat sector, where technologies such as heat pumps and hydrogen are priorities alongside improved energy efficiency) and removal technologies, as well as supply chains that contribute to both (including CCS and sustainable biomass). However, a new ambitious target that is not supported by additional plans and actions to meet it risks undermining the credibility of UK climate policy.

On balance, we have concluded that a new net-zero target should not be set now. The UK will have to set a new target in future that reflects the global need to reach net zero emissions, as the Government has recognised, but the precise timing and the way of achieving net zero in the UK is not yet clear. This contrasts with the current carbon budgets and the 2050 target, which can be achieved in various ways based on well-characterised technologies. The Government should continue to plan for net zero, at least for CO_2 emissions, and the case for a target should be revisited in the near future (see Section 4).

3. Considering raising the ambition of the UK's existing targets

The UK's 2050 target is derived as a contribution to a global path aimed at keeping global average temperature rise to around 2°C, with the UK carbon budgets on the lowest-cost path to 2050. In contrast, the aim of the Paris Agreement is to limit warming to well below 2°C and to pursue efforts to limit it to 1.5°C.

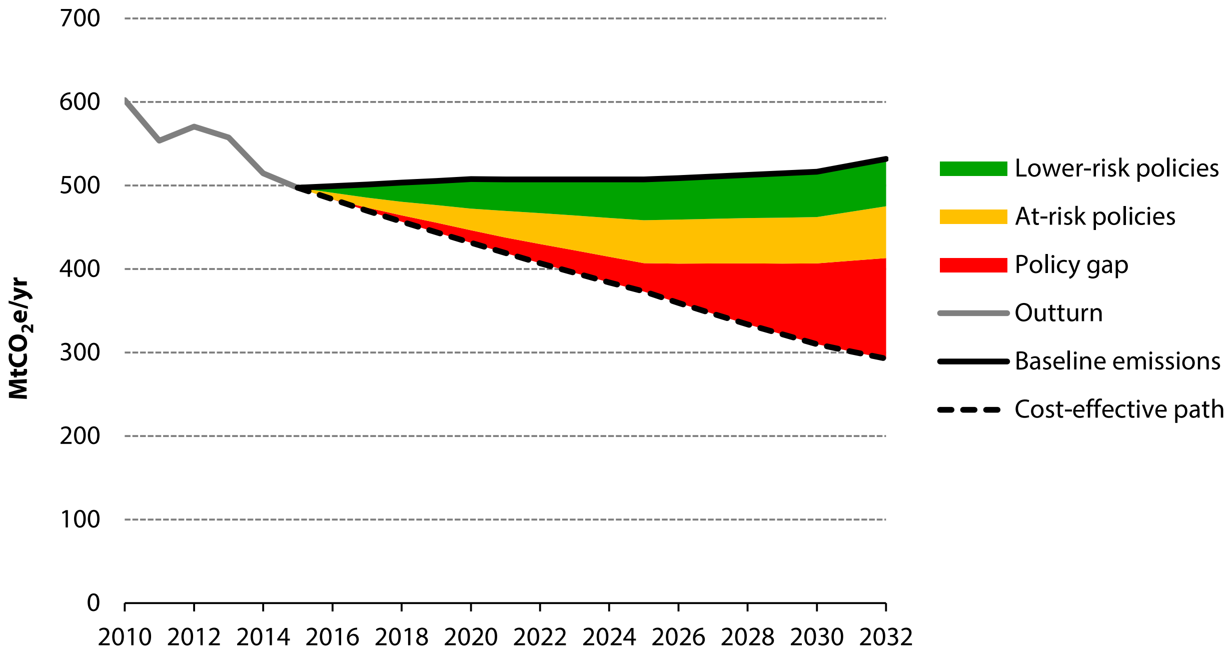
Limiting global temperature rise to 1.5°C is an extremely challenging goal. Cost-effective pathways to below 2°C require global emissions to fall to around 40 $GtCO_2e$/yr by 2030, with further reductions thereafter, while under current pledges of action emissions will grow to around 56 $GtCO_2e$/yr.[33] We therefore interpret the goal of pursuing efforts to 1.5°C as implying a desire to strengthen and potentially to overachieve on efforts towards 2°C.

We have considered whether the UK should commit now to increased efforts by revising the targets in the Climate Change Act (i.e. the 2050 target to reduce emissions at least 80% below 1990 levels and the carbon budgets, which require a 57% reduction by 2030). Our conclusion is that these targets are already stretching and should not be tightened now, but should be kept under review:

[33] UNFCCC (2016) *Updated synthesis report on the aggregate effect of INDCs*.

- UK emissions need to fall by around a third from 2015 to 2030 to meet the fifth carbon budget. Current policies would, at best, deliver about half of the reduction required by 2030 (Figure 4.1). This gap must be closed before any higher ambition can be achieved.
- In terms of absolute emissions reduction below 1990 levels, the UK reduction set by the fifth carbon budget is at the more ambitious end of the range of international pledges to 2030.[34] Methods for assessing a fair contribution suggest this is appropriate. The fifth carbon budget also implies a deeper reduction by 2030 than the UK was due to be allocated as an 'effort share' under the EU's pledge to the Paris Agreement.[35]

Figure 4.1. Assessment of current policies against the cost-effective path to meet carbon budgets and the 2050 target



Source: CCC (2016) *Meeting carbon budgets - Implications of Brexit for UK climate policy*
Notes: 'Lower-risk policies' (green) are those that aim to address known barriers and have sufficient funding and ambition to deliver with reasonable confidence. 'At-risk policies' (amber) either lack sufficient funding, do not address known barriers or have important design elements still to be confirmed. No funded policies exist to close the 'policy gap' (red), even though the Committee's scenarios identify abatement options to do so that are on the lowest cost path to meet the carbon budgets and the 2050 target. 'Baseline emissions' is the likely path of emissions in the absence of policy effort.

[34] http://www.c2es.org/indc-comparison
[35] CCC (2015) *The fifth carbon budget - the next step towards a low-carbon economy*

However, we note that there is scope to outperform the UK's existing targets:

- The UK's 2050 target is for a reduction of *at least* 80% relative to 1990. Similarly carbon budgets prescribe the maximum level of emissions, but do not preclude deeper reductions.
- As part of good budget management the Government should aim to deliver emissions reductions in all areas of the economy. That would provide some contingency should any one area under-deliver. If all areas deliver fully, emissions would be reduced below the level of the existing targets (e.g. our most ambitious scenarios imply emissions 66% below 1990 levels in 2030 and around 90% below by 2050).[36]

If UK emissions do fall further than required by carbon budgets, this would help support the aim in the Paris Agreement of pursuing efforts to limit global temperature rise to 1.5°C. The presumption in this case should be that effort is not reduced and that any excess emissions are not carried forward to reduce effort in future budgets.[37]

Emissions trading and other forms of international assistance are important ways in which the UK contributes in addition to domestic action. Efforts over the next couple of decades could play a key role in raising international action:

- Emissions accounting allows for purchase of international credits to count towards UK carbon budgets. In our fifth carbon budget advice we noted that the carbon budgets should be met through domestic action in order to keep on track to the 2050 target, but emissions credits could be used to raise international ambition further.
- The UK is already committed to several forms of international co-operation. It has pledged £5.8 billion during 2016-21 to the International Climate Fund, as well as supporting a number of bilateral and multinational projects.[38] These were pledged before the Paris negotiations and its raised global ambition were agreed. Maximising the effectiveness of UK assistance could be an effective part of the global effort to make action more consistent with ambition.

The UK played an important role in reaching the Paris Agreement, and should continue its support and co-ordination of action with other nations. Enhancing this support and co-ordination could contribute to meeting the aims of the Paris Agreement alongside a full delivery of the UK's domestic commitments to reduce emissions.

4. Future decision points for reviewing UK targets

The “pledge and review” mechanism created by the Paris Agreement sets a schedule of global stocktaking intended for nations to revisit their commitments and steadily ratchet them up. Together with the five-yearly setting of carbon budgets under the Climate Change Act, this creates a number of decision points over the next two Parliaments (Figure 4.2).

Notably in this Parliament, an international “facilitative dialogue” will occur in 2018 in order to take stock of the collective effort and inform the next round of emissions pledges. Each party to the UN negotiations will also need to communicate a revised pledge, as well as a mid-century low greenhouse-gas development plan by 2020. This will be an important indicator of collective long-term ambition for domestic emissions.

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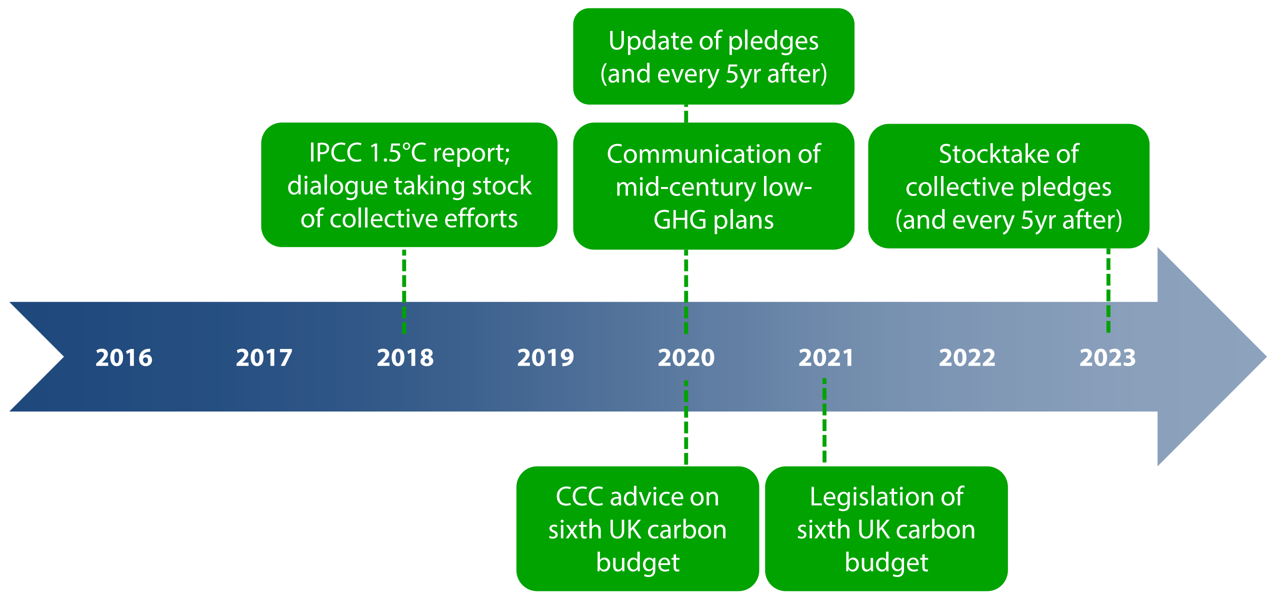
[36] This is in terms of actual UK emissions, without any adjustment for trading in the EU Emissions Trading System.
[37] The Climate Change Act includes provisions (clause 17) to carry forward emissions from one budget to the next when emissions are below the level of the earlier budget and with advice from the Committee.
[38] DECC (2015) *The UK’s Second Biennial Report under the United Nations Framework Convention on Climate Change*.

Figure 4.2. Timeline of decision points set by national and international legislation for reassessing UK emissions targets



We will revisit our conclusions on a net zero target for the UK, and the possibility of tightening existing targets, as and when these events or any others give rise to significant developments.

5. Near-term implications for UK domestic policy

Although we do not recommend changing existing targets or setting a new net zero target now, the Paris Agreement does have new implications. It is clear that the UK should aim towards reaching net zero in future and may need to increase effort beyond existing budgets.

That will only be possible if the UK fully delivers on existing targets and develops options for greenhouse gas removals.

i) Meeting existing budgets

The Government is required by the Climate Change Act to set out proposals and policies for achieving carbon budgets, and has committed to publishing its plan in the coming months. That plan needs to strengthen policy in a number of areas to provide a robust route to the 2030s.

Our annual progress report to Parliament[39] revealed a mixed picture of UK progress to date in reducing emissions cost-effectively:

- Overall UK emissions have fallen and some policy areas have progressed, such as extended support for offshore wind, renewable heat and electric vehicles.
- There have been backward steps in other areas, such as cancellation of the Commercialisation Programme for CCS, reduction in support for energy efficiency and cancellation of the zero carbon homes standard.

[39] CCC (2016) *Meeting carbon budgets - 2016 progress report to Parliament*

- Other priorities have not moved forward, such as the lack of further auctions for the cheapest low-carbon electricity generation (onshore wind and solar) even where locally accepted, the lack of an effective approach to drive uptake of low-carbon heat and energy efficiency in buildings, and the lack of vehicle efficiency standards beyond 2020.

We concluded that current policies are on course to deliver, at best, about half the necessary emissions reductions from now to 2030. In order to close that policy gap we identified priorities across the economy for the Government's forthcoming plan (Table 4.1). These include:

- **Heat in buildings.**[40] Clear, consistent and credible policies are needed, both for new homes to be built highly energy efficient and ready for low-carbon heating, and for existing buildings to be better insulated and fitted with heat pumps and district heating. Policies should incentivise owners and landlords of homes and workplaces, overcome behavioural barriers and build up skills and supply chains. Alongside these measures, the Government should prepare for a set of decisions in the next Parliament on the role of hydrogen.

- **Carbon capture and storage (CCS).**[41] CCS is critically important to a range of options to reduce emissions and to developing greenhouse gas removals in the longer term. Despite some global progress, there is no UK strategy for the development of CCS following the cancellation of the Commercialisation Programme in November 2015. A new strategic approach is needed based around 'clusters' in areas of industrial activity and with separate support for shared CO_2 transport and storage infrastructure.

- **Transport policy beyond 2020.** Standards for CO_2 emissions from new cars and vans need to be extended and strengthened through the 2020s. Standards should also be set for HGVs. Compliance should be based on real-world driving and tested by independent authorities. Electric vehicles should be supported by developing a nationwide infrastructure for charging and addressing cost barriers while they remain. Measures to encourage walking, cycling, ride sharing and public transport would help reduce emissions and have a range of co-benefits.

- **Contracts for low-carbon power generation.** Effective policy has been developed to support low-carbon electricity generation through contracts for difference allocated by competitive auctions. However, no auctions have taken place since 2015 and none are planned for the cheapest technologies (e.g. onshore wind and solar). Funding for offshore wind to 2025 and the contract signed for a new nuclear station at Hinkley Point would provide only around a third of the additional low-carbon generation required in the 2020s. The Government should offer and sign more contracts for low-carbon power in the 2020s, consistent with reducing emissions intensity to below 100 gCO_2/kWh by 2030.

The international agreement to raise long-term ambition and the new system of pledge-and-review mean it should be a priority to ensure existing UK carbon budgets are met. Only by delivering on existing targets can higher ambition be delivered in future, as is likely to be required to meet the aims of the Paris Agreement.

[40] CCC (2016) *Next steps for UK heat policy*

[41] CCC (2016) *Letter to Rt Hon Amber Rudd: A strategic approach to Carbon Capture and Storage, https://www.theccc.org.uk/publication/letter-to-rt-hon-amber-rudd-a-strategic-approach-to-carbon-capture-and-storage/*

Table 4.1. Requirements in the Progress Report for the Government's plan to meet carbon budgets

Policy requirement	New policy required	Stronger implementation required
Power (21% of 2015 emissions): Emissions intensity to fall by around 75% (to below 100 gCO_2/kWh) between 2015 and 2030, with options developed to allow near-zero emissions by 2050		
A strategic approach to carbon capture and storage deployment in the UK	✗	
An approach to bring forward the cheapest low-carbon generation (e.g. auctions for generation from onshore wind, solar and sustainable biomass)	✗	
Support for offshore wind as costs are driven down, based on funding and cost goals announced in the 2016 Budget		✗
Plans for flexibility options (e.g. storage, interconnection, demand response), including rapid development of market rules to ensure that revenues available to these options reflect their full value to the electricity system		✗
Contingency plans for delay or cancellation of planned projects, for example new nuclear power plants	✗	
Buildings (18% of 2015 emissions): Emissions to fall by around 22% between 2015 and 2030, with options developed to allow near-zero emissions by 2050		
Clear, consistent and credible policies to drive deployment of heat pumps and district heating, including: immediate action to address barriers (e.g. upfront cost, low awareness) alongside the Renewable Heat Incentive and development of a more comprehensive policy package to drive the higher uptake needed in the long run	✗	
Standards to ensure new-build properties are highly energy efficient and use low-carbon heating systems by default	✗	
A stronger policy framework to drive residential energy efficiency improvement by addressing gaps and strengthening existing policies, including: addressing behavioural factors for the able-to-pay, increased funding for fuel poor households, an effective approach to the private-rented sector	✗	✗
More progress on improving the energy efficiency of non-residential buildings, including: a consolidated reporting mechanism for commercial and public buildings, new emissions reduction targets for the public estate, new policies to support SMEs in England	✗	✗
Industry (23% of 2015 emissions): Emissions to fall by around 20% between 2015 and 2030		
An overall approach to long-term industrial decarbonisation, developing existing 'Roadmaps' into specific actions and milestones and extending coverage to other industrial sectors		✗
A strategic, funded approach to industrial carbon capture and storage, based around clusters alongside power installations and shared infrastructure, with a new funding mechanism for industry	✗	

An effective approach to drive sustained uptake of low-carbon heat in industrial processes and buildings	✗	
A stronger policy framework for industrial energy efficiency, including reviewed Climate Change Agreements and an effective reporting mechanism		✗
<u>Domestic transport</u> (24% of 2015 emissions): Emissions to fall by around 43% between 2015 and 2030 with options developed to allow near-zero emissions by 2050		
Stretching standards for new car and van CO_2 beyond 2020, that require increased electric vehicle sales, are independently enforced and use real-world testing procedures	✗	
Policies to achieve a high uptake of electric vehicles by 2030, of around 60% of new sales, including: direct or indirect financial support until costs are driven below conventional vehicles, and development of a national network of charge points		✗
Policy to increase uptake of sustainable biofuels to around 8% (by energy) by 2020		✗
Policies to reduce emissions from HGVs, including vehicle efficiency improvements based on 'real-world' testing, driver training, more efficient logistics, modal shift to rail and development of ultra-low emission technologies, such as electric and hydrogen options	✗	
National and local policies to reduce demand for car travel, sufficient to deliver car-km reductions of around 5% below the baseline trajectory, including through shifts to public transport, cycling and walking	✗	✗
A plan to limit UK aviation emissions to around 2005 levels by 2050, implying around a 60% potential increase in demand, supported by strong international policies	✗	
<u>Agriculture, land use, land-use change and forestry</u> (8% of 2014 emissions): Emissions to fall by around 15% between 2014 and 2030, and afforestation rate to increase to 15,000 hectares per year		
The new Smart Inventory to be introduced in 2017		✗
A stronger policy framework for agriculture emissions reduction across all nations, both to 2022, as current progress is not on track, and after 2022; that should move beyond the current voluntary approach of providing information and advice	✗	✗
Addressing financial and non-financial barriers to increase afforestation and agro-forestry		✗
<u>Waste</u> (3% of 2014 emissions): Emissions to fall by around 50% between 2014 and 2030		
Strengthened approaches through the waste chain, including waste prevention, separate collections (e.g. of food waste), diverting biodegradable waste from landfill and increased methane capture at landfill sites	England N Ireland	Wales Scotland
<u>F-gases</u> (3% of 2014 emissions): Emissions to fall by at least 70% between 2014 and 2030		
Monitoring, implementation and enforcement of the existing F-gases regulation		✗
Seeking cost-effective opportunities to reduce F-gas emissions further than existing legislation requires, including assessing and addressing barriers to action	✗	

Source: CCC (2016) *Meeting carbon budgets - 2016 progress report to Parliament.*
Notes: 1. In some areas success will need both new policies and stronger implementation of existing plans/policies. In these cases both columns are checked. In all cases plans and policies, whether new or existing, will need to be strongly implemented. 2. The latest non-CO_2 data is for 2014.

ii) Developing a strategy for greenhouse gas removal

Chapter 3 considered the need to develop options for removing greenhouse gases from the air, given the likelihood of continued emissions from some sources. The diversity of options, with their uncertain costs and impacts, mean it is currently unclear which options might be best. A portfolio approach to their development should be pursued.

Elements of a strategy to develop GGR technologies have been proposed in the literature.[42] Any such strategy is likely to require a mix of support through basic research, targeted deployment and development of suitable regulatory frameworks:

- **Support for research, development and demonstration.** Research will help clarify whether options deliver genuine long-term greenhouse gas removal and address technical, environmental and social challenges. Examples include improving measurement of land carbon, assessing impacts over the lifecycle of bioenergy crops and biochar, and testing of direct air capture processes.
- **Support for deployment.** Targeted deployment provides the opportunity to bring down costs and further understand impacts for options that are technically more mature. Support can be in the form of removal of barriers as well as incentives. Examples for deployment include carbon capture and storage infrastructure,[43] sustainable bioenergy crops, afforestation and wood in construction.
- **Integration into policy and accounting frameworks.** Greenhouse gas removal by suitably effective, permanent sinks should count equally with reduction of emissions. The lack of a long-term policy commitment to rewarding removals is a key barrier to development. Schemes such as the EU ETS and the Common Agricultural Policy (CAP) could be structured to provide economic incentives but currently are not.
- **Integration into a global strategy** that pools international resources (given greenhouse gas removals are of global benefit), fosters good governance and reflects the fact that different removal technologies may be best deployed in different locations.

Ways to further reduce residual emissions from hard-to-treat sectors (aviation, agriculture and industry) are also an innovation priority. Options could, for example, include support for new technologies, products and innovation in each of these areas and shifting demand to lower-emissions alternatives (e.g. increased re-use of products and materials, and further shifts towards virtual conferencing in place of international travel). Global initiatives such as Mission Innovation and the Breakthrough Energy Coalition could usefully target both these sectors and GGR technologies.

Funding and policy support for GGR research, development and demonstration in general is currently very low.[44] UK-based funding for GGR research has emerged in recent months[45] but it will need to be expanded and accompanied by other elements noted above in order to develop

[42] Lomax et al. (2015) *Reframing the policy approach to greenhouse gas removal technologies*, Energy Policy

[43] CCC (2016) *A strategic approach to Carbon Capture and Storage*, Letter to DECC Secretary of State

[44] Centre for Carbon Removal (2016) *Philanthropy beyond carbon neutrality : How near-term grants to carbon removal can make long-term climate goals a reality*

[45] http://www.nerc.ac.uk/research/funded/programmes/ggr/news/ao-ggr/; https://www.leverhulme.ac.uk/news/leverhulme-trust-invests-£40-million-new-uk-centres-innovative-research

a full and effective strategy. Given that options will be required around the world to reach net zero emissions, UK efforts could have a significant international impact and secure a leadership position in this area. The fact that new technologies typically take 30-40 years to develop from invention to mass deployment[46] means a strategy for sustainable deployment at scale by 2050 should start now.

[46] UKERC (2015) *A review of the evidence on the time taken for new technologies to reach widespread commercialisation.*

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