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Net Zero
The UK's contribution to stopping global warming

Committee on Climate Change
May 2019

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Foreword

In this report, the Committee on Climate Change recommends a new emissions target for the UK: net-zero greenhouse gases by 2050.

Our recommendation emerges clearly from the extensive evidence presented here for the first time. We have reviewed the latest scientific evidence on climate change, including last year's IPCC Special Report on Global Warming of 1.5°C, and considered the appropriate role of the UK in the global challenge to limit future temperature increases. We have built a new understanding of the potential to achieve deep emissions reduction in the UK and made a fresh appraisal of the costs and benefits to the UK economy of doing so.

We conclude that net-zero is necessary, feasible and cost-effective. Necessary – to respond to the overwhelming evidence of the role of greenhouse gases in driving global climate change, and to meet the UK's commitments as a signatory of the 2015 Paris Agreement. Feasible – because the technologies and approaches that will deliver net-zero are now understood and can be implemented with strong leadership from government. Cost effective – because falls in the cost of key technologies permit net-zero within the very same costs that were accepted as the likely costs by Parliament in 2008 when it legislated the present 2050 target.

This is the continuation of an important journey in the UK. In 2003, the UK pursued a target to reduce CO_2 emissions by 60% from 1990 levels on the understanding it would carry a cost of 0.5 - 2.0% of GDP in 2050. In 2008, on the advice of this Committee, Parliament moved to an 80% target for all greenhouse gases, accepting that the costs were between 1-2% of GDP in 2050. Now, our analysis demonstrates that we can adopt an even more ambitious target, within the same cost envelope as before.

But net-zero is a more fundamental aim than previous targets. By reducing emissions produced in the UK to zero, we also end our contribution to rising global temperatures. That this outcome is now within reach is testament to the UK's progress – deploying new solutions, learning by doing, driving costs down, as required by the Climate Change Act. The Act was the world's first legally-binding framework for tackling climate change and it remains one of the strongest in the world to this day. Committing to net-zero will reaffirm the Act's strength, but it is essential that the commitment is comprehensive, achieved without use of international credits and covering international aviation and shipping.

Climate change is a global issue and UK leadership is a strong theme of our advice. UK emissions now constitute only a small proportion of the global total, but those who say the UK's actions no longer matter are wrong. Every tonne of carbon counts, wherever it is emitted. In setting a net-zero target, the UK will be among a small group of countries handling climate change with appropriate urgency. The new target meets fully the requirements of the Paris Agreement, including the stipulation of 'highest possible ambition', and sets the standard for the EU and other developed countries as they consider their own pledges to the global effort.

It is right that the UK takes a lead on this issue. We have played a major part in the battle against global climate change to date. The UK is one of the largest historical contributors to climate change. And there is the prospect of real benefits to UK citizens: cleaner air, healthier diets, improved health and new economic opportunities from clean growth.

All of this rests, however, on more than a new target. Our advice is offered with the proviso that net-zero is only credible if policies are introduced to match. Existing ambitions must be delivered in full, challenges that have so far been out of scope must now be confronted. The UK must make firm plans for housing and domestic heat; for industrial emissions; carbon capture and storage; road transport; agriculture; aviation and shipping. There is a manageable cost to tackling these challenges, and the lesson of the last decade is that costs fall when there is a concerted effort to act.

More and more we understand the importance of policies made outside of Westminster. How housing and transport needs are met in our towns and cities, or how the natural environment is managed in each area of the UK. Achieving net-zero overall requires an integrated set of policies throughout the UK, which make the most of the attributes of each of the UK nations. The Governments of Scotland, Wales and Northern Ireland must make full use of the policy levers available to them and work with the UK Government on UK-wide plans.

We have assessed the contribution that Wales and Scotland can make to net-zero in the UK, under their respective statutory frameworks. In Wales, we recommend a 95% reduction in greenhouse gases by 2050. In Scotland, we recommend a net-zero date of 2045, reflecting Scotland's greater relative capacity to remove emissions than the UK as a whole. These are tough, but achievable targets, in line with the UK net-zero target.

This is the most thorough assessment my Committee could compile; our recommendations the most robust we can offer. My sincere thanks to the brilliant team who have helped us reach these conclusions.

I urge the governments of the UK, in London, Edinburgh, Cardiff to consider our advice carefully and legislate for these new targets as swiftly as possible. We must now increase our ambition to tackle climate change. The science demands it; the evidence is before you; we must start at once; there is no time to lose.

The Rt Hon. the Lord Deben, Chairman

Executive summary

The UK should set and vigorously pursue an ambitious target to reduce greenhouse gas emissions (GHGs) to 'net-zero' by 2050, ending the UK's contribution to global warming within 30 years.

Reflecting their respective circumstances, Scotland should set a net-zero GHG target for 2045 and Wales should target a 95% reduction by 2050 relative to 1990.

A net-zero GHG target for 2050 will deliver on the commitment that the UK made by signing the Paris Agreement. It is achievable with known technologies, alongside improvements in people's lives, and within the expected economic cost that Parliament accepted when it legislated the existing 2050 target for an 80% reduction from 1990.

However, this is only possible if clear, stable and well-designed policies to reduce emissions further are introduced across the economy without delay. Current policy is insufficient for even the existing targets.

A net-zero GHG target for 2050 would respond to the latest climate science and fully meet the UK's obligations under the Paris Agreement:

- It would constitute the UK's '**highest possible ambition**', as called for by Article 4 of the Paris Agreement. The Committee do not currently consider it credible to aim to reach net-zero emissions earlier than 2050.
- It goes beyond the reduction needed globally to hold the expected rise in global average temperature to **well below 2°C** and beyond the Paris Agreement's goal to achieve a balance between global sources and sinks of greenhouse gas emissions in the second half of the century.
- If replicated across the world, and coupled with ambitious near-term reductions in emissions, it would deliver a greater than 50% chance of limiting the temperature increase to **1.5°C**.

Now is a crucial time in the global effort to tackle climate change, with revised pledges of effort currently being considered ahead of the UN climate summit in late-2020. An ambitious new UK target would encourage increases in ambition elsewhere, including the adoption of other net-zero GHG targets, such as the 2050 target currently under consideration by the European Union.

In committing to a net-zero GHG target, Parliament must understand that, while many of the policy foundations are in place, a major ramp-up in policy effort is now required:

- **The foundations are in place.** Policy development has begun for many of the components needed to reach net-zero GHG emissions: low-carbon electricity (which must quadruple its supply by 2050), efficient buildings and low-carbon heating (needed throughout the building stock), electric vehicles, carbon capture and storage (CCS), diversion of biodegradable waste from landfill, phase-out of fluorinated gases, increased afforestation and measures to reduce emissions on farms. These policies must be strengthened and they must deliver action.
- **A net-zero GHG target is not credible unless policy is ramped up significantly.** Most sectors will need to reduce emissions close to zero without offsetting; the target cannot be met by simply adding mass removal of CO_2 onto existing plans for the 80% target.
  - **Delivery must progress with far greater urgency.** Many current plans are insufficiently ambitious; others are proceeding too slowly, even for the current 80% target:
    - 2040 is too late for the phase-out of petrol and diesel cars and vans, and current plans for delivering this are too vague.

- Over ten years after the Climate Change Act was passed, there is still no serious plan for decarbonising UK heating systems and no large-scale trials have begun for either heat pumps or hydrogen.
- Carbon capture (usage) and storage, which is crucial to the delivery of zero GHG emissions and strategically important to the UK economy, is yet to get started. While global progress has also been slow, there are now 43 large-scale projects operating or under development around the world, but none in the UK.
- Afforestation targets for 20,000 hectares/year across the UK nations (due to increase to 27,000 by 2025), are not being delivered, with less than 10,000 hectares planted on average over the last five years. The voluntary approach that has been pursued so far for agriculture is not delivering reductions in emissions.

– **Challenges that have not yet been confronted must now be addressed** by government. Industry must be largely decarbonised, heavy goods vehicles must also switch to low-carbon fuel sources, emissions from international aviation and shipping cannot be ignored, and a fifth of our agricultural land must shift to alternative uses that support emissions reduction: afforestation, biomass production and peatland restoration. Where there are remaining emissions these must be fully offset by removing CO_2 from the atmosphere and permanently sequestering it, for example by using sustainable bioenergy in combination with CCS.

– **Clear leadership is needed, right across Government, with delivery in partnership with businesses and communities.** Emissions reduction cannot be left to the energy and environment departments or to the Treasury.[1] It must be vital to the whole of government and to every level of government in the UK. Policies must be fully funded and implemented coherently across all sectors of the economy to drive the necessary innovation, market development and consumer take-up of low-carbon technologies, and to positively influence societal change.

- **Overall costs are manageable but must be fairly distributed.**
  – There have been rapid cost reductions during mass deployment for key technologies (e.g. offshore wind and batteries for electric vehicles). As a result, we now expect that a net-zero GHG target can be met at an annual resource cost of up to **1-2% of GDP** to 2050, the same cost as the previous expectation for an 80% reduction from 1990.
  – The transition, including for workers and energy bill payers, must be fair, and perceived to be fair. Government should develop the necessary frameworks to ensure this. An early priority must be to review the plan for funding and the distribution of costs for businesses, households and the Exchequer.

The background for this report is one of increased awareness of climate risks and falling low-carbon technology costs, but where global emissions continue to rise:

- Global average temperature has already risen 1°C from pre-industrial levels and climate risks are increasingly apparent. The Special Report of the Intergovernmental Panel on Climate Change (IPCC) in October 2018 emphasised the critical importance of limiting further

[1] i.e. the Department for Business, Energy and Industrial Strategy (BEIS); the Department for Environment, Food and Rural Affairs (Defra); and HM Treasury (HMT).

warming to as low a level as possible and the need for deep and rapid reductions in emissions to do so.

- Current pledges of effort from countries across the world would lead to warming of around 3°C by the end of the century. This is an improvement on the warming of over 4°C expected when the UK Climate Change Act was passed, but it is well short of the Paris Agreement's long-term goal to limit the rise to well below 2°C and to pursue efforts to 1.5°C.
- While the UK has demonstrated that it is possible to cut emissions while growing the economy, global emissions continue to rise.
- However, falling costs for key technologies mean that the future will be different from the past: renewable power (e.g. solar, wind) is now as cheap as or cheaper than fossil fuels in most parts of the world.

This report responds to a request from the Governments of the UK, Wales and Scotland, asking the Committee to reassess the UK's long-term emissions targets.[2] The UK Government has already committed to reducing UK emissions to net-zero[3] - the key question for this report is by when.

We do not start from an assumption that the world will meet the Paris Agreement's temperature goal. Instead, we have sought to identify a UK target that is within reach and best supports an increase in global effort, consistent with bringing the expected temperature rise down from the current trajectory. Success will bring huge benefits for the world and for the UK by limiting some of the worst climate risks.

In developing our advice we have consulted widely, issued a public Call for Evidence, and compiled an extensive evidence base. Our new emissions scenarios draw on ten new research projects, three expert advisory groups, and reviews of the work of the IPCC and others.

We also make recommendations for the statutory frameworks in Scotland and Wales, which are contingent on the UK adopting a net-zero GHG target for 2050, given the importance of reserved UK policy levers alongside devolved action. The key recommendations are set out in Box 1 and Figure 1 summarises how the evidence has informed our advice.

The rest of this summary addresses the questions posed in the governments' request, along with next steps and conclusions. It is set out in seven sections:

1. Is now the right time to set a net-zero target?
2. Should the net-zero target be for CO_2 or all GHGs?
3. When should the UK reach net-zero GHGs and what should the long-term targets be for the UK, Scotland and Wales?
4. How can the UK reach net-zero GHGs?
5. What are the expected costs and benefits of a UK net-zero GHG target for 2050?
6. Next steps
7. Conclusion

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[2] In the absence of a Minister, Northern Ireland officials indicated their support for the advice being sought. Northern Ireland does not currently have its own long-term target for emissions, but is included within UK targets.
[3] www.parliament.uk/business/publications/written-questions-answers-statements/written-question/Commons/2016-04-18/34423/

Figure 1. The analysis in this report supports the setting of a UK net-zero GHG target for 2050

Science & International context

Global 2050 per capita emissions aligned to Paris: -0.4-1.7 tCO_2e for 1.5°C; 0.8-3.2 tCO_2e for well below 2°C

The UK can and should go further than the world's average

Other climate leaders are aiming for net-zero GHG emissions by 2050 or before

Reaching net-zero emissions in the UK

Credible scenarios can reduce UK GHG emissions to net-zero by 2050

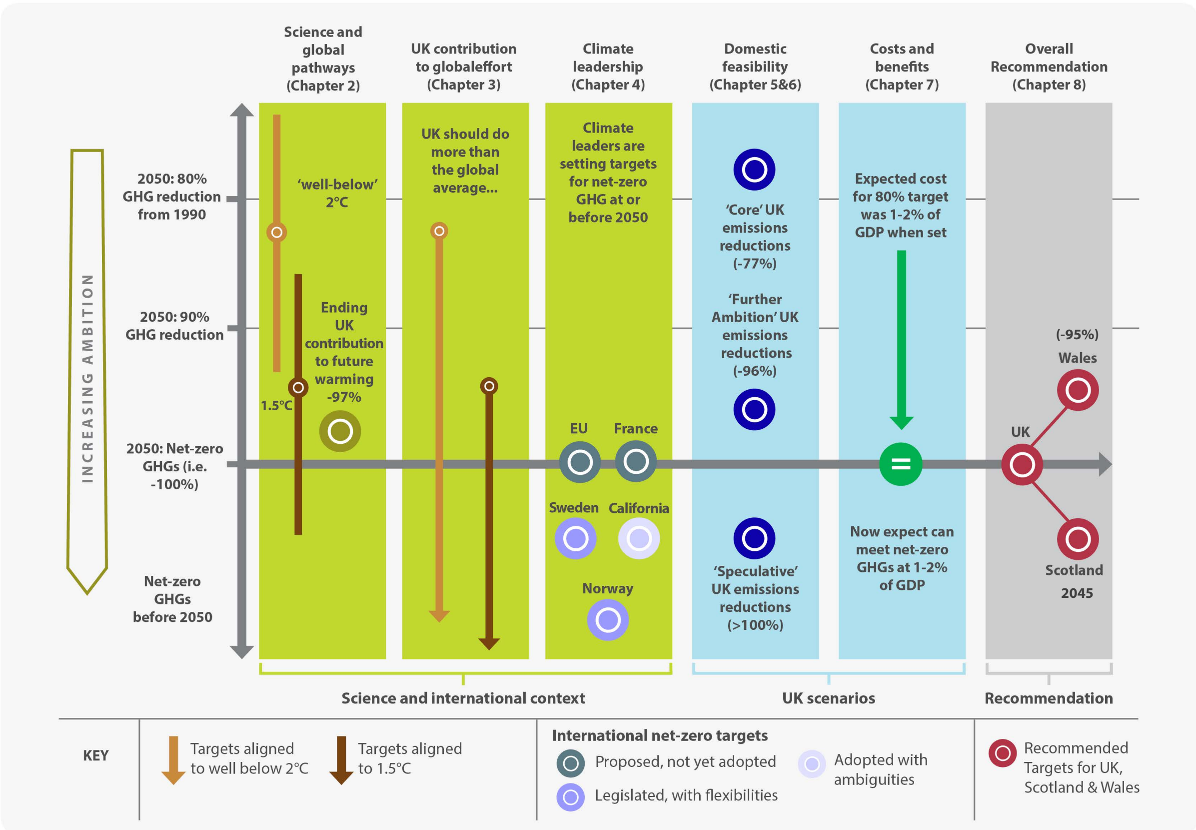
The foundations for the change are in place, but a major ramp-up and acceleration in policy effort is required

Expected cost of a net-zero target is the same as the cost accepted by Parliament when the existing 80% target was set

UK should target net-zero GHG emissions by 2050 / Scotland 2045 / Wales -95% in 2050

Backed by significant policy strengthening

HM Treasury should review where the costs of the transition fall



Notes: Sweden and Norway allow offsetting towards their targets; California have not been explicit that their target covers all GHGs or whether offsetting will be allowed (see Table 2).

Box 1. Recommendations on revising the UK's long-term emissions targets

- The UK should legislate as soon as possible to reach **net-zero greenhouse gas emissions by 2050**. The target can be legislated as a 100% reduction in greenhouse gases (GHGs) from 1990 and should cover all sectors of the economy, including international aviation and shipping.
- The aim should be to meet the target **through UK domestic effort**, without relying on international carbon units (or 'credits').
- **This target is only credible if policy to reduce emissions ramps up significantly.**
  - The target can only be delivered with a strengthening of policy to deliver emissions reductions across all levels and departments of government. This will require strong leadership at the heart of Government.
  - Policies must be designed with businesses and consumers in mind. They must be stable, long-term and investable. The public must be engaged, and other key barriers such as low availability of necessary skills must be addressed.
  - In this report, we highlight particular priorities where progress has been too slow: low-carbon heating, hydrogen, CCS and agriculture and land use. As well as driving deployment, Government must ensure that the necessary infrastructure is delivered.
- HM Treasury should undertake a review of how **the transition** will be funded and where the costs will fall. It should develop a strategy to ensure this is, and is perceived to be, fair. A broader strategy will also be needed to ensure a **just transition** across society, with vulnerable workers and consumers protected.
- The UK can benefit from the international influence of setting a bolder target, using it as an opportunity for further **positive international collaboration**.
- **Wales** has less opportunity for CO_2 storage and relatively high agricultural emissions that are hard to reduce. On current understanding it could not credibly reach net-zero GHGs by 2050. Wales should set a target for a 95% reduction in emissions by 2050 relative to 1990.
- **Scotland** has proportionately greater potential for emissions removal than the UK overall and can credibly adopt a more ambitious target. It should aim for net-zero greenhouse gas emissions by 2045. Interim targets should be set for Scottish emissions reductions (relative to 1990) of 70% by 2030 and 90% by 2040.

1. Is now the right time to set a net-zero target?

A net-zero target requires deep reductions in emissions, with any remaining sources offset by removals of CO_2 from the atmosphere (e.g. by afforestation). Net emissions, after accounting for removals, must be reduced by 100%, to zero.

The Paris Agreement (Article 4) includes an objective in order to achieve its long-term temperature goal, which is widely interpreted as requiring net-zero GHG emissions globally in the second half of the century (expressed as '*a balance between anthropogenic emissions by sources and removals by sinks*'). The UK Government has also recognised the need to reach net-zero GHG emissions in the UK, a position with which the Committee agreed in our 2016 report on *UK climate action following the Paris Agreement*.

In 2016 we advised that the Government should not set a net-zero target at that time, but should instead keep a target under review as the evidence develops. We now conclude that the evidence supports setting a net-zero target in the UK and that this evidence is robust: a net-zero target should now be set.

It is also an important moment for the UK to make a positive international impact.

- Globally, current pledges of effort do not go far enough. The Paris Agreement began a process of ratcheting up climate ambition, with the intention of closing the gap to pathways consistent with the long-term temperature goal. Parties to the Agreement are currently developing revised pledges, which need to be submitted next year. Setting a net-zero target for greenhouse gases (GHGs) in 2050 in the UK would send a strong signal to support increasing ambition in those pledges.
- The UK published its plans for meeting existing GHG targets in 2017. Although the *Clean Growth Strategy* does not fully close the policy gap to the UK's existing carbon budgets, it represents a material step forward in the UK's approach to emissions reduction. Intentions set out in the Clean Growth Strategy still need to be backed up by detailed policy designs in many cases, but they cover most of the areas where action is needed to deliver a net-zero target and the strategy continues to offer an appropriate framework for action.

The UK can credibly adopt a higher ambition now, which can help influence those countries considering increased effort in the future.

2. Should the net-zero target be for CO_2 or all GHGs?

All greenhouse gases (GHGs) contribute to climate change and must be reduced substantially to meet the Paris temperature goal. To stabilise global temperatures, emissions of long-lived gases like CO_2 must be reduced to net-zero. Emissions of short-lived gases like methane must be stabilised, but need not reach net-zero.

We develop scenarios in this report that reduce UK emissions of CO_2 and other long-lived gases to net-zero. Alongside cuts in methane emissions these would result in a UK reduction across greenhouse gases of around 97% relative to 1990.[4] This would end the UK's contribution to rising global temperatures.

[4] With different gases weighted using the 'GWP100' metric, in line with international convention and recognising changes to those weightings proposed in the IPCC's work.

Rather than set a 97% target that leaves a small residual amount of emissions, and recognising that there are options available to reduce emissions further, we recommend that the UK sets a net-zero target for all greenhouse gases (i.e. a 100% reduction from 1990 levels):

- This would align to the requirement for a balance between sources and sinks of GHGs in the Paris Agreement.
- It would send a much stronger signal internationally. Other climate leaders, including the EU, are considering targets for net-zero emissions for all GHGs. If the UK were to adopt a weaker ambition it could undermine these negotiations.
- Within the UK, a 100% all-GHG target sends a clear signal that all greenhouse gases matter and all need to be reduced. No sources of emissions can qualify for special treatment. All emissions from all sectors must be eliminated or offset with removals.

As we set out below, there are compelling reasons to expect the UK to go beyond what is required from the world overall. A net-zero target for all GHGs would imply that the UK will be actively *reducing* its large historical contribution to global warming.

3. When should the UK reach net-zero GHGs and what should the long-term targets be for the UK, Scotland and Wales?

The Governments asked for advice on when the UK should achieve a net-zero GHG target and on what the long-term emissions targets should be for the UK, Scotland and Wales.

- **UK.** We recommend that the UK should achieve net-zero GHG emissions by 2050 (i.e. a 100% reduction from 1990). This would be an appropriate UK contribution to the Paris Agreement. Based on our current understanding, it is the latest date for the UK credibly to maintain its status as a climate leader and the earliest to be credibly deliverable alongside other government objectives.
- **Scotland** (Box 2) has different capabilities, notably its larger land area per person and its significant CO_2 storage potential, meaning it can credibly reach net-zero GHGs earlier. We recommend that Scotland legislates for net-zero GHGs in 2045.
- **Wales** (Box 3) has less opportunity for CO_2 storage and relatively high agricultural emissions that are hard to reduce. On current understanding it could not credibly reach net-zero GHGs by 2050. We recommend it sets a target for a 95% reduction in emissions by 2050 relative to 1990. This would still cut Welsh net emissions of long-lived greenhouse gases to below zero and therefore end Wales's contribution to rising global temperatures.

Our rationale is set out in Boxes 2 and 3 and in the following three sub-sections:

(a) An appropriate contribution to the Paris Agreement
(b) A target in line with other climate leaders
(c) A target that is achievable in the UK

Box 2. Recommendations on revising the long-term emissions targets for Scotland

- **Background.** Scotland currently has a target to reduce emissions of all greenhouse gases including international aviation and shipping by at least 80% by 2050, relative to 1990. The target was set in the Climate Change (Scotland) Act (2009) and is under review in a new Climate Change Bill currently being considered by the Scottish Parliament.
- **Recommendation.** The Scottish Government should legislate to reach net-zero greenhouse gas emissions by 2045. The target can be legislated as a 100% reduction in GHGs from 1990 and should cover all sectors of the economy, including international aviation and shipping.
- **Interim targets.** The Scottish Climate Change Bill also requires interim targets. We recommend these are set for a 70% reduction by 2030 and a 90% reduction by 2040 against the 1990 baseline. Scotland should not adjust its 2020 target.
- **A fair share.** These targets represent Scotland's fair contribution to the recommended UK target and hence to the Paris Agreement. They do not imply higher policy ambition or effort, but reflect the excellent opportunities to remove CO_2 from the atmosphere through afforestation and carbon capture and storage in Scotland.
- **Contingent on UK ambition.** These targets are contingent on the UK adopting our recommended 2050 net-zero GHG target. Scotland cannot deliver net-zero emissions by 2045 through devolved policy alone. It will require both UK-wide and Scottish policies to ramp up significantly. If the UK does not commit to a net-zero GHG target for 2050 then Scotland may need to revise its target.
- **A just transition.** The new Scottish Just Transition Commission has an important role to help plan and deliver a just transition across Scotland that protects vulnerable workers, consumers and rural and island populations.

Box 3. Recommendations on revising the long-term emissions targets for Wales

- **Background.** Wales has a target to reduce emissions of all greenhouse gases including international aviation and shipping by at least 80% by 2050, relative to 1990. The target was set in the Environment (Wales) Act (2016).
- **Recommendation.** The Welsh Government should legislate for at least a 95% reduction in all greenhouse gas emissions against the 1990 baseline by 2050. The new target could enter legislation in 2020, alongside Wales's third carbon budget. Achieving this target would cut net emissions of long-lived greenhouse gases to below zero (the remaining 5% would be methane emissions), ending Wales's contribution to rising global temperatures.
- **A fair share.** This target represents Wales's fair contribution to the UK target and hence to the Paris Agreement. It does not imply lower policy ambition or effort in Wales, but reflects the large share of agriculture emissions in Wales and lower access to suitable sites to store captured CO_2.
- **Contingent on UK ambition.** This target is contingent on the UK adopting our recommended 2050 net-zero GHG target. A 95% reduction target in Wales cannot be delivered through devolved policy alone, and will require both UK-wide and devolved policies to ramp up significantly. If the UK does not commit to a net-zero GHG target for 2050 then Wales may need to set a looser target.
- **A just transition.** Our recommendation is consistent with the Well-being of Future Generations (Wales) Act (2015). Actions to reduce emissions can deliver significant benefits against Wales's global responsibility, resilience, health and prosperity well-being goals. A just transition must be in place to ensure a more equal Wales with cohesive communities is delivered.

(a) An appropriate contribution to the Paris Agreement

The Paris Agreement aims to limit the increase in global average temperature to well below 2°C and to pursue efforts to limit the rise to 1.5°C. The Agreement makes clear it should be 'implemented to reflect equity', with an expectation that developed countries should continue to take the lead.

Notably, the Paris Agreement shifted from the top-down approach of the previous Kyoto Agreement to a bottom-up approach, in which parties are required to determine their own national contributions and successively increase them to reflect their 'highest possible ambition'. This has led the Committee to reconsider our approach to assessing an appropriate UK contribution:

- The Committee's 2008 advice on the UK's current 2050 emissions target reflected a judgement that it was 'difficult to imagine' a global deal where UK per capita emissions were significantly above the global average in 2050. The UK's current target for at least an 80% reduction in emissions from 1990 by 2050 was therefore based on an equal per capita share of global emissions in 2050 for the pathways that the Committee analysed in 2008.
- However, we do not believe an equal per capita share of emissions in 2050 would be a sufficient contribution to the Paris Agreement, given its emphasis on equity and given the UK's capability to go further.
  - **Equity.** The UK has a significant carbon footprint attached to imported products, for which the emissions are counted in other countries. The UK also has large cumulative historical emissions of CO_2: despite only making up 1% of global population, 2-3% of human-induced global warming to date has resulted from GHG emissions in the UK. It is a high-income economy. These characteristics are often cited as reasons for countries to adopt tighter targets as their equitable contribution.
  - **Capability.** UK per capita emissions are close to the global average and falling, while global emissions are rising. The UK has strong established governance processes to tackle GHG emissions (i.e. the Climate Change Act) and a track record of being a leader in policy development in key emitting sectors (e.g. energy market reform). More broadly, the UK's higher income suggests more capacity to act, while its population is generally supportive of well-designed action to cut GHG emissions.

We therefore consider that an appropriate UK contribution to the Paris Agreement in 2050 should go *beyond* what is required for the world overall.

A net-zero GHG target for the UK (i.e. a 100% reduction in emissions) would go beyond per capita emissions reductions in global pathways that are necessary to limit temperature rise to well below 2°C and would be towards the high end of the estimated range of necessary reductions for a limit of 1.5°C (Table 1).

Table 1. Per capita emissions compatible with the Paris Agreement temperature goal

	Well below 2°C	1.5°C
Global 2050 GHG emissions per person (tCO_2e/year)	0.8 - 3.2	-0.4 - 1.7
Equivalent reduction in total UK GHG emissions from 1990 for same per capita emissions - the UK should go beyond the global average	72% - 93%	85% - 104%

Source: IPCC SR1.5 scenario database.
Notes: The range shown is the minimum and maximum across the full range of the IPCC scenario groupings with a >66% probability of warming below 2°C and a >50% probability of 1.5°C with no or low overshoot. CO_2e refers to aggregation of different greenhouse gases to a CO_2-equivalent basis using GWP_{100} values from the IPCC 4th Assessment Report.

(b) A target in line with other climate leaders

The UK is currently a climate leader. It has international credibility in the climate arena built on a strong record of fulfilling its obligations and robustly tackling its own emissions. This leadership matters: UK activities support the implementation of the Paris Agreement and help other countries to increase their own ambition and action.

- **Leading by example.** The Climate Change Act set the world's first legally-binding long-term emissions target, with a supporting framework to deliver it - it has been the model for climate legislation in many other countries. The UK also trialled the first major emissions trading scheme - a pilot for the EU Emissions Trading System (EU ETS). More broadly, the UK has demonstrated that a major nation can reduce its emissions (down over 40% from 1990 to 2018) while growing its economy (GDP grew over 70% from 1990 to 2018).
- **Diplomacy and capacity building.** The UK has consistently played an important and positive role in climate negotiations: in the UN, in the EU and in the international aviation and shipping agencies (ICAO and IMO). It has also launched (with Canada) the Powering Past Coal Alliance and helped initiate the High Ambition Coalition. The UK Foreign and Commonwealth Office has run sustained climate engagement activities for over a decade to support other countries on the politics, economics and practicalities of tackling climate change.
- **Technology development.** The UK has taken a lead role in the development and deployment of some of the key low-carbon technologies. For example, becoming the largest market for offshore wind in the world, driving down costs through deployment. Such developments can now support decarbonisation elsewhere, at these low costs.
- **Climate finance.** The UK, through the aid budget, spends around £1 billion a year on climate finance activities. A recent performance review by the Independent Commission for Aid Impact reports that the UK positively influences the international agencies it engages with and increasingly contributes to transformational impact.[5]

[5] ICAI (2019) *International Climate Finance: UK aid for low-carbon development. A performance review.*

Setting and pursuing a UK net-zero GHG target for 2050 will confirm the UK as a leader among the developed countries on climate action. It demonstrates important principles of including emissions from all greenhouse gases and all sources (i.e. including international aviation and shipping), not relying on international offsetting and targeting 'highest possible ambition'. Crucially it would be supported by the strong statutory emissions framework of the Climate Change Act.

Other climate leaders (e.g. the European Union, Sweden, France, California) have set or are considering net-zero GHG targets by 2050 or before (Table 2). Were the UK to pursue a later date or a weaker target it would undermine these discussions, most notably for the European Union, who are aiming to reach agreement in 2020 for a net-zero GHG target. Those choices could then have wider repercussions for choices by countries beyond the leadership group.

(c) A target that is achievable in the UK

We describe below how the UK can reach net-zero GHG emissions by 2050. Our scenarios are based on current consumer behaviours and known technologies, with prudent assumptions over their cost reduction. They are technically possible (e.g. there are enough sites for offshore wind and materials for electric vehicles), albeit with strong leadership needed from government.

Reaching net-zero GHG emissions requires extensive changes across the economy, with complete switchovers of several parts of the UK capital stock to low-carbon technologies. Major infrastructure decisions need to be made in the near future and quickly implemented. These changes are unprecedented in their overall scale, but large-scale transitions have been achieved successfully in the UK before, such as the natural gas switchover in the 1970s or the switch to digital broadcasting in the 2000s.

We have considered whether an earlier date than 2050 should be targeted. An earlier date has been proposed by some groups[6] and might send a stronger signal internationally to those considering increasing their own ambition, but only if it is viewed as credible.

While our scenarios demonstrate that some sectors (e.g. the power sector) could reach net-zero emissions by 2045, for most sectors 2050 currently appears to be the earliest credible date. An earlier date would also give less time to develop currently speculative options as alternatives to make up for any shortfall from other measures. That could lead to a need for punitive policies and early capital scrappage to stay on track to the target.

Part of the strength of the Climate Change Act – as a tool for driving change in the UK and as an international signal – is that it sets legally-binding, evidence-based and credible targets, which must be delivered against. Our recommendation is also strong in its coverage (including international aviation and shipping) and its recommended implementation (without international offsets). Setting a legal target to reach net-zero GHG emissions significantly before 2050 does not currently appear credible and the Committee advises against it at this time.

[6] For example, a cross-party group of over 180 MPs have proposed reaching net-zero GHG emissions before 2050 and a coalition of NGOs have proposed 2045.

Table 2. Emerging net-zero commitments in other countries

	Net-zero: CO_2 or GHGs	Date to achieve target by	Formality	International offsetting?	International aviation and shipping?
Proposed UK target	GHGs (Green)	2050	To be legislated in Climate Change Act	(Green)	(Green)
Net-zero targets under consideration					
European Union	GHGs (Green)	2050	Proposed by European Commission	(Green)	(Amber)
France	GHGs (Green)	2050	Bill - not yet legislated	(Green)	(Green)
New Zealand	To decide (Amber)	2050	Bill - currently being drafted	(Amber)	(Amber)
Net-zero targets that have been adopted					
California	Unclear (Amber)	2045	Executive Order	(Amber)	(Amber)
Sweden	GHGs (Green)	2045	Legislation	(Red)	(Red)
Denmark	Unclear (Amber)	2050	Legislation	(Amber)	(Amber)
Norway	GHGs (Green)	2030	Binding Agreement	(Red)	(Red)

A number of other countries have mid-century or earlier net-zero targets and ambitions: Ethiopia, Costa Rica, Bhutan, Fiji, Iceland, the Marshall Islands, and Portugal. They are contained in NDCs and strategy documents, rather than legislation.

Source: CCC analysis.
Notes: Green = Explicit aim to meet without credits / international aviation and shipping (IAS) included. Red = explicit allowance for international offsetting / IAS excluded. Amber = unclear or undecided. NDC = Nationally Determined Contribution submitted to the Paris Agreement.

4. How can the UK reach net-zero GHGs?

Scenarios for UK net-zero GHGs in 2050

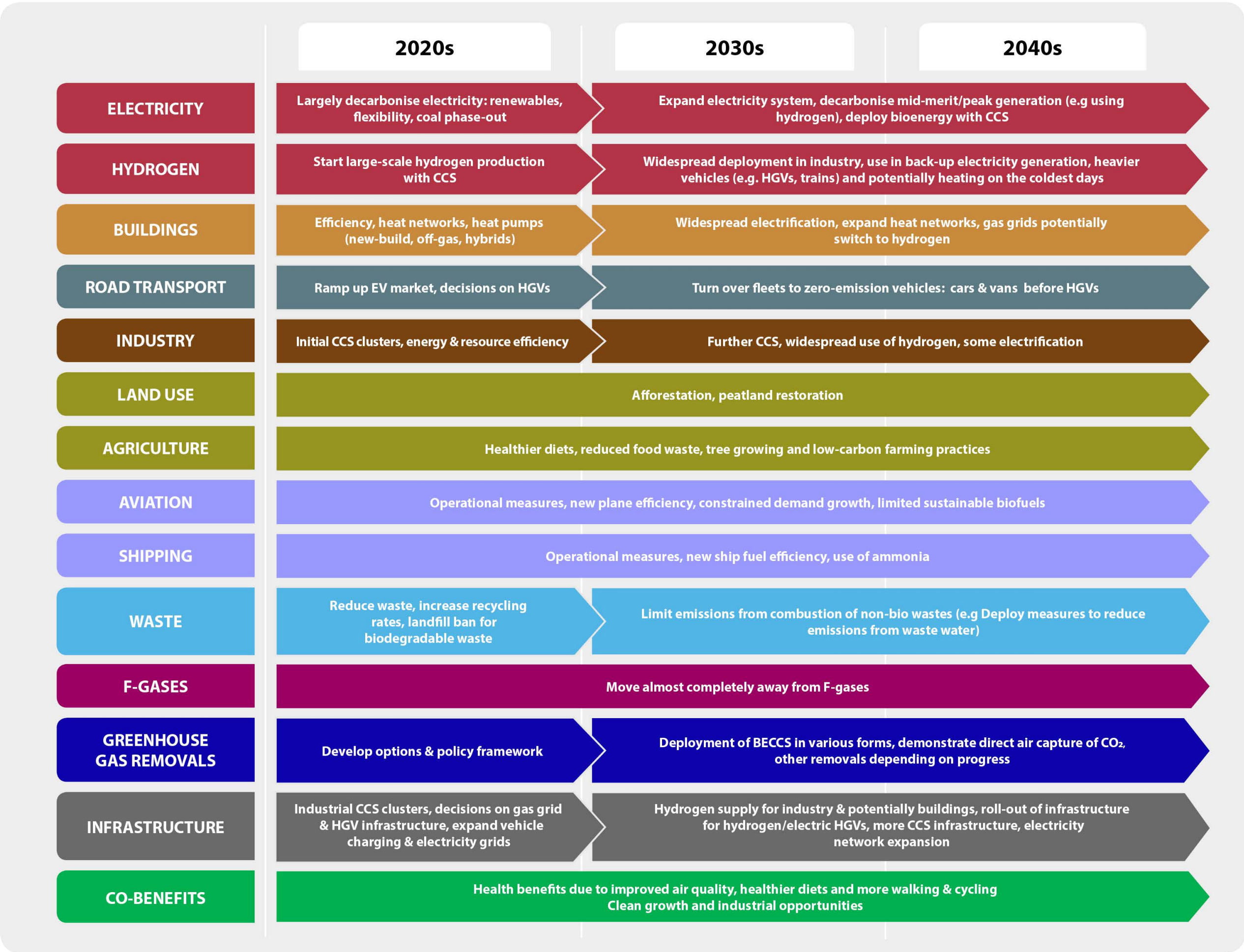
It is impossible to predict the exact mix of technologies and behaviours that will best meet the challenge of reaching net-zero GHG emissions, but our analysis in this report gives an improved understanding of what a sensible mix might look like. The scenarios (Figure 2 and Box 4) include:

- **Resource and energy efficiency,** that reduce demand for energy across the economy. Without these measures the required amounts of low-carbon power, hydrogen and carbon capture and storage (CCS) would be much higher. In many, though not all, cases they reduce overall costs.
- Some **societal choices** that lead to a lower demand for carbon-intensive activities, for example an acceleration in the shift towards healthier diets with reduced consumption of beef, lamb and dairy products.
- Extensive **electrification**, particularly of transport and heating, supported by a major expansion of renewable and other low-carbon power generation. The scenarios involve around a doubling of electricity demand, with all power produced from low-carbon sources (compared to 50% today). That could for example require 75 GW of offshore wind in 2050, compared to 8 GW today and 30 GW targeted by the Government's sector deal by 2030. 75 GW of offshore wind would require up to 7,500 turbines and could fit within 1-2% of the UK seabed, comparable to the area of sites already leased for wind projects by the Crown Estate.
- Development of a **hydrogen** economy to service demands for some industrial processes, for energy-dense applications in long-distance HGVs and ships, and for electricity and heating in peak periods. By 2050, a new low-carbon industry is needed with UK hydrogen production capacity of comparable size to the UK's current fleet of gas-fired power stations.
- **Carbon capture and storage** (CCS) in industry, with bioenergy (for GHG removal from the atmosphere), and very likely for hydrogen and electricity production. CCS is a necessity not an option. The scenarios involve aggregate annual capture and storage of 75-175 $MtCO_2$ in 2050, which would require a major CO_2 transport and storage infrastructure servicing at least five clusters and with some CO_2 transported by ships or heavy goods vehicles.
- Changes in the way we farm and use our **land** to put much more emphasis on carbon sequestration and biomass production. Enabled by healthier diets and reductions in food waste, our scenarios involve a fifth of UK agricultural land shifting to tree planting, energy crops and peatland restoration.

Taken together, these measures would reduce UK emissions by 95-96% from 1990 to 2050. Tackling the remaining 4-5% would require some use of options that currently appear more speculative. That could involve greater shifts in diet and land use alongside more limited aviation demand growth, a large contribution from emerging technologies to remove CO_2 from the atmosphere (e.g. 'direct air capture'), or successful development of a major supply of carbon-neutral synthetic fuels (e.g. produced from algae or renewable power).

The scenarios involve additional reductions in the UK's consumption emissions as they include measures like resource efficiency that cut emissions from production overseas as well as in the UK. However, consumption emissions will only reach net-zero once the rest of the world's territorial emissions are also reduced to net-zero. At this point the UK can expect to pay slightly more to cover the costs of low-carbon production of the goods we import.

Figure 2. UK net-zero GHG scenario



Source: CCC analysis.
Notes: CCS = carbon capture and storage. EV = electric vehicle. BECCS = bioenergy with CCS.

Box 4. Actions that people can take to reduce their emissions

Our scenarios to reduce UK GHG emissions to net-zero point to actions that individuals and households can take to reduce their carbon footprints and contribute to the UK and global goals:

- The way you travel:
  - Choose to walk and cycle or take public transport in preference to a car.
  - Make your next car an electric one, and then charge it 'smartly'.
  - Minimise flying, especially long-haul, where possible.
- In your home:
  - Improve the energy efficiency of your home (or ask your landlord to) through draught-proofing, improved insulation, choosing LED light-bulbs and appliances with high efficiency ratings.
  - Set thermostats no higher than 19°C and the water temperature in heating systems no higher than 55°C.
  - Consider switching to a low-carbon heating system such as a heat pump, especially if you live off the gas grid; if you are on the gas grid consider a hybrid system.
- What you eat and buy:
  - Eat a healthy diet, for example with less beef, lamb and dairy.
  - Eliminate food waste as far as possible and make sure that you use separate food waste collections if available. Reduce, reuse and recycle your other waste too.
  - Use only peat-free compost.
  - Choose good quality products that will last, use them for longer and try to repair before you replace.
  - Share rather than buy items like power tools that you don't use frequently. If you don't/won't use your car regularly then consider joining a car club instead.
- Look for changes that you can make in your workplace or school to reduce emissions and support your colleagues to make changes too.
- Talk about your experiences and help to raise awareness of the need to act. Consider the wider impacts of your actions (e.g. through your pension or ISA and via the companies you buy from).

Source: CCC analysis.
Note: Many of these changes will save money as well as reduce greenhouse gas emissions.

Differences from scenarios with an 80% reduction from 1990 to 2050

Compared to scenarios that the Committee has previously published for the existing 2050 target for at least an 80% reduction relative to 1990, there are several key differences. These largely relate to further opportunities to reduce emissions, rather than increasing removals:

- **More abatement in industry.** Our understanding of what is possible in industry has significantly strengthened through deeper evidence and analysis. We can now identify ways to reduce emissions close to zero for the vast majority of industrial processes and activities. In many cases these involve similar changes to those in the rest of the economy: efficiency, electrification, application of CCS and switching heat sources to low-carbon hydrogen. It will also involve better resource efficiency, for example product designs that last longer and use less material alongside increased reuse and recycling.

- **More low-carbon electricity, hydrogen and CCS.** The net-zero scenarios require more electrification and use of hydrogen. Increased supplies of low-carbon electricity and hydrogen, along with more CCS to support those supplies, will therefore be needed.
- **Almost all HGVs and heating of buildings must be low-carbon by 2050.** These were already desirable goals for an 80% target, but will be necessary for a net-zero target.
- **Aviation, agriculture and land must play their part.** Updated evidence for aviation points to greater potential to reduce emissions, although we still expect the sector to emit more than any other in 2050. Our 80% scenarios did not assume any diet change, or major land use changes on the freed-up land, but these are both needed for a net-zero target.

Part of the challenge in shifting to a net-zero target, therefore, is that there is less flexibility and less scope for under-delivery in areas that prove difficult to change. This adds to the importance of developing currently speculative options, given that these may be needed to meet the target in full domestically.

Contingency

Many of the options for reducing emissions have alternatives available. For example: lower demand would permit reduced roll-out of low-carbon technologies; hydrogen could be used instead of low-carbon electricity for some applications. Furthermore, if the speculative options emerge successfully then they could potentially make up for shortfalls elsewhere.

We have made judgements in our approach that are deliberately cautious:

- Our scenarios are based on existing technologies and make conservative assumptions around their development and take-up of low-carbon behaviours. If mass roll-out of currently niche technologies leads to rapid cost reductions (e.g. as witnessed globally for batteries and solar panels and in Europe for offshore wind), the scenarios will be significantly easier to deliver.
- We have accounted for expected future revisions (inclusion of peatland emissions and an increase to the weighting for methane recommended by the IPCC) that will increase estimates of the current level of UK emissions.
- We have made cautious but realistic assumptions on bioenergy supply. Our estimates of global bioenergy supply (set out in detail in our recent Biomass review)[7] are notably lower than assumed in many of the scenarios assessed by the IPCC.
- Inclusion of land-based removals and CCS in our net-zero scenarios means minimal residual emissions can be tolerated in most sectors. This, in turn, offers flexibility should some niche emissions sources prove very difficult to avoid.

While the policy challenge in delivering these scenarios is undeniable, there is good reason to believe that the range of options could be wider and/or cheaper than we have assumed.

If the speculative options to reduce UK emissions do not develop sufficiently, or if there is a shortfall in delivery of the other elements of the scenarios, then international carbon units (i.e. 'credits' or 'offsets') could provide contingency. The Paris Agreement puts in place processes

[7] CCC (2018) *Biomass in a low-carbon economy*.

(both centralised and bilateral) for international markets in carbon units to develop and they could be valuable to support some aspects of the required global transition. As required in the Climate Change Act the Committee would advise closer to the time on an acceptable level of credit purchase and acceptable schemes to use.

However, the UK should aim to meet the net-zero GHG target through domestic action. Use of international carbon units should not be planned for, and their use should only be as a contingency. If carbon units are required, only those offering genuinely additional emissions reduction or removal should be allowed, and these must be part of schemes that also support sustainable development.

5. What are the expected costs and benefits of a UK net-zero GHG target for 2050?

In considering the costs of a net-zero GHG target for the UK, we are interested in the overall cost and its distribution: costs to the Exchequer and the risks of an unfair burden on vulnerable people or of undermining UK competitiveness. Against these there will also be large benefits, including reduced climate risks and cleaner air.

Our assessment integrates changes across the energy system, including the need to provide low-carbon electricity and hydrogen and to strengthen networks so that they reach consumers when needed. We exclude taxes and subsidies from our assessment - these constitute a transfer from one part of the economy to another while we are interested in the extra *resource cost* for the economy as a whole.

Total costs across the economy

Many of the changes required involve no or only limited additional costs. For example:

- Contracts for renewable power can be signed at prices below recent wholesale electricity prices (and below the costs of building and running a new gas-fired plant).
- Electric cars are expected to be cheaper to purchase than conventional cars by 2030 and yield considerable savings in their running costs (without existing subsidies or advantageous tax treatment).
- Costs for these options have fallen far more quickly than the Committee assumed to be possible when we first advised in 2008 on the UK's long-term emissions targets. The expected costs of reducing emissions have fallen markedly as a result.
- Efficiency improvements have barriers to uptake and upfront costs but often recoup these costs through fuel savings. That is true for many sources of emissions: buildings, agriculture, aviation and industry. Similarly, costs can be reduced through improved resource efficiency and shifting consumer choices towards healthier diets, reduced waste and reduced flying.

Some other changes have higher costs, such as switching from natural gas to hydrogen, applying CCS, installing heat pumps to replace gas boilers across the existing housing stock and GHG removals. Many of the options required to get from an 80% to a 100% target currently appear relatively expensive (e.g. with costs of around £200/tCO_2e).

Taken together, and without assuming major cost breakthroughs akin to those seen for renewable power and batteries, we estimate an increased annual resource cost to the UK economy from reaching a net-zero GHG target that will rise to around 1-2% of GDP by 2050. Within this, around 1% of GDP is the cost in moving from 80% to 100%. This is the value of the extra resources needed to eliminate UK emissions, although (as we set out in Chapter 7) the actual impact on UK GDP could be lower or even positive.

While future costs are inherently difficult to predict, we can have reasonable confidence in the conclusion that costs are likely to be no more than a very small fraction of annual GDP:

- Other estimates, for example for a net-zero GHG target across the EU, also report economic impacts of a percentage point or two of GDP, and possibly a small overall benefit to GDP.
- The conclusion would stand even if every additional tonne of abatement beyond 80% had costs as high as currently expected for our most expensive abatement options. For example, we expect that direct air capture to remove CO_2 from the atmosphere could be scaled up by 2050 and could cost around £300/tCO_2. If it delivered all the extra abatement for a net-zero GHG target (i.e. around 170 MtCO_2) the annual cost of moving from 80% to 100% would be up to 1.5% of projected 2050 GDP (rather than the 1% implied by our scenarios).
- If the rest of the world were not to increase effort materially in order to meet the temperature goal of the Paris Agreement, technology progress could be much slower and costs correspondingly higher. This is particularly concerning for global technologies like low-carbon HGVs. However, in such a situation cheap international carbon units ('offset credits') are likely to be available and if needed a revision to the UK target could be permitted by the Climate Change Act.

Many of the costs would involve increased investments, generally offset by reduced fuel costs. For example, wind and solar farms are costly to build, but avoid the need to pay for gas and coal; energy efficiency involves an upfront cost followed by reduced energy use. CCS and hydrogen are important exceptions requiring both increased upfront spend and higher fuel costs.

Investment

Capital cost increases in our scenarios are highest for the power and buildings sectors. Power sector annual investment rises to around £20 billion. Investment in buildings is around £15-20 billion higher in 2050 than it would have been without decarbonisation (the precise figure will depend on the mix of technologies deployed). By comparison, investment in the power sector averaged around £10 billion over 2013-2017. Total annual capital investment in the UK economy ranged from 15% to 24% of GDP over 1990-2017; our scenarios imply an extra investment requirement of around 1% in 2050.

This increase in investment emphasises the importance of ensuring that policies are designed with investors in mind. They should be clear and stable and avoid exposure to unnecessary risks. The long-term contracts offered under the Government's Electricity Market Reform are a good example of an effective policy and have been vital to reducing costs for renewable power.

It also suggests that wider policies that encourage investors to prioritise low-carbon investments are valuable, for example: mandatory disclosure of exposure to climate risks and assessment by investors of how their portfolios are consistent with a transition to net-zero emissions across the economy.

Distribution of costs

A key challenge is to ensure that the distribution of costs does not disproportionately affect some groups. Despite low overall costs, some industries, regions and households could suffer if appropriate policies are not put in place to mitigate the effects of what will be a major structural change.

Industry and heating in buildings stand out as sectors with potentially high annual costs that cannot simply be passed on. Therefore careful consideration is needed regarding where funding will come from:

- **Electricity** bill payers (households and businesses) currently pay around £7 billion a year towards the roll-out of low-carbon power. This is expected to rise to around £12 billion by 2030 then fall to 2050 as contracts for existing renewable generators come to an end and they are replaced by newer cheaper generation (e.g. our scenarios involve an annual resource cost of around £4 billion in 2050). For households, the average costs so far, of £105 per household per year in 2016, have been more than outweighed by savings from improved energy efficiency: energy bills fell £115 in real terms from 2008 to 2016. That balance will continue to 2030 (i.e. overall bills need not rise as a result of climate policy).
- **Switching homes to low-carbon heating** remains a major challenge. It is currently funded by Exchequer spending, but roll-out is limited and less than £100 million was spent in 2018. Our estimates imply an annual cost, reflecting higher upfront costs, for switching to low-carbon heating of the order of £15 billion. Large-scale deployment must begin before 2030. It would be regressive, and probably restrict progress, to pass the cost on fully to households. This should be a key focus for the HMT funding review. We note that in the long run this cost is similar to the combined saving from falling power costs (see above) and electric vehicles (see below).
- **Industry** decarbonisation in our scenarios also has an annual cost of the order of £5-10 billion. Some of this could be passed on to consumers, where industry is not exposed to international competition or where the incremental costs are small. However, trade-exposed industries will require a level playing field to ensure that emissions are reduced, not offshored. That could involve schemes similar to those in place today - free allocation of allowances within the EU ETS and compensation for costs resulting from UK climate policies. Alternatively it could involve taxpayer funding, new schemes such as border tariff adjustments or product and building standards that drive demand for low-carbon goods.
- **Electric vehicles** currently benefit from capital subsidies and lower fuel and vehicle taxation. Each of these can be phased out in the long run as electric vehicles reach cost parity. By 2050, we expect the shift to low-carbon options like electrification to cut the annual costs of UK transport by around £5 billion. That can be achieved while maintaining transport's tax contribution and allows for the costs of charge-points and other infrastructure.
- **Farmers** and land managers currently receive large subsidies from the EU's Common Agricultural Policy (CAP), but not for reducing GHG emissions. The UK Agriculture Bill intends to redirect subsidies towards public goods and could support the major transition in land use and farming practices required by a net-zero GHG target. Our cost estimates for land and agriculture in our scenarios (under £2 billion annually) are lower than UK payments under CAP (over £3 billion).
- The annual costs of **removing emissions** from the atmosphere are potentially large in our scenarios (e.g. of the order of £10 billion in 2050, possibly as high as £20 billion). These could be paid by industries, like aviation, that have not reduced their own emissions to zero. That would imply increasing costs (e.g. for flights) from 2035, as emission removals scale up in our scenarios.

The distribution of these costs will be determined by Government policy and will be crucial to public acceptance. Finding the most effective ways to limit costs and provide funding will be fundamental to success.

Benefits

Set against the costs, there will be significant benefits, including avoided costs:

- **Improved quality of life**:
  - Benefits to human health (and savings to the NHS) from better air quality, less noise, more active travel and a shift to healthier diets.
  - Improved air and water quality, enhanced biodiversity, increased resilience to climate change, and recreational benefits from changes to land use.
  - Monetising benefits is not straightforward. However, estimates using HM Treasury's *Green Book* guidance[8] suggest that these would partially or possibly even fully offset the resource costs we have estimated (i.e. up to 1-2% of GDP in 2050).
- **Lower risks from climate change** (Box 5). These include direct benefits (e.g. lower risk of flooding in the UK) and indirect benefits (e.g. reduced exposure to rising food prices and disaster-induced migration and conflict). We have not attempted to monetise these benefits.
- **There could be industrial opportunities.** With appropriate policy and support there could be an industrial boost to the UK from being one of the early movers in some key sectors (e.g. specialised supporting services like finance and engineering for low-carbon technologies, carbon capture and storage), with potential benefits for exports, productivity and employment. The shift in resources from imported fossil fuels to UK investment could also stimulate further economic activity. However, we do not factor these into our cost estimates.

Overall, a well-managed transition can be achieved and lives can be improved. People can benefit from better physical and mental health, an improved environment and, crucially, a reduced exposure to climate risks.

6. Next steps

Setting the net-zero target and determining the cost-effective path

The Committee expects to advise on the sixth carbon budget (covering the years 2033-2037), once Parliament has considered the setting of a new long-term target. The advice of the Committee on the sixth carbon budget is due in 2020. The net-zero GHG target for 2050 should be set in legislation as soon as possible - and before the end of 2019 to allow time to develop advice on the cost-effective path to the new target.

We do not recommend changes to the fourth or fifth carbon budgets at this time, but note that both were set on the path to the existing 80% target and therefore are likely to be too loose.

We already recommend that the Government aim to out-perform the legislated budgets based on revisions to our estimate of the cost-effective path to the 80% target.[9] We reiterate that recommendation and we will consider whether the fourth and fifth carbon budgets should be tightened in legislation as part of our advice on the sixth carbon budget.

[8] HM Treasury (2019) *The Green Book: appraisal and evaluation in central government*.
[9] See CCC (2018) *Progress Report to Parliament* for more details.

Box 5. Climate risks

Limiting warming to **below 2°C** would avoid a number of damaging climate risks that are expected under the current trajectory.

- Risks of extreme weather events would be reduced. For example, keeping warming to below 2°C would nearly halve the expected global average drought length relative to a 3°C warmer world from 18 months to 11 months and improve crop yields in many countries.
- Significant changes in ecosystems would occur at 2°C warming, but there would be clear benefits compared to higher levels of warming, with global species extinction risk reducing to a 'moderate' level compared to 'high' levels under 4°C warming. However, the rate of climate change would still likely be too fast for many species to be able migrate to regions with acceptable climates.
- The probability of an ice-free Arctic summer (i.e. a summer when there would be no sea ice in the Arctic) would be reduced from over 1 in 2 to nearly 1 in 10 relative to a 3°C warmer world . Sea ice is critical for the unique Arctic ecosystem and may have links to mid-latitude weather.
- Impacts on human systems and the economy would be lower, but not zero, across a range of different indicators, including impacts on crop yields and flooding risks.
- Risks of 'tipping points' in the climate system are still moderate at 2°C, but are lower than at higher levels of warming.
- Benefits from avoided climate risks will also be felt within the UK, including reduced water stress, less flooding, reduced coastal erosion and reduced summer heat stress. These are set out in detail in the Climate Change Risk Assessment, which the Committee is currently updating.

The IPCC Special Report identified a number of substantial climate risks that would be avoided by keeping warming to **below 1.5°C** compared to higher levels.

- **Climate extremes.** Temperature extremes are expected to increase by 2-3 times the increase in global average temperature between 1.5°C and 2°C. Around 420 million fewer people would be exposed to extreme heatwaves if warming was kept to 1.5°C than 2°C.
- **Ecosystems.** Risks of species extinction on the land and in the ocean are lower at 1.5°C than 2°C. For example, the fraction of global land area that would change ecosystem type due to climate change factors at 2°C (13%) would be roughly halved if warming was kept below 1.5°C (7%).
- **Distribution of risks.** The additional increase in climate risk between 1.5°C and 2°C warming would affect poor and vulnerable people most of all. Poverty and disadvantage have increased with recent warming and are expected to increase for many populations as average global temperatures increase from 1°C to 1.5°C and higher.
- **Irreversible changes.** Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could possibly be triggered by warming between 1.5°C and 2°C. Keeping warming as low as possible reduces the risk of triggering these large-scale irreversible shifts in the climate.

Source: IPCC (2018) *Special Report on Global Warming of 1.5°C*. Other sources are set out in Chapter 2.

Maximising the international influence of the net-zero target

The Government should consider when and how to announce the new target to maximise its influence internationally. Others are actively considering increasing their targets and the UK has an opportunity to support increased ambition.

The UK could also submit a strengthened Nationally Determined Contribution (NDC) for 2030 and revised long-term strategy.

- Currently the UK's official contribution to the Paris Agreement is set through the EU's collective pledge to reduce emissions by at least 40% by 2030 relative to 1990.
- Outside the EU, the UK would need to submit its own NDC to the UN.
- For now, this could be based on the higher ambition in the UK's fifth carbon budget (which was set to require a 57% reduction in UK emissions from 1990 to 2030) but ultimately it should be based on the more ambitious pathway that the Committee will advise on next year, on the path to net-zero GHG emissions in 2050.
- The Paris Agreement asks countries 'to formulate and communicate long-term low greenhouse gas emission development strategies'. The UK has previously submitted the Government's *Clean Growth Strategy*. Setting a net-zero GHG target and introducing long-term plans to meet it would provide a basis for a strengthened strategy.

The UK should continue to collaborate internationally, including through provision of climate finance, and support increased ambition elsewhere. A key part of the UK's leadership has been as a positive example: setting and meeting ambitious targets within a robust legal framework while growing the economy and developing key emerging technologies. This track record allows the UK to have an influence diplomatically and politically, in negotiations and in new initiatives such as sustainable finance. This should continue, including contributing to strengthening governance for bioenergy and removals, which play a key role in our scenarios.

Although the aim should be to meet the net-zero GHG target without international carbon units, the UK should take steps to develop markets for carbon units as a potentially useful mechanism to mobilise finance and to support increased effort internationally, and as a contingency mechanism for meeting UK targets. The Paris Agreement allows this and the UK is well placed to help develop effective rules and governance as well as to build capacity in countries that could be sellers.

UK emissions, in line with our population, are only 1% of global emissions. It is therefore vital for the UK to maximise the impact of any new target on actions beyond the UK in order to tackle climate change and avoid some of the largest risks that would involve. This will also make the UK's task easier by stimulating the innovation and cost reduction for low-carbon technologies that global roll-out can bring.

Building on the existing foundations to prepare for a net-zero target in the UK

Our conclusion that the UK can achieve a net-zero GHG target by 2050 and at acceptable cost is entirely contingent on the introduction of clear, stable and well-designed policies. Government must set the direction and provide the urgency. Our analysis points to a number of obstacles that Government will need to overcome if it is to succeed (Box 6).

Box 6. Overcoming obstacles to reaching net-zero emissions

- **Strengthening policy-making.** The net-zero challenge must be embedded and integrated across all departments, at all levels of Government and in all major decisions that impact on emissions. It must also be integrated with businesses and society at large. Since many of the solutions cut across systems (e.g. hydrogen has a role in electricity generation, transportation, industry and heating), fully integrated policy, regulatory design and implementation is crucial. That may require new frameworks, for example to ensure that departments, other than BEIS alone, sufficiently prioritise net-zero GHG emissions. Policy teams across departments must be sufficiently resourced to develop and implement the changes required.
- **Ensuring businesses respond.** Some previous policies have delivered the desired business response in full (e.g. the banning of inefficient gas boilers in the 2005/06 Building Regulations, the offering of long-term contracts to offshore wind farms). Others, like the Green Deal and vehicle emissions standards, have not. For a net-zero GHG target, standards will need strict enforcement and incentive schemes must be designed with businesses and investors in mind. The ends (i.e. stopping GHG emissions) should be clear, but there should be flexibility to meet them in the most effective way. Crucially, there should be a stable and long-term approach.
- **Engaging the public to act.** Much of the success so far in reducing emissions (e.g. power sector decarbonisation and even the phase-out of inefficient gas boilers) has happened with minimal change or awareness needed from the public. However, this cannot continue if the UK is to reach net-zero emissions. Public engagement and support will be particularly vital for the switch to low-carbon heating - people will need to make changes inside their homes and co-ordinated central decisions must be taken on the balance between electrification and hydrogen. People should understand why and what changes are needed, to see a benefit from making low-carbon choices and to access the information and resources required to make the change happen.
- **Determining who pays.** If policies are not sufficiently funded or their costs are seen as unfair, then they will fail. HM Treasury should undertake a review of how the transition will be funded and where the costs will fall. The review should cover the use of fiscal levers and Exchequer revenue, costs from carbon trading schemes, the impact on energy bill-payers and motorists, and the costs to industries especially where they are carbon-intensive and trade-exposed. It should cover costs from now through to 2050.
- **Providing the skills.** The Government has recognised the importance of developing skills in its Industrial Strategy and sector deals. These should be used to tackle any skills gaps that would otherwise hinder progress. For example, new skills support for designers, builders and installers is urgently needed for low-carbon heating (especially heat pumps), energy and water efficiency, ventilation and thermal comfort, and property-level flood resilience.
- **Ensuring a just transition.** Building on the reviews of who pays and of skills, the Government should assess more broadly how to ensure that the overall transition is perceived as fair and that vulnerable workers and consumers are protected. That must include analysis at the regional level and for specific industrial sectors. We note that Scotland has already appointed an independent Just Transition Commission to advise on 'a carbon-neutral economy that is fair for all'.
- **Developing the infrastructure.** Reaching net-zero emissions will require development or enhancement of shared infrastructure such as electricity networks, hydrogen production and distribution and CO_2 transport and storage. Government, in partnership with the National Infrastructure Commission, should give urgent consideration to how such infrastructure might best be identified, financed and delivered. Regional coordination will be required, including for transport where powers are devolved.

Specific policies are now required to address the key areas of emissions across the economy. This is a pre-condition of achieving a net-zero GHG target by 2050. Many of our recommendations here are not new: the Committee has already recommended strengthened approaches to heat decarbonisation, CCS and hydrogen, electric vehicles, agriculture, waste, and low-carbon power. The interdependencies between these sectors must be taken adequately into account, emphasising the importance of a coherent overall strategy.

- **Heating buildings.** An overhaul of the approach to low-carbon heating and energy efficiency is needed. The Government's planned 2020 Heat Roadmap must establish a new approach that will lead to full decarbonisation of buildings by 2050. This must be fully-funded, following the Spending Review, and it is essential that the Treasury commits now to working with BEIS on this. Recent announcements on new build must be delivered.
- **CCS.** Carbon capture and storage (CCS) is essential. We previously recommended that the first CCS cluster should be operational by 2026, with two clusters, capturing at least 10 $MtCO_2$, operating by 2030. For a net-zero target it is very likely that more will be needed. At least one of the clusters should involve substantial production of low-carbon hydrogen. The Government will need to take a lead on infrastructure development, with long-term contracts to reward carbon capture plants and encourage investment.
- **Electric vehicles.** By 2035 at the latest all new cars and vans should be electric (or use a low-carbon alternative such as hydrogen). If possible, an earlier switchover (e.g. 2030) would be desirable, reducing costs for motorists and improving air quality. This could help position the UK to take advantage of shifts in global markets. The Government must continue to support strengthening of the charging infrastructure, including for drivers without access to off-street parking.
- **Agriculture.** Agriculture is already facing a period of considerable change. Future success will require diversification of incomes and taking the opportunities that come with transformational land use change. Policy to encourage farming practices that reduce emissions must move beyond the existing voluntary approach. Financial payments in the UK Agriculture Bill should be linked to actions to reduce and sequester emissions, to take effect from 2022.
- **Waste.** Bio-degradable waste streams should not be sent to landfill after 2025. This will require regulation and enforcement, with supporting actions through the waste chain, including for example mandatory separation of remaining waste.
- **Low-carbon power.** The supply of low-carbon power must continue to expand rapidly, and increasingly, from around 2030, some may need to run for only part of the year. While many options no longer need subsidies, Government intervention may still be needed, for example by backing long-term contracts aligned to expected wholesale prices. Policy and regulatory frameworks should also encourage flexibility (e.g. demand response, storage and interconnection).

In setting a net-zero target, these actions must be supplemented by stronger approaches to policy for industry, land use, HGVs, aviation and shipping, and GHG removals.

- **Industry.** Government must implement an approach to incentivise industries to reduce their emissions through energy and resource efficiency, electrification, hydrogen and CCS in ways that do not adversely affect their competitiveness. In the short-term, this is likely to imply a role for Exchequer funding. Longer term, it could involve international sectoral agreements (e.g. for industries like steel where there are relatively few global companies), procurement and product standards that drive change by requiring consumers to buy or use low-carbon products (e.g. where UK consumption is a large part of an industry's market) or through border-tariff adjustments that reflect the carbon content of imports. Wider infrastructure developments to support CCS and hydrogen roll-out will support industry to make the required changes.

- **Land use.** Consumer-facing policies should be used to support shifts to healthier diets with lower beef, lamb and dairy consumption. These would allow changes in UK land use without increasing reliance on imports. Forest cover should increase from 13% of UK land to 17% by 2050. Policy must support land managers with skills, training and information.
- **HGVs.** The Government will need to make a decision on the required infrastructure for zero emission HGVs, with international coordination, in the mid-2020s ready for deployment in the late 2020s and throughout the 2030s. To help prepare for that, trials of zero emission HGVs and associated refuelling infrastructure are now needed. Vehicle and fuel taxation from the 2020s onwards should be designed to incentivise commercial operators to purchase and operate zero-emission HGVs.
- **Aviation and shipping.** ICAO and IMO, the international agencies for aviation and shipping, have adopted targets to tackle emissions. The scenarios in this report go beyond those targets, suggesting increased ambition and stronger levers will be required in the long run. We will write to the Government later this year on its approach to aviation, building on the advice in this report.
- **GHG removals.** The Government should expand support for early-stage research across the range of greenhouse gas (GHG) removal options, including trials and demonstration projects. It should also signal the longer-term market, which is clearly needed to meet a net-zero target, by developing the governance rules and market mechanisms to pay for emissions removals. Aviation stands out as an obvious sector that could require removals to offset its emissions – either through CORSIA (the international aviation industry's planned trading scheme), the EU ETS or unilaterally the UK could support a net-zero target for aviation, requiring that all emissions are offset by removals.

While a net-zero GHG target brings additional challenges, it also brings clarity around policy objectives and what each sector is aiming for. There are opportunities for UK businesses to gain competitive advantage as they shift to the future zero-carbon basis required in the UK and the world. Government should make the most of those opportunities with a bold new programme for emissions reduction, which it should begin to introduce immediately.

7. Conclusion

There have been significant changes in the decade since the Climate Change Act was passed. Those changes can be accommodated within the Act, but they require an increase in the headline ambition.

We now have an understanding of how UK emissions can be reduced by 100% to net-zero and expect it to be delivered within the costs previously agreed by Parliament, provided all parts of government act quickly, effectively and in a coordinated fashion. Many businesses in the UK are ready to implement it; some have already set net-zero targets of their own.

A new UK target for net-zero GHGs by 2050, backed by a robust set of plans to achieve it within the UK's strong and widely-respected legislative framework, would send a strong international signal at a critical time. It can act as the benchmark for developed nations and position the UK as a progressive climate leader on the global stage.

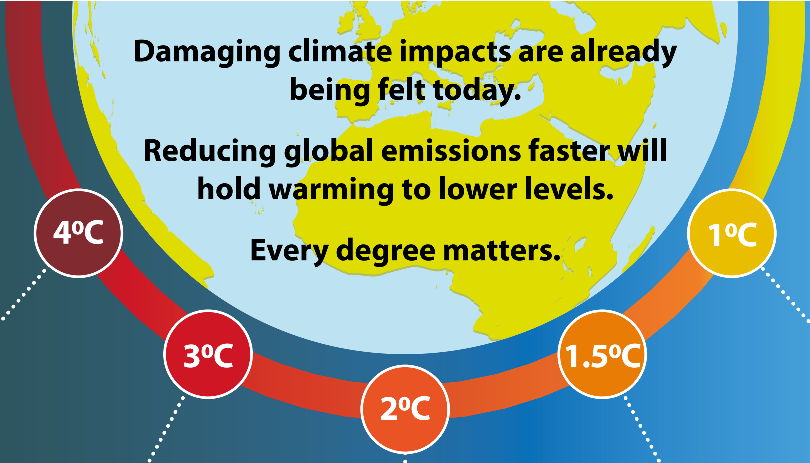
The changes required are substantial, but the foundations are already in place. Strong leadership is now required from governments throughout the UK, beginning with acceptance of the need to ramp up policy effort significantly and a rapid adoption of our recommendations by the Parliaments of the UK.

Committee on Climate Change

Damaging climate impacts are already being felt today.

Reducing global emissions faster will hold warming to lower levels.

Every degree matters.



Climate change is here today:

- The frequency of heatwaves has increased around the world. Many extreme events are being made more likely due to climate change.
- Sensitive ecosystems, such as coral reefs, are being damaged due to extreme heat.
- Animals on the land and the ocean are shifting their territories in response to climate change.

Damaging climate impacts are already being felt today at 1°C of warming.

Unchecked emissions growth would lead to very severe and widespread climate change at 4°C or more by 2100.

The world is moving towards a low-carbon future, reducing some risks. We are currently on track for around 3°C of warming by 2100.

The world has committed to reduce emissions faster to keep warming 'well-below' 2°C. This would help limit the most damaging effects of climate change.

Keeping below 1.5°C would limit many important risks further, helping to protect key ecosystems and reducing impacts on poorer people around the world.

UK action to address climate change can have an international impact

The UK can and should act as a leader in the global response to climate change - UK emissions contributed to causing it, and its leadership can have an international impact.

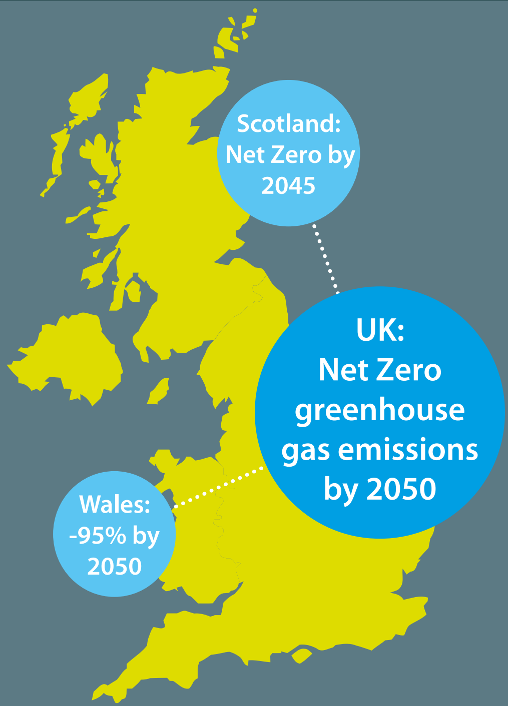
The UK has been a leader on climate change action. The UK has the opportunity to continue its leadership and join other countries already pursuing net-zero emissions targets.

The UK has committed to act by signing the Paris Agreement. This provides many options for countries to collaborate to reduce their emissions and prepare for the impacts of climate change.

Annual costs of achieving net-zero emissions are between 1-2% of GDP in 2050, comparable to those estimated in 2008 for achieving an 80% target.

80% reductions in emissions relative to 1990 levels estimated 2008	**100% reduction in emissions in 2050** estimated today

- Innovation has driven down the costs of key technologies, such as offshore wind & battery storage.
- Some costs to consumers, such as increased heating bills, can be offset by cheaper transport costs (thanks to a widespread shift to electric vehicles) and cheaper electricity bills (thanks to low cost renewable electricity).



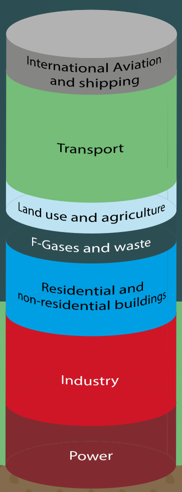
There are many benefits of phasing out harmful emissions

For the economy
New green industries with new jobs and export opportunities for the UK.

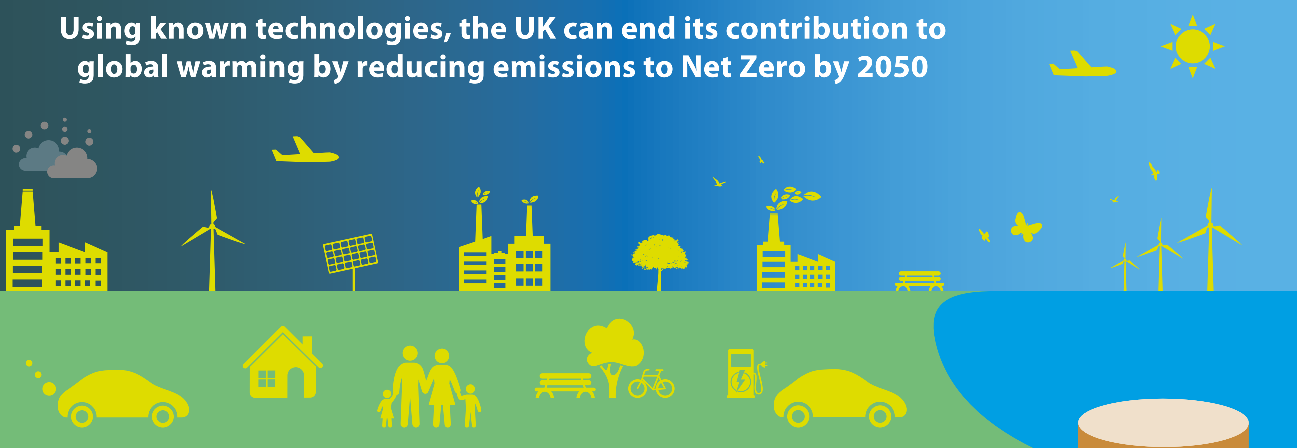
For the individual
Quieter streets, cleaner air, less congestion.
Smarter cities and more comfortable homes.
Healthier lifestyles, with more active travel and healthier diets.

For the country
More biodiversity, cleaner water, more green space to enjoy.
Reduced global warming, avoiding climate damages like flooding.

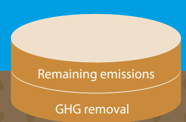
Using known technologies, the UK can end its contribution to global warming by reducing emissions to Net Zero by 2050



Emissions today



This transition will require a concerted effort and action by all



Any remaining emissions in 2050 must be offset

Chapter 1: Principles and approach in considering the UK's long-term climate targets

Introduction and key messages

This report responds to a request from the Governments of the UK, Scotland and Wales to provide updated advice on their long-term emissions targets, including the possibility of setting a new 'net-zero' target. The request comes 10 years after the UK's current target was set in the Climate Change Act 2008: to reduce greenhouse gas emissions by at least 80% by 2050 relative to 1990.

This chapter provides background on the government request and the UK's climate framework. It briefly reviews progress globally and in the UK over the last decade, and sets out the approach taken in the rest of this report.

Key messages in this chapter are:

- **Now is a good time to review the UK targets.**
  - In the Climate Change Act, the criteria for changes to the long-term emissions target are: significant developments in scientific knowledge, or in international law. The Paris Agreement of 2015 is a major change in international circumstances and the 2018 report of the Intergovernmental Panel on Climate Change (IPCC) adds significantly to scientific evidence.
  - The Committee also identified these criteria as legitimate reasons for a future review of the long-term target when we first advised on it in 2008.
  - Falling costs for key technologies (i.e. renewable power and batteries for electric vehicles) also imply major changes to what is possible and at what cost, both in the UK and globally.
- **A change to long-term targets would have implications for the nearer-term.** The Climate Change Act requires that carbon budgets are set on the path to the long-term target and policies are developed to meet the carbon budgets and the long-term target. A more ambitious long-term goal is likely to require more ambitious carbon budgets and more ambitious policies to meet them.
- **Well-designed policy can reduce emissions.** The UK has had a period of sustained reduction in greenhouse gas (GHG) emissions, achieved alongside growth in the economy. A particular recent success has been the reduction in coal-fired electricity generation, which has resulted from a combination of: regulations that drove efficiency improvement, subsidies that increased renewable power supply and a carbon tax. Other areas, including transport, buildings and agriculture, have not matched this success and will need stronger and more effective policies.
- **A net-zero target will be needed.** To stop contributing to further global warming, the UK would have to reduce emissions of long-lived GHGs to net-zero (i.e. any remaining emissions must be offset by removing an equivalent amount from the atmosphere, e.g. through afforestation). The UK Government has previously recognised that the UK will need a net-zero target at some point. This report seeks to identify when the target should be for and whether it should cover all GHGs.
- **Our advice is based on an extensive evidence base.** The Committee has compiled and reviewed an extensive evidence base for this report. In line with the Governments' request, much of that is focused on how the UK can reduce emissions to net-zero and the costs and benefits of doing so.

The rest of this report sets out the new evidence on which we base our recommendations for revised targets that are scientifically robust, consistent with our international commitments while supporting increased international effort, and feasible to achieve in the UK while delivering other Government objectives.

This chapter is set out in six sections:

1. The request for advice
2. The framework for emissions reduction in the UK
3. Global progress since 2008
4. UK progress since 2008
5. Redefining the UK contribution to tackling global climate change
6. Approach to determining a suitable net-zero emissions target for the UK

1. The request for advice

This report responds to a request for advice from the Governments of the UK, Scotland and Wales. A joint letter to the Committee on 15 October 2018 requested advice on their respective long-term emissions targets (Box 1.1).

The request is in line with the UK Government's previous statement to Parliament that it is a case of when, not if, a net-zero emissions target is set.[10] The key UK recommendations required from this report are therefore *when* the UK should aim to reach net-zero emissions, on what *basis* that should be (e.g. CO_2 or all GHGs) and whether now is the right time to *set* such a target. Our evidence must cover how the target might be met and the costs and benefits of doing so.

Box 1.1. The Government request for advice

On 15 October 2018 the Governments of the UK, Wales and Scotland wrote to the Committee to request "an update to the advice… on UK climate action following the Paris Agreement":

- "the date by which the UK should achieve (a) a net zero greenhouse gas target and/or (b) a net zero carbon [dioxide] target in order to contribute to the global ambitions set out in the Paris Agreement"
- "whether now is the right time for the UK to set such a target"
- "the range which UK greenhouse gas emissions reductions would need to be within, against 1990 levels, by 2050 as an appropriate contribution to the global goal of limiting global warming to well below 2°C" and "towards global efforts to limit the increase to 1.5°C"
- "how reductions in line with your recommendations might be delivered in key sectors of the economy"
- "the expected costs and benefits across the spectrum of scenarios in comparison to the costs and benefits of meeting the current target"
- "updated advice on the long-term emissions targets for Scotland and Wales", "provided with regards to the respective devolved statutory frameworks on climate change"

Source: Letter to Lord Deben, CCC Chairman, 15 October 2018.

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

We respond to the Governments' questions in our recommendations in Chapter 8, based on the latest evidence on scientific understanding (Chapter 2), international context (Chapters 3 and 4), technical opportunities for reducing emissions in the UK (Chapter 5), how those can be delivered (Chapter 6), and the costs and benefits involved (Chapter 7).

2. The framework for emissions reduction in the UK

(a) The UK's current long-term emissions target

The UK's current long-term emissions target is to reduce emissions of greenhouse gases (GHGs) by at least 80% by 2050 relative to 1990 levels.

- It includes all the greenhouse gases included in the UN's Kyoto Protocol and the Climate Change Act (i.e. carbon dioxide, methane, nitrous oxide and fluorinated gases)[11].
- The target was designed to cover all sectors of the economy, including UK emissions from international aviation and shipping.

The target was legislated in the Climate Change Act, which passed with strong cross-party support (by over 400 votes to 5). That strong Parliamentary support for climate action continues today.[12]

(b) The long-term target as a guide to UK policy

The UK's long-term emissions target is not a merely aspirational or theoretical goal. Once legislated in the Climate Change Act there is a process to ensure it is delivered in the real world (Figure 1.1).

- The Act requires that carbon budgets – five-year caps on the UK's GHG emissions – are set on the path to the long-term target. These have been legislated in line with the Committee's independent advice, requiring a 57% reduction from 1990 to 2030 (Figure 1.2). In 2017 emissions were 42% below 1990 levels, provisional 2018 figures are 44% below.
- The Secretary of State with responsibility for climate change must prepare and publish policies and proposals that enable the carbon budgets and long-term target(s) to be met. Should a budget be missed, the Secretary of State must publish proposals and policies for compensating in future periods.
- Each year, the Committee must publish an independent assessment of progress towards the carbon budgets and the 2050 target and of whether the targets are likely to be met. The Secretary of State must respond to the points in these progress reports, providing a mechanism to get progress back on track if budgets are at risk of being missed.

This process – of legislating a long-term emissions target consistent with both the latest climate science and the UK's international commitments, and requiring that nearer-term policies keep the UK on track to deliver it – was groundbreaking at the time and remains a world-leading framework for continued progress. It continues to act as a model for legislative frameworks in other countries (e.g. Mexico, Sweden, France).

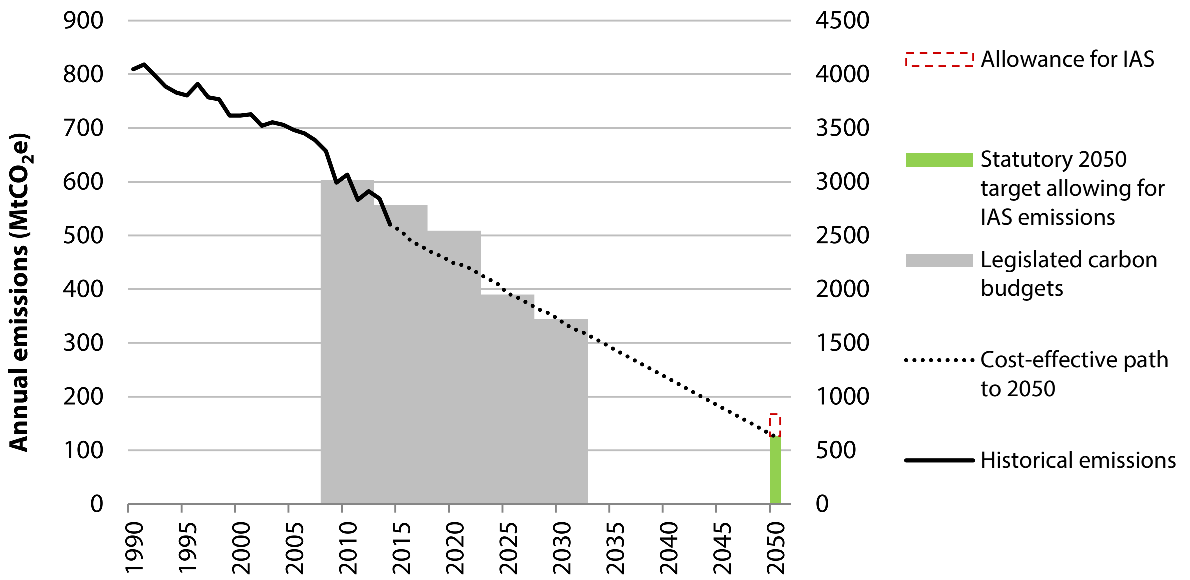
[11] The base year for the F-gases (HFCs, PFCs, SF_6, NF_3) is 1995, in line with the provisions of the Kyoto Protocol.
[12] For example, over 180 MPs from across parties have signed a letter to the Prime Minister to support the setting of a "*target of net zero for greenhouse gases before 2050*", www.theclimatecoalition.org/joint-letter.

Figure 1.1. The Climate Change Act requires that near-term policy is set to deliver the path to the long-term target

The Climate Change Act 2008

A goal	**2050 Emissions Target**
A pathway	**Carbon Budgets**
A toolkit	Requirement that Government brings forward **policies** to meet targets
A monitoring framework	**Committee on Climate Change** to monitor progress and suggest changes

Figure 1.2. The UK's existing long-term emissions target (set in 2008) has guided the setting of earlier targets and actions to deliver them



Source: Adapted from CCC (2015) *Fifth Carbon Budget Advice*. Based on DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; CCC analysis.

Notes: This chart is from the CCC's 2015 fifth carbon budget report. GHG emissions shown are the actual emissions, while carbon budgets represent the emissions under the net carbon account; IAS stands for International Aviation and Shipping, which are included in the 2050 target but not the carbon budgets.

In considering a net-zero GHG target, it is therefore important for Parliament to understand that it will mean that a ramp-up in policy effort will be required in earlier years. We set out the policy challenge for delivering a net-zero target in Chapter 6.

However, we do not attempt in this report to develop a full cost-effective pathway to the proposed target. We will advise on that pathway, including any changes needed to existing carbon budgets, when we provide our advice on the sixth carbon budget (covering the years 2033-2037) by the end of 2020.

The combination of a new long-term target and a revised path to that target will determine the UK's impact on global temperature increase.

(c) The basis for the UK's current 2050 target

The 80% target was set in 2008 based on advice[13] from the Committee that this was an appropriate contribution from the UK towards global efforts, at that time, to limit dangerous climate change:

- **The climate objective.** No global agreement existed at the time for the appropriate temperature goal. The Committee judged, based on the available climate science (i.e. the IPCC Fourth Assessment Report), that an appropriate climate objective would be "to limit the central expectation of global temperature rise to, or close to, 2°C" and to "ensure that the probability of crossing the extreme danger threshold of 4°C is reduced to an extremely low level (e.g. less than 1%)."
- **Global emissions pathways.** An analysis of possible global emissions paths identified that, to meet this objective, global emissions needed to fall by 50-60% by 2050, to 20-24 $GtCO_2e$.[14] That would imply an average per capita level of emissions of 2.1-2.6 tCO_2e.
- **UK share.** The expectation at the time was that a global climate agreement could be reached in the coming years. The Committee expected the UK's share of global effort to be subject to international negotiations and judged that it was difficult to imagine a global deal in which UK emissions per capita in 2050 were significantly above the global average. Average global emissions of 2.1-2.6 tCO_2e per capita implied around an 80% reduction for the UK from 1990.

Based on an assessment of the range of options for reducing emissions the Committee judged that meeting an 80% target would be "challenging but feasible" and deliverable at an annual cost of 1-2% of GDP in 2050. The Committee believed "that this level of cost is affordable and that it is appropriate to accept it given the potential consequences and costs of inaction".

The Committee was clear that "any climate strategy should cover all GHGs and all sectors" and that the 80% target was designed on that basis. However, the Climate Change Bill[15] did not include emissions from international aviation and shipping. The Committee therefore recommended that the target be legislated as "at least 80%" to cover the possibility that the sectors covered by the Bill may need to compensate for lower reductions in emissions from international aviation and shipping.

[13] CCC (7 October 2008) *Letter from Lord Turner to Ed Miliband, Advice on the long-term (2050) target for reducing UK greenhouse gas emissions.*
[14] Here and throughout this report, emissions of different greenhouse gases are combined using the GWP100 metric, in line with international convention.
[15] The Bill was legislated (becoming the Climate Change Act) after the Committee advised on the long-term target.

(d) Previous CCC advice on reviewing the UK's long-term emissions target

The Committee's first full report noted that it may be appropriate to adopt a new target in future as new information and analysis becomes available.[16] For example, the report identified that understanding of climate science could develop and the actual path of global emissions could diverge from the Committee's modelled trajectories. That was in line with the Climate Change Act, which allows changes to the 2050 target if, and only if, there have been significant developments in scientific knowledge or international law or policy.

The Committee noted in 2016 that the Paris Agreement (which was adopted at the end of 2015) set a more ambitious goal to limit the increase in global average temperatures than the basis for the UK emissions targets. Global paths that were available consistent with limiting warming close to 1.5°C, at the upper end of the ambition in the Paris Agreement, implied lower emissions per capita than implied by the UK's target for an 80% reduction from 1990 levels by 2050.

The Paris Agreement also contains a goal to reach "*a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century*" (which is widely interpreted as implying net-zero GHG emissions globally).

The Committee concluded in 2016 that the UK would probably need to reach net-zero emissions no later than the world as a whole and that a target to that effect would be needed (see Box 1.2 for a definition of net-zero emissions).

However, the Committee concluded in 2016 that the time was not right to set such a target:[17]

- Few global pathways for emissions were available that were consistent with the Paris Agreement's 1.5°C goal.
- No UK scenarios existed for reaching net-zero emissions.
- UK policies were not yet sufficient to put the UK on track to existing emissions targets.
- The UK's targets remained relatively ambitious compared to targets in other countries.

The Committee therefore recommended in 2016 that the setting of a new long-term target for UK emissions be kept under review. The publication of the Special Report from the Intergovernmental Panel on Climate Change (IPCC) on global warming of 1.5°C provides the first important review point.

[16] CCC (2008) *Building a low-carbon economy – the UK's contribution to tackling climate change.*
[17] CCC (2016) *UK climate action following the Paris Agreement.*

Box 1.2. What does 'net-zero' emissions mean?

Long-lived greenhouse gases like carbon dioxide accumulate in the atmosphere. Therefore, their emissions must be reduced to zero in order to stop their cumulative warming effect from increasing and to stabilise global temperatures (see Chapter 2).

Some activities, such as afforestation, actively remove CO_2 from the atmosphere.

'Net-zero' emissions means that the total of active removals from the atmosphere offsets any remaining emissions from the rest of the economy. The removals are expected to be important given the difficulty in entirely eliminating emissions from some sectors.

Sometimes 'net-zero' is used to refer to CO_2 only, and sometimes it refers to all GHGs. There are some merits in each, which we consider in this report. Our recommendation in this report (Chapter 8) is that the UK should set a net-zero target to cover all GHGs and all sectors, including international aviation and shipping.

3. Global progress since 2008

(a) The Paris Agreement and the work of the IPCC

Following relatively slow progress in international negotiations after 2008, the 2015 Paris Agreement was the first fully global agreement to tackle climate change. Chapter 2 sets out some of the key characteristics of the Paris Agreement, including its global coverage, a temperature goal that is more ambitious than the basis for the targets in the UK's Climate Change Act and the process to increase effort from all parties.

All countries have signed up to the Paris Agreement, although the US has signalled its intention to leave, which it can do immediately after the next Presidential election in late-2020.

The Paris Agreement also requested an update from the IPCC on the impacts of global warming of 1.5°C, to be provided in 2018. There has been a steady increase in scientific evidence since 2008. Chapter 2 summarises the IPCC's findings. These include observed impacts to-date, increasing attribution of extreme events to climate change, and improved understanding of the adverse effects that can be expected as global average temperatures increase. The IPCC also set out global emissions pathways to deliver the Paris Agreement temperature goal based on the latest estimates of climate sensitivity.

(b) Global emissions and international ambition

Global emissions have continued to grow since 2008, although slightly more slowly than assumed in the Committee's 2008 advice. While estimated CO_2 emissions briefly plateaued in the middle of this decade, subsequent rises indicate that emissions have not yet peaked.

The combined effect of pledges made under the Paris Agreement and the policies implemented to deliver those pledges has been to bring expected warming this century down from around 4°C to around 3°C. Many countries, like the UK, are also actively considering increasing their pledges and/or adopting net-zero targets for emissions in the long term. Chapters 3 and 4 set out the latest evidence on these areas.

(c) Technology and economics

One of the most positive and important developments since 2008 has been the very rapid cost reduction that has accompanied the global expansion of renewable electricity generation (especially for wind and solar power) and an accompanying fall in the cost of batteries. These technologies have benefited from major scale-ups in global deployment, open global markets that have supported lower cost manufacturing and well-designed policy environments such as auctions of long-term contracts for renewable power.

These changes are crucial given the importance of power generation and surface transport in global emissions (in combination making up around 40% of the global total in 2017) and their projected growth, particularly in middle-income and developing countries.

There have also been technologies that played significant roles in the Committee's UK scenarios in 2008 that have under-performed, either as projects have been delayed and costs have overrun (e.g. nuclear) or as policy has failed to drive take-up effectively (e.g. heat pumps and carbon capture and storage, CCS). Alongside these, new options have emerged (e.g. information technology and artificial intelligence could help make energy demand lower or more flexible than the Committee assumed in 2008, while technologies to remove carbon dioxide from the atmosphere have gained prominence in scenarios for both global and UK emissions reduction).

The economics of low-carbon technologies have been further bolstered by an increasing prevalence and strength of carbon pricing and regulations to drive efficiency improvements:

- Carbon pricing is now in place in 46 national jurisdictions, covering over 20% of global emissions, while vehicle efficiency standards are even more widespread, with nearly 80% of new light duty vehicles sold globally subject to GHG emission or fuel economy standards as of 2017.[18]
- UK carbon prices have risen since the introduction of the Carbon Price Floor in 2013 and more recently as reforms to the EU Emissions Trading System (EU ETS) have restricted the number of permits and increased the price of carbon allowances in the EU ETS.

Globally, these changes make low-carbon development paths far more likely (see Chapter 3), as low-carbon options like wind and solar power are now generally of comparable or lower cost than power from fossil fuels, while bringing significant co-benefits such as reduced air pollution. The requirement for policy is therefore increasingly to enable low-carbon energy paths rather than to subsidise them.

4. UK progress since 2008

Emissions can be cut while growing the economy

Since the Climate Change Act was passed in 2008, the UK has continued to demonstrate that it is possible to decouple emissions growth and economic growth – leading the G7 group of advanced economies in this decoupling. Greenhouse gas emissions have fallen by 30% while the economy has grown by 13% over 2008-2018, continuing trends of falling emissions and rising GDP since the 1990 base year (Figure 1.3 and see Chapter 7). Per capita emissions are now close to the global average at 7-8 tCO_2e/person, having been over 50% above in 2008.

[18] ICCT (2017) *2017 Global update: Light-duty vehicle greenhouse gas and fuel economy standards.*

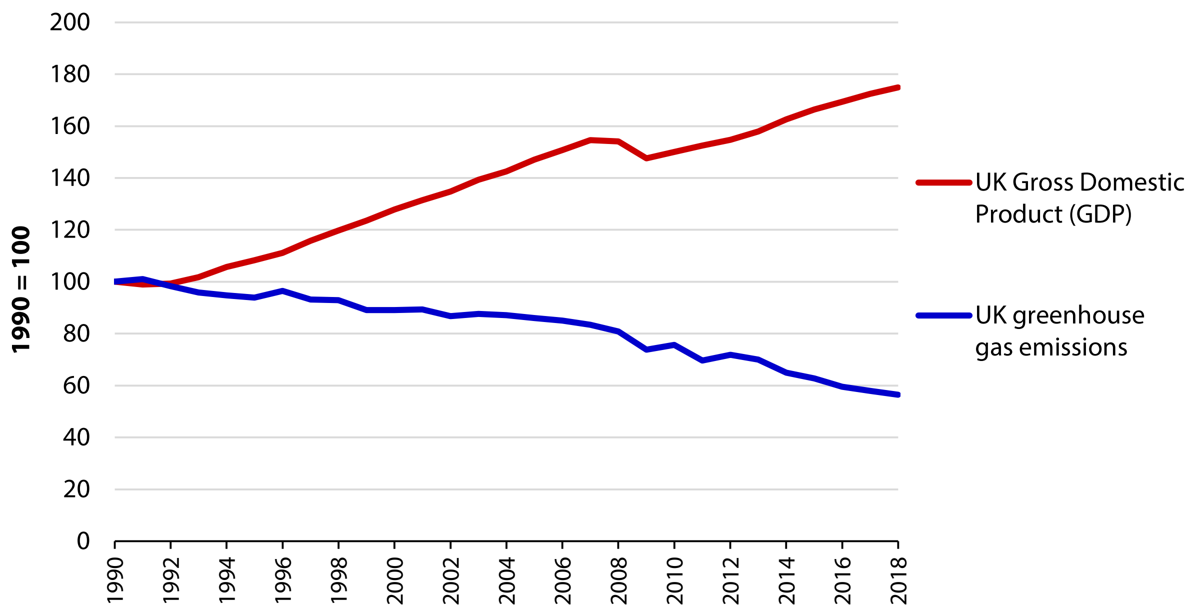
As of 2018, the emissions reductions since 2008 (30%) have been larger than in the most ambitious scenarios proposed in the Committee's 2008 report (a 22% reduction)[19]. That partly reflects the impact of the financial crisis in reducing energy demand. It has been delivered primarily through reducing reliance on coal-fired power generation, with limited progress in the transport, buildings and agriculture sectors (see below).

At the same time the expected costs for meeting the UK's existing emissions target have fallen as the costs of key technologies have fallen (see Chapter 7).

The success in reducing emissions while growing the economy has been reflected in the Government's Industrial Strategy, which recognises the opportunities that a low-carbon economy may bring and places Clean Growth at its core.

These figures are based on the UK's 'territorial' emissions. Estimates of the UK's 'consumption' emissions (that include overseas emissions from providing goods and services that are imported to the UK) are much higher and have not fallen as quickly, although they have also fallen in recent years. In part that reflects slower progress in tackling territorial emissions in other parts of the world. See Chapters 3 and 5 for further consideration of consumption emissions.

Figure 1.3. The UK as a positive exemplar – falling emissions in a growing economy (1990-2018)



Source: BEIS (2019) *Final UK greenhouse gas emissions national statistics 1990-2017*; BEIS (2019) *2018 UK greenhouse gas emissions: provisional figures*; ONS (February 2019) *Gross Domestic Product: chained volume measures: Seasonally adjusted £m*; CCC analysis.
Notes: Series indexed to start at 100. In 2018 UK GDP was approximately £2 trillion and GHG emissions were 449 $MtCO_2e$. Emissions shown on a 'territorial' basis in line with accounting of the Climate Change Act and excluding international aviation and shipping. 'Consumption' emissions (not shown in the chart) include emissions embedded in products consumed in the UK but produced elsewhere, and have fallen less quickly, reflecting that emissions in the rest of the world have been increasing.

[19] The 'Stretch' scenario from CCC (2008) *Building a low-carbon economy*.

The role of good UK policy

Emissions falls since 2008 partly reflect the financial crisis – in the period between 2008 and 2018, GDP growth was on average 1.2% below the growth level expected in 2008, with emissions falling sharply at the start of that period as a result of reduced economic activity.

However, overall UK progress also reflects the impact of several important and effective policies:

- A combination of policies drove a reduction in coal-fired power generation from over 40% of UK power in 2012 to under 10% in 2017. EU standards for the efficiency of electrical products have cut overall electricity demand, renewables subsidies have increased the supply of low-carbon power generation and the UK's carbon price floor has ensured that coal rather than gas generation has fallen as a result.
- Energy used for heating has reduced as UK building regulations have required that only efficient boilers can be installed and the Carbon Emissions Reduction Target required energy companies to install energy efficiency measures until it was scrapped in 2012 halting further progress. These policies have also helped to reduce customers' energy bills.
- The landfill tax, which was introduced in 1996 and has since increased in price more than tenfold, has driven a reduction of over 75% in biodegradable waste being sent to landfill and a diversion to other disposal routes such as recycling. It has been supported by policies to reduce waste arisings, such as the Love Food Hate Waste campaign.

These policies demonstrate that there are multiple routes to success, including regulating out high-carbon products (like inefficient boilers, lights and appliances), subsidising low-carbon technologies to drive cost reduction through learning-by-doing (e.g. power renewables) and taxing high-carbon activities (e.g. landfill and coal-fired power generation). In many cases they also involve positive opportunities – for lower bills, cleaner air and the wider environment, and possibly for the wider economy.

The UK experience of the last decade also shows both the advantages to collaborating across borders (e.g. Products Policy and vehicle standards have been implemented at EU level and therefore have affected manufacturers' designs at a wider market scale than the UK could achieve alone) and the opportunity to go further alone (e.g. the UK carbon price underpin has gone beyond the EU ETS and driven the UK's rapid reductions in coal consumption).

Remaining challenges

Policy success and progress reducing emissions has been far from universal (Figure 1.4):

- During the **second carbon budget** period (2013-2017), for those sectors not covered by the EU ETS, only the waste sector met the performance indicators previously laid out by the Committee.[20]
- **Transport** is now the largest source of UK GHG emissions (23% of the total) and saw emissions rise from 2013 to 2017.
- Progress installing **insulation** and reducing emissions from buildings has stalled since policy changed in 2012 (from the Carbon Emissions Reduction Target to the Green Deal).
- Installation of **heat pumps** remains at very low levels, despite generous funding under the Renewable Heat Incentive.

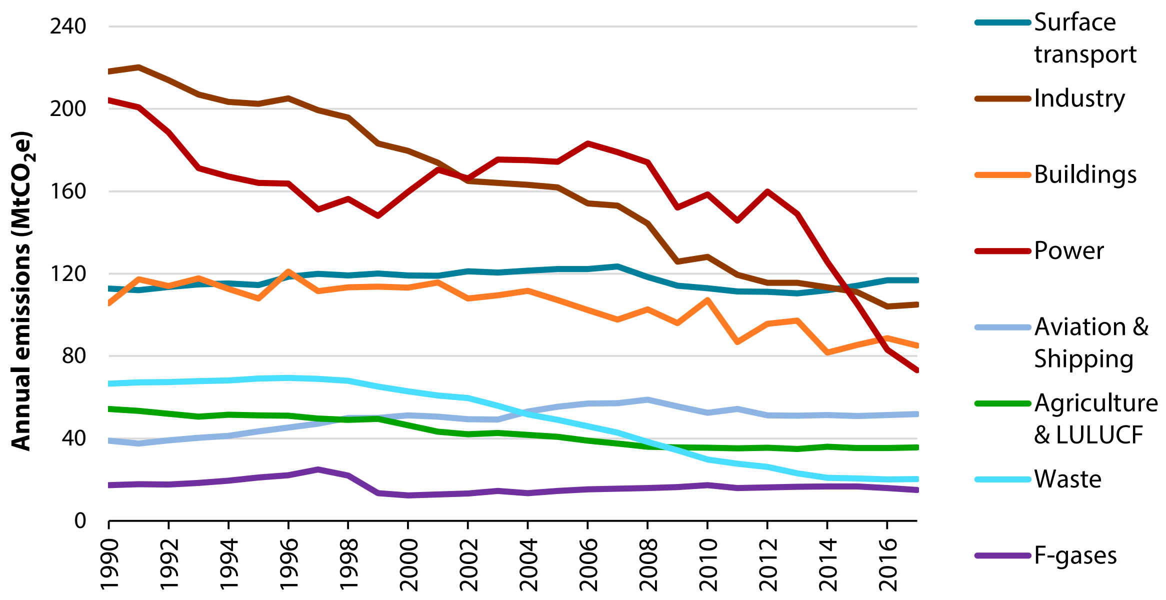
[20] See, Table 1 of CCC (18 February 2019) *Letter from Lord Deben to Claire Perry – Surplus emissions*.

- **Agriculture** emissions have been broadly flat over the last decade, suggesting stronger policy levers are required than the voluntary approach that is currently used.

Despite these challenges, a clear lesson from the past decade is that well-designed policy can drive changes that lead to reductions in emissions within a growing economy.

In one sense some of the easy opportunities have been taken – the centralised nature of the power sector makes it easier to design policies to drive change. However, this has also involved tackling one of the most expensive parts of the energy transition – now that renewables costs have been driven down, low-carbon power can be rolled out further and to other sectors at much reduced cost.

Figure 1.4. Progress reducing emissions in the UK has been imbalanced



Source: BEIS (2019) *Final UK greenhouse gas emissions national statistics 1990-2017*; CCC analysis. LULUCF = land use, land use change and forestry.

5. Redefining the UK contribution to tackling global climate change

(a) Stopping further warming requires net-zero emissions

It has been well understood for some time that global temperatures will only stop rising once global emissions of CO_2 and other long-lived greenhouse gases are reduced to net-zero. That is therefore a necessary condition of the Paris Agreement, since it aims to hold temperature increase to defined levels. Chapter 2 summarises the latest climate science, including the conclusions of the IPCC's Fifth Assessment Report and Special Report on 1.5°C.

This relationship also holds at the national level. Once the UK cuts its emissions of CO_2 and other long-lived greenhouse gases to net-zero we will stop adding to global warming.

If the UK goes further and cuts emissions of all greenhouse gases to zero (i.e. including short-lived gases like methane) the UK will be actively *reducing* our impact on global temperatures. That could offset the remaining impact of other countries or begin redressing the UK's large historical contribution to global warming. Net-zero emissions for all GHGs would also reflect the requirement in Article 4 of the Paris Agreement, which calls for a balance between anthropogenic sources and sinks at the global level.

Our judgement for this report is that the UK should as a minimum set a target at which we will no longer be contributing to the problem and ideally begin redressing our historical contribution.

(b) Defining an appropriate contribution to global effort

The Committee's advice on the existing long-term emissions target was based on a judgement that it was "difficult to imagine" a global deal in which the UK had higher emissions per capita than the global average in 2050. Extending this assumption would imply reaching net-zero emissions (in terms of CO_2 and GHG) no later than the world overall.

The Paris Agreement does not specify how the global effort should be shared between countries. Instead it takes a bottom-up approach, requiring 'highest possible' contributions from all parties, with developed countries continuing to take the lead.

There are several reasons to suppose that the UK can reach net-zero GHG emissions before the world overall:

- UK emissions are already close to the global average and have been falling consistently for several decades, while global emissions are not yet falling.
- The drivers that tend to increase emissions are stronger in the world overall than in the UK – expected population and economic growth are higher and the UK development path is based more on the service sector, which is less emissions-intensive.
- The UK has strong established governance processes to tackle GHG emissions (i.e. the Climate Change Act) and a track record of being a leader in policy development in key emitting sectors (e.g. energy market privatisation).
- More broadly, the UK benefits from higher GDP per person than the global average and a population that is supportive of well-designed action to cut GHG emissions.

We make a detailed assessment in Chapters 5-7 of whether deeper reductions in UK emissions than currently targeted are feasible whilst still delivering on other government objectives and what these would cost. That assessment recognises areas where the UK's challenge may be harder than that of other countries, for example due to our high population density and relatively high emissions from aviation.

Considerations of 'equity' also suggest that the UK should aim to reach net-zero emissions before the world as a whole. The UK has much higher historical emissions than the global average and a significant carbon footprint attached to imported products, for which the emissions are counted in other countries. Both these factors are cited in international negotiations, as strong reasons for richer developed countries like the UK to set more stretching goals for cutting emissions.

Chapter 3 explores the balance between UK and global effort in more detail and explores these issues based on the latest evidence and modelling.

(c) The benefits of UK climate leadership

The UK's GHG emissions are around 1% of global emissions, the same as its population. Therefore the UK's power to affect global climate change and to reduce the resulting risks to the UK depends on our ability to influence emissions beyond our borders. The Committee therefore consider UK climate leadership to be an important factor when assessing the UK's long-term emissions targets.

The UK has been a climate leader historically. In Chapter 4 we set out the various ways in which the UK has been and can continue to be an effective climate leader. That includes: acting as a positive exemplar for climate action while growing the economy, sharing the good governance models of the Climate Change Act and EU ETS, deploying and bringing down the cost of key technologies like offshore wind, supporting action elsewhere including by providing climate finance and through development aid, and taking a lead on green finance, adaptation and other issues.

Climate change can only be tackled with global cooperation. Continuing leadership, from the UK and other major economies, will be needed to move the world overall towards the emissions pathways required to deliver on the goals of the Paris Agreement. It could also support the UK's global standing by building on an area where we have a proven track record of positive action and influence.

6. Approach to determining a suitable net-zero emissions target for the UK

The Committee's overall approach in this report

In considering potential changes to the long-term emissions targets for the UK, Scotland and Wales, the Committee has sought to identify targets that best reflect the needs of the science, international circumstances including considerations of equity and climate leadership, and feasibility in the UK, Scotland and Wales:

- Any target must be scientifically robust and recognise the need for urgency that was clearly emphasised by the IPCC. We set out our assessment of this within the context of the latest climate science in Chapter 2.
- Targets should be aligned to the UK's international commitments, including through the Paris Agreement. That implies a need to reflect both the UK's capability and considerations of equity. We consider the international context in Chapter 3.
- To limit the effects of climate change on the UK and the world, global emissions must fall. UK action should support increasing global action. We consider the role of UK leadership in Chapter 4.
- Targets should be realistic. Therefore it is also vital to identify what can be feasibly delivered in the UK at an acceptable cost (in the long run and during the transition) and alongside other government objectives. Chapters 5 to 7 set out evidence on these areas.

We bring the evidence on these areas together for our conclusions and recommendations in Chapter 8 (Figure 1.5).

Figure 1.5. Factors determining the appropriate long-term emissions target for the UK

Science & International context (Ch 2-4)

- Global emissions pathways consistent with the Paris Agreement (Ch2)
- An appropriate UK contribution to the global emissions pathways (Ch3)
- UK climate leadership (Ch4)

Reaching net-zero emissions in the UK (Ch 5-7)

- Scenarios to reduce UK emissions to net-zero (Ch5)
- How UK net-zero scenarios can be delivered (Ch6)
- Costs and benefits of meeting a UK net-zero target (Ch7)

Recommendations (Chapter 8)

Evidence that the Committee has considered

We have considered an extensive evidence base for this report, including a significant amount of new evidence. That includes published sources, responses to our Call for Evidence, input from three expert advisory groups and results from 10 new research projects commissioned for this report (Figure 1.6, Box 1.3).[21]

A significant amount of the Committee's work programme has been focused on understanding what it would take to reduce UK GHG emissions to net-zero. In most cases, the question of whether that is realistic by a particular date is not a simple one and involves assessments across a range of criteria.

- As in much of the Committee's previous work we base those judgements on detailed bottom-up scenarios, as set out in Chapter 5 and the accompanying technical report.
- The scenarios include changes in behaviour and adoption of new technologies.
- We base the scenarios on the latest understanding of existing technologies and expected improvements without assuming radical breakthroughs. We recognise the possibility that innovation could progress more rapidly than we have assumed, particularly as technologies are deployed at very large scale in the UK and beyond. Against this, there could be under-performance in some existing technologies or failures of policies to successfully drive change.

We are able to give clear options for how GHG emissions could be reduced to net-zero. Actions would be needed across the economy. The scenarios do not mean central planning, but allow us to assess the challenges, opportunities and potential costs involved. They also enable identification of the policies and market rules needed to allow the best solutions to come through and help prioritise innovation.

[21] The responses to the Call for Evidence and a brief summary synthesis are published on www.theccc.org.uk.

Figure 1.6. Engagement and analysis that has informed the net-zero advice

Box 1.3. Call for Evidence

The Committee regularly issues calls for evidence to gather the views of a wide range of experts when developing its advice. In October 2018 the Committee called for evidence on building a zero-carbon economy. There were 14 questions covering:

- Climate science (two questions).
- International collaboration (two questions).
- UK opportunities (eight questions).
- Devolved Administrations (one question).
- The Committee's planned work programme (one question).

The Committee received 133 responses to the Call for Evidence. Responses came from a wide range of stakeholders, including business and industry, NGOs, academia and individuals. All of the responses are provided in full on the Committee on Climate Change website.

There was general support for a net-zero target, and an acceptance of climate science, as represented by the IPCC's reports. Most submissions focused more on how to achieve a net-zero target, rather than the specifics of the target itself. There was a strong call for:

- Clear and stable policies.
- Collaboration with or support from Government.
- Coordination between sectors.
- A just transition to a low emission economy.

Respondents were encouraged only to answer questions where they had particular expertise and to provide links to supporting evidence where possible. Over a thousand sources of evidence were referenced. The two questions with the most responses came under the category 'UK Opportunities', focusing on how to reduce emissions in sectors where it is more difficult, and how to deliver changes.

Chapter 2: Climate science and international circumstances

Introduction and key messages

At the time of the Committee's 2016 report *UK climate action following the Paris Agreement*, there was limited evidence on the global greenhouse gas (GHG) emissions pathways compatible with limiting warming to 1.5°C, the lower level in the Paris Agreement's long-term temperature goal, and the avoided climate impacts relative to higher levels of warming. The Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C (IPCC-SR1.5), published in October 2018, assessed a large new body of evidence that was produced to fill this knowledge gap.

This chapter reviews the updated understanding of the science of climate impacts and global emissions reductions needed to address climate change in light of the Paris Agreement.

Our key conclusions are:

- **Climate change is already here.** Human activity has already led to 1°C of global warming from pre-industrial levels which has resulted in damaging impacts on lives, infrastructure and ecosystems that are apparent today.
- **Any action to reduce emissions helps limit future climate risks.** Risks can significantly increase even with relatively small increases in global average temperature. There are clear benefits from cutting global emissions faster and deeper whatever the currently expected level of warming. The world has already shifted away from a 4 - 5°C business-as-usual trajectory, with end-of-century projected warming reduced to 3°C under current policies. This will bring benefits in terms of limiting future increases in climate risks.
- **Meeting the temperature goal of the Paris Agreement would lead to significantly smaller increases in future climate risks.** The world has committed in the Paris Agreement to keep warming 'well-below' 2°C and to pursue efforts to keep it below 1.5°C. Future increases in climate risks would be lower if warming were limited to 1.5°C instead of 2°C, but will still be greater than today's levels. Achieving this will require global emissions of *all* greenhouse gases to reduce rapidly over the next few decades, with more rapid decreases needed to limit warming to 1.5°C.
- **Net-zero emissions of *long-lived* greenhouse gases are needed to stop the planet warming.** Global temperature, which is a good indicator of wider climate risks, will only stop rising when global emissions, net of active removals from the atmosphere, of long-lived greenhouse gases including CO_2 are reduced to zero alongside approximately stable or falling emissions of short-lived gases. The Paris Agreement aims for a 'balance' between sources and sinks of emissions in the second half of the century - we interpret that as net-zero for the aggregated total of all GHG emissions.
- **Global emissions pathways reach net-zero CO_2 emissions by around 2050 for a 1.5°C limit and around 2075 for 'well below 2°C'.** Emissions of all greenhouse gas emissions (aggregated using standard 'CO_2 equivalence' metrics) reduce from around 7 tCO_2e/yr per capita today to -0.4 - 1.7 tCO_2e/yr by 2050 for 1.5°C and 0.8 - 3.2 tCO_2e/yr for 'well-below' 2°C pathways.
- **The UK can stop its contribution to rising global temperature by reducing its own emissions of long-lived greenhouse gases to net-zero.** Achieving and then sustaining net-zero emissions for aggregated total GHG emissions in the UK would go further and contribute to decreasing global temperature, implying a slow reversal of past UK contributions to warming.

We set out our analysis in five sections:

1. The science fundamentals
2. Climate impacts: every bit of warming matters
3. International ambition to tackle climate change - the Paris Agreement
4. Defining 'net-zero' emissions
5. Global emissions pathways that align to the Paris goal

1. The science fundamentals

The evidence of a changing climate continues to mount. This section provides an update on observed climate change and human influence on aspects of it.

The climate is changing as a result of human activity

The fundamentals of human influence on the climate system have been understood for a long time, with basic understanding of the greenhouse effect going back over a century. Scientific assessments of the cause of recent climate changes have regularly been undertaken and have come to the conclusion that humans have been the dominant influence.

Observations show continuing warming and other changes in the climate system:

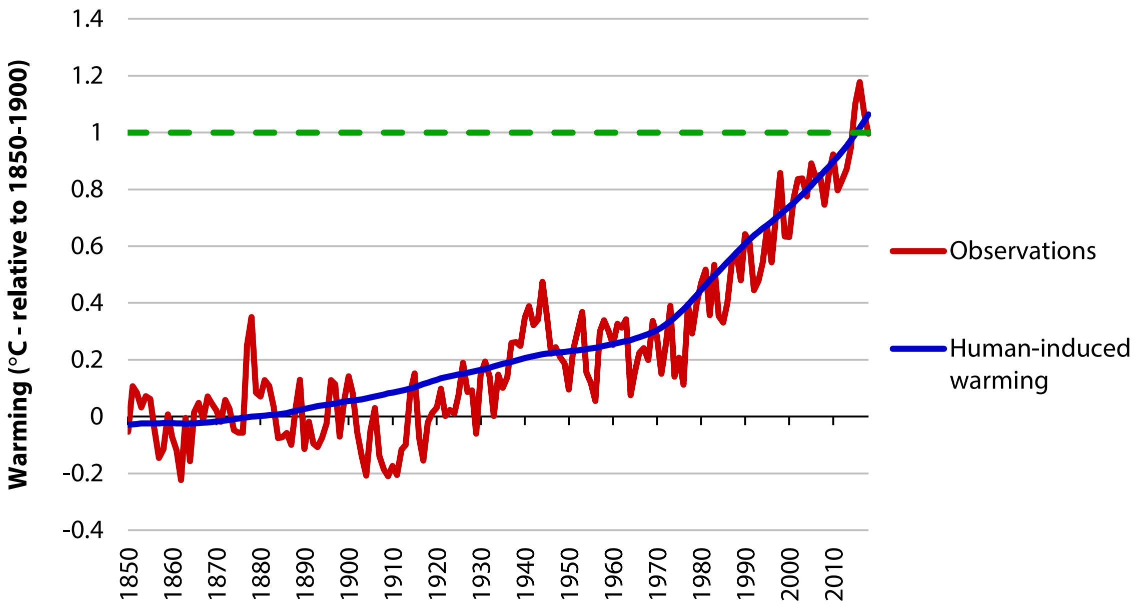
- The global average surface temperature over the 2006-2015 decade was 0.87°C (+/- 0.12°C) warmer than the 1850-1900 period (used as an approximation for pre-industrial levels by the IPCC) and was the hottest decade recorded since modern records began.[22]
- September Arctic sea-ice extent has declined by around 13% per decade since 1979.[23]
- Global sea-level has risen by about 20cm since the start of the 20th century and the oceans have increased in acidity. These ocean conditions are unprecedented in at least the last 65 million years.[24]
- The heat stored in the planet's oceans continues to rise.[25] Temperatures are rising in the deep ocean (below 2 km depth) with more than 90% of the extra energy trapped by GHGs ending up in the oceans.

IPCC-SR1.5 concluded that human-induced warming[26] has exceeded 1°C above pre-industrial levels and continues to increase at a rate of 0.2°C per decade (Figure 2.1). Human-induced warming will exceed 1.5°C around 2040 if this rate of increase continues.

- Human influence explains all the observed warming in the 2006-2015 decade with very little overall contribution from natural factors.
- This warming has not been uniform across the planet. Around 20 - 40% of the world's people are living in areas where at least one season has warmed by more than 1.5°C already.[27]

[22] IPCC (2018) *Chapter 1 - Framing and Context* and IPCC (2013) *Summary for policymakers*, Working Group 1 - 5th Assessment Report.
[23] National Snow and Ice Data Center.
[24] IPCC SR1.5 (2018) *Chapter 3 - Impacts of 1.5°C of Global Warming on Natural and Human systems*.
[25] WMO (2019) *Statement on the State of the Global Climate in 2018*.
[26] Warming caused by past and present human activities. This is independent of temporary warming and cooling from natural climate oscillations such as El Niño and volcanic eruptions.
[27] IPCC (2018) *Chapter 1 - Framing and Context*.

Figure 2.1. Observed and human-induced warming



Source: HadCRUT4, NOAA, NASA and Cowtan & Way datasets; IPCC (2018) *Chapter 1 - Framing and Context.*
Notes: 'Observations' are the average of the four datasets above as in IPCC-SR1.5 including for the full year of data for 2018.

Additional 'fingerprints' of human-induced change are being seen. These include warming of the troposphere (the lower part of the atmosphere) and cooling of the lower stratosphere, as would be expected from how increased GHG concentrations change the profile of heating and cooling throughout the atmosphere's depth.

The IPCC 5th Assessment Report (IPCC-AR5) provided a thorough assessment of the impacts that the current level of warming is already having. It concluded that 'recent climate changes have had widespread impacts on human and natural systems on all continents and across the oceans'. Attributable impacts included an impact of climate change on crop yields, shrinking glaciers and changing rainfall patterns affecting water availability, and changing geographic ranges of species on land and ocean.

Further evidence of human influence on aspects of extreme weather and its impacts on society have been detected since IPCC-AR5. Not all extreme weather events have been found to be made more likely by climate change[28], however around the globe more frequent heat-waves are occurring in most land regions, global-scale extreme precipitation has intensified and climate change has increased heat-related mortality during particular heatwaves.

Specific examples of recent detailed analysis include:

[28] For an example see Schaller, N. et al. (2014) The heavy precipitation event of May-June 2013 in the upper Danube and Elbe basins. *Bulletin of the American Meteorological Society*, 95(9), p.S69.

- The UK winter floods in 2013/14 (which created around £450 million in insured losses)[29] and the European summer heatwave in 2018 (which led to wildfires across parts of the United Kingdom)[30], were both made more likely by climate change.
- The extreme rainfall from Hurricane Harvey which hit Texas in 2017, causing around $125 billion in damage, was made more likely and more intense by human-induced warming.[31]
- Human-induced warming was found to be a significant contribution to the additional heat-related deaths in London during the extreme European heatwave of summer 2003 in which crop yields fell, power stations were shut down due to overheating and the heat-related death toll ran into tens of thousands.[32]

It is clear that climate change is here today. There is no longer a 'safe' level of warming in which climate impacts can be avoided entirely. Future warming will bring additional increases in the climate-related risks already present as well as the emergence of new ones.

Scientific understanding of drivers of warming

The driver of this ongoing climate change is human emissions of GHGs into the atmosphere. Global emissions of GHGs have continued to increase in recent years:

- Human emissions of CO_2 have grown to a new high of 41.2 $GtCO_2$/yr in 2018, increasing 2% above 2017 levels after several years of near-to-zero increase.[33]
- Global emissions of all GHGs regulated under the Kyoto Protocol of the UNFCCC are also estimated to have reached a record high of 55.1 $GtCO_2e$/yr[34] in 2017.[35] A further increase is expected in 2018 data.

A large body of literature convincingly demonstrates that the main cause of human-induced climate change is the cumulative total emissions of CO_2 since pre-industrial times.[36]

Cumulative emissions of CO_2 are also expected to be the main cause of future warming:

- Every tonne of CO_2 causes approximately the same increase in the long-term global average temperature no matter where and when it is emitted.
- To stop global temperature increasing, global emissions of CO_2 must be reduced to net-zero. Emitting less CO_2 in total will lead to lower levels of warming.

Estimates of the remaining carbon budget (the total amount of future net CO_2 emissions consistent with keeping warming below a certain level) for limiting warming to below 1.5°C has recently been updated by the IPCC. Keeping warming to below 1.5°C with at least 66%

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[29] Schaller, N. et al. (2016) Human influence on climate in the 2014 southern England winter floods and their impacts. *Nature Climate Change*, 6(6), p.627.
[30] Met Office (2018) *Chance of summer heatwaves now thirty times more likely*, https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave
[31] van Oldenborgh, G.J. et al. (2017) Attribution of extreme rainfall from Hurricane Harvey, August 2017. *Environmental Research Letters,* 12, 124009.
[32] Mitchell D. et al. (2016) Attributing human mortality during extreme heat waves to anthropogenic climate change. *Environmental Research Letters*, 11(7), 074006.
[33] Updated from Le Quéré, C. et al. (2018) Global Carbon Budget 2018. *Earth System Science Data*, 10(4), 2141-2194.
[34] Aggregated using GWP_{100} metric values from the IPCC 4th Assessment Report.
[35] Olivier, J. & Peters, J. (2018) *Trends in global CO_2 and total greenhouse gas emissions*.
[36] Cumulative emissions of CO_2 are estimated to have caused around 75% of human-induced warming observed thus far. Non-CO_2 GHGs and cooling effects of human-emitted aerosols represent other significant contributors, with an overall net warming effect.

probability corresponds to less than 10 - 14 years at current global emissions rates. This increases to 14 - 18 years for a 50% probability.[37]

Non-CO_2 GHGs with long lifetimes in the atmosphere (e.g. nitrous oxide - N_2O) affect the climate in similar ways to CO_2, but GHGs that are much shorter-lived (such as methane - CH_4) behave differently:

- The effect of these short-lived GHGs on global average temperature is much more closely controlled by their emissions *rate* as opposed to the *cumulative total* of emissions over time.[38]
- Emissions of short-lived GHGs do not need to be rapidly brought to net-zero, but rather stabilised and then slowly decreased to prevent continually increasing global average temperature.

Lower levels of short-lived GHG emissions will lead to a lower global temperature, but global temperature can be stabilised without reducing emissions of these short-lived gases rapidly to net-zero.

2. Climate Impacts: every bit of warming matters

Future climate risks to society are dependent on the interaction of hazard, exposure and vulnerability:[39]

- **Hazard** represents the possibility of a specific kind of weather or climate event that may have an impact on people or ecosystems (e.g. a river flood). Hazards can change in the future as climate change makes some hazards more or less likely. Future changes in hazards are uncertain as the exact changes in the climate system in response to GHG emissions are not precisely known. However, the level of global average warming is a good indicator for the aggregated level of climate-related hazards across the globe.
- **Exposure** refers to the amount of natural or human assets that could be impacted if a hazard were to occur. For example, people living within a one-in-ten year flood plain would be exposed to potential damage under such a flood.
- **Vulnerability** reflects the fraction of exposed assets that would actually be impacted if a given climate or weather event happened. Actions can be taken to reduce vulnerability. For example, ensuring houses within an exposed flood plain have a floodable ground floor would reduce the amount of household assets at risk of damage in a flood.

Actions to cut future emissions around the globe can and are helping to limit expected increases in future hazards from climate change. Alongside reducing exposure and vulnerability, emissions reductions will bring smaller increases in future climate risk.

[37] The range of remaining budgets for a given probability corresponds to different possible definitions of global average temperature. Smaller budgets correspond to defining a level of warming as the average near-surface air temperature at all locations rather than as a mixture of air temperature over land and ocean surface temperature over water. This is because global air temperature has increased slightly more than the blended combination of air and water temperatures since the 1850-1900 reference period.

[38] Smith, S.M. et al. (2012) Equivalence of greenhouse-gas emissions for peak temperature limits. *Nature Climate Change*, 2 (7), p.535.

[39] Expected future climate risks to the UK are assessed under the Climate Change Risk Assessment using this framework.

The following sub-sections summarise projected climate risks at different levels of future warming.

(a) Climate change is already here

Human-induced warming of around 1°C is having detectable and damaging impacts on people and ecosystems today. Amongst other impacts, examples include:

- The frequency of heatwaves has increased in most land regions.[40] This is leading to negative effects on human-health and heat-related mortality around the world.[41] The frequency and intensity of heavy precipitation has increased at a global scale due to climate change.[40]
- Patterns of water availability are changing due to melting land-ice and shifting rainfall in some parts of the world. Glaciers have been melting across the world due to climate change, affecting runoff and downstream water availability.[42]
- Ecosystems and species have been impacted by climate change, with many species changing their geographical extent and/or migratory patterns. Coral reefs and other ocean ecosystems have been more severely and frequently damaged due to climate change. For example, the ocean heat that created the worst recorded bleaching of the Great Barrier Reef off the coast of Australia in 2016 would have been essentially impossible in a pre-industrial climate. Those sea conditions are now expected nearly every one in three years today.[43]
- Climate change has affected crop yields, with more negative impacts than positive effects. Climate change has been acting to reduce global average yields of wheat and maize by around 1% per decade since 1960, preventing yields increasing as fast as they would otherwise have done due to other factors.[44]

Further warming will bring additional increases in climate risks with many becoming widespread and pervasive over the century. The levels of warming that would trigger abrupt and irreversible change in the climate system are uncertain but risks increase at higher levels.

The evidence of a changing climate is also becoming apparent in the UK:

- The 2008-2017 decade was 0.8°C warmer and 20% wetter than the 1961-1990 average.[45]
- UK sea levels have risen by over 16 cm since the early 20th century, increasing the possibility of coastal flooding.
- Changes in the probability of a number of UK extreme weather events have been attributed to climate change. For example, the conditions of the summer 2018 heatwave would now be expected to occur in about 12% of UK summers, an increase from less than 0.5% under pre-industrial conditions.[46]

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[40] IPCC (2018) *Chapter 3 - Impacts of 1.5°C of Global Warming on Natural and Human systems*.
[41] Ebi, K.L. et al. (2017) Detecting and attributing health burdens to climate change. *Environmental Health Perspectives*, 125 (8), 085004.
[42] IPCC (2014) *Chapter 18 - Detection and Attribution of Observed Impacts*, Working Group 2 - 5th Assessment Report.
[43] King, A.D., Karoly, D.J. & Henley, B.J. (2017) Australian climate extremes at 1.5°C and 2°C of global warming. *Nature Climate Change*, 7 (6), 412.
[44] IPCC (2014) *Summary for policymakers*, Working Group 2 - 5th Assessment Report.
[45] Met Office (2018) *State of UK Climate 2017*. Warming in the UK relative to 1961-1990 average is similar to warming since 1900.
[46] Met Office (2018) *Chance of summer heatwaves now thirty times more likely*, https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave

Some aspects of the climate system will continue to change over the very long term, even under the most ambitious future reductions in global emissions. For example, global sea levels would continue to rise for decades to centuries even if global GHG emissions were brought very rapidly to zero.[47]

(b) Actions to cut emissions are already helping to limit future increases in climate risks

Global emissions will continue to rise without action to reduce them. This **business-as-usual** trajectory would lead to an expected **4 - 5°C** increase in global average temperature above pre-industrial levels by 2100 with more warming expected afterwards. This would lead to severe and widespread climate impacts:

- Large increases in water-stress are projected for many regions, particularly already arid ones. At the same time, increases in extreme precipitation would mean many more people are exposed to flooding risks than today. A recent study estimates that nearly 80% of the world's population could be exposed to significant river flood risks in a 4°C world.[48] Warming and increases in humidity in many regions could make outdoor activities very difficult or even impossible. This could create substantial possible economic impacts on agriculture, construction and tourism.
- Large risks of wide-spread biodiversity loss would be expected. Many freshwater and land-based species would face substantial risk of extinction with limited suitable places available to migrate to.
- Large risks to the functioning of the global food system could occur with a substantial chance of large-scale crop failures. These risks are expected to be felt particularly by poor and vulnerable populations across the world. Large-scale failures of food systems and other climate impacts, such as increases in climate-related extreme events, could contribute to large-scale migration of people around the world creating pressures on social and economic systems.
- Risks of crossing irreversible tipping points within the climate system (such as triggering slow but inevitable collapses in ice-sheets or the permanent loss of ecosystems) would be high. These could lead to large and very long-lasting changes in the climate. For instance, an irreversible loss of the Greenland ice-sheet could raise global sea-levels by several metres over centuries to millennia.

However, the world has already begun to move away from a business-as-usual future. Continuing to mitigate global emissions through to 2100 in line with **commitments submitted to the Paris Agreement** would lead to expected end-of-century warming of around **3°C**.[49] Uncertainties in the response of the climate to GHG emissions means that there is still a range of outcomes consistent with this current trajectory. Based on an assessment of uncertainties,

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[47] Mengel, M., Nauels, A., Rogelj, J. & Schleussner, C.F. (2018) Committed sea-level rise under the Paris Agreement and the legacy of delayed mitigation action. *Nature Communications*, 9 (1), 601.

[48] Alfieri, L. et al. (2017) Global projections of river flood risk in a warmer world. *Earth's Future*, 5 (2), 171-182.

[49] Jeffery, M.L., Gütschow, J., Rocha, M.R. & Gieseke, R. (2018) Measuring Success: Improving Assessments of Aggregate Greenhouse Gas Emissions Reduction Goals. *Earth's Future*, 6 (9), 1260-1274. This assumes a generally similar level of effort of decarbonisation is continued post-2030 as prior to 2030 to achieve the NDC level of emissions and a fragmented implementation of international climate policy. Essentially it assumes broadly flat emissions in the near-term rather than rises assumed in the business-as-usual trajectory.

maintaining current rates of emissions reduction relative to business-as-usual would reduce the risk of exceeding 4°C of warming by 2100 to around 10%.[50]

In this **3°C** world exposure to climate risks would still be high but would be reduced compared to business-as-usual:

- Heatwave exposure is still expected to be large across the world, but lower than under business-as-usual. For example, research suggests that the global population exposed to heatwave risks in 2100 could be halved from over 8 billion under business-as-usual to around 4.5 billion in a 3°C world.[51]
- Risks to land-based ecosystems are still projected to reach very high levels, but evidence suggests these will be lower than at higher warming levels. For example, the fraction of mammal species that are expected to lose over 50% of their geographical range by 2100 reduces from around 40% under business-as-usual to 25% at 3°C warming.[52]
- Risks of 'tipping points' are reduced. For example rapid and widespread high-latitude and rainforest dieback could destroy critical regions of biodiversity and high carbon storage. Risks of triggering these tipping points would be significantly reduced under the current trajectory compared to business-as-usual. However, the overall risks of 'large-scale singular events' would still be high at 3°C, in part due to new evidence for possible instability in the West Antarctic ice-sheet.[53]

Whilst the current trajectory has lower climate risks than the business-as-usual trajectory, it would still leave an undesirably high exposure to climate risk and will not be sufficient to avoid damaging climate change.

(c) More climate risks can be avoided by additional global action to cut emissions faster and deeper

Limiting future increases in climate risks to lower levels requires lower global cumulative emissions of long-lived gases and deeper cuts in short-lived GHGs.

Any further increases in emissions reduction will help limit future increases in climate risk:

- Small increases in global average temperature have detectable consequences for climate extremes. Whilst the average global temperature increase between 1960-1979 and 1991-2010 was only 0.5°C, one-quarter of the planet's land area experienced an increase in the annual-maximum daily-high temperature of over 1°C for the same period.[54]
- Climate modelling suggests that each additional 0.1°C restriction in expected future warming would help limit increases in the intensity of damaging climate extremes.[55]

Increasing emissions reduction, so as to keep warming to **below 2°C**, would avoid a number of damaging climate risks that are expected under the current trajectory. Climate risks would be

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[50] Rogelj, J. et al. (2016) Paris Agreement climate proposals need a boost to keep warming well below 2°C. *Nature*, 534 (7609), 631.
[51] Arnell, N. et al. (2015) *The global impacts of climate change under 1.5ºC, 2ºC, 3ºC and 4ºC pathways (AVOID2)*.
[52] Warren, R. et al. (2018) The implications of the United Nations Paris Agreement on climate change for globally significant biodiversity areas. *Climatic Change*, 147 (3-4), 395-409.
[53] IPCC (2018) *Chapter 3 - Impacts of 1.5°C of Global Warming on Natural and Human systems*.
[54] Schleussner, C.F., Pfleiderer, P. & Fischer, E.M. (2017) In the observational record half a degree matters. *Nature Climate Change*, 7 (7), 460.
[55] Seneviratne, S.I. et al. (2016) Allowable CO_2 emissions based on regional and impact-related climate targets. *Nature*, 529 (7587), 477.

significantly greater than today, but keeping warming to below 2°C could enable adaptation actions to be effective in reducing impacts on people and ecosystems:

- Risks from extreme weather events would still be 'high' at 2°C warming above pre-industrial levels, but lower than at higher levels of warming. These lower risks of climate extremes would have benefits for people and society. For example, recent research indicates that keeping warming to below 2°C would nearly halve the expected global average drought length relative to a 3°C warmer world from 18 months to 11 months.[56]
- Significant changes in ecosystems would occur at 2°C warming, but there would be clear benefits compared to higher levels of warming, with global species extinction risk reducing to a moderate level compared to high levels under 4°C warming.[57] However, the rate of climate change would still likely be too fast for many species to be able migrate to regions with acceptable climates.
- Impacts on human systems and the economy would be lower than at higher levels, but not zero. For example, research estimates that impacts on human systems would be lower if warming was limited to 2°C compared to 3°C across a range of different indicators, including impacts on crop yields and flooding risks.[58]
- As there is substantial uncertainty regarding where 'tipping points' within the climate system might be, risks of 'large-scale singularities' in the climate system are still moderate at 2°C, but lower than at higher levels of warming.

Global efforts to increase emission reductions are also expected to lead to lower future increases in climate risk within the UK (Box 2.1).

An international UN review of climate risks determined that considering 2°C of warming as a 'guardrail' that can keep climate risks within 'safe' levels isn't appropriate.[59] Climate impacts are already here today and would be substantially greater at 2°C of warming. Efforts to keep warming as low as possible will help in keeping the future increase in damaging climate risks as little as possible. For instance, IPCC-SR1.5 identified a number of expected additional climate risks that would be avoided by keeping warming to **below 1.5°C** compared to higher levels.[60] A summary of these is provided in Box 2.2.

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[56] Naumann, G. et al. (2018) Global changes in drought conditions under different levels of warming. *Geophysical Research Letters*, 45 (7), 3285-3296.

[57] For example, the probability of an ice-free Arctic summer each year would be reduced to 10% from over 50% in a 3°C world. Arctic sea-ice is critical for the unique Arctic ecosystem.

[58] Arnell, N. et al. (2015) *The global impacts of climate change under 1.5ºC, 2ºC, 3ºC and 4ºC pathways (AVOID2)*.

[59] UNFCCC (2015) *Report on the structured expert dialogue on the 2013-2015 review.*

[60] A 1.5°C warmer world would still see significant increases in climate risk compared to today.

Box 2.1. Future climate risks in the UK

The UK is expected to be exposed to a number of key climate risks. These risks are likely to come from direct climate changes in the UK and the indirect effect of climate change overseas affecting interconnected global systems.

In a business-as-usual world reaching a global warming of 4°C by 2100, significant and systemic impacts are projected to occur. There would likely be limits to adaptation actions to reduce these risks in many cases. Examples of these climate risks include:

- **Extreme heat.** Warming across the entirety of the UK is expected, with summers warming more than winters. Central England average summer temperature could increase by between 1.1 and 5.8°C by the 2070s (compared to the 1990s). Temperatures experienced during the 2018 summer would be expected more often than every other year by the 2090s.
- **Water availability.** Wetter winters and drier summers are expected, with around 40% less precipitation in an average summer across the UK (compared to the 1981-2000 average), leading to water deficits in around 25% of water resource zones.
- **Sea-level rise and flooding**. The projected range of sea level rise for the UK's capital cities is between 30 cm to 1.15 metres by 2100. This is creating a growing threat of damaging coastal flooding. The population at significant risk of surface, river or coastal flooding would be expected to rise to 3.3 million by 2050 in a 4°C scenario.
- **Systemic risks**. Climate-related disruptions to global food systems and livelihoods is likely to create significant risks of food price shocks and possibly increase migratory pressures.

Limiting global average warming to 2°C by 2100 would bring a smaller increase in future climate risks to the UK in contrast to a 4°C world. For example:

- **Extreme heat.** Central England summer temperature rises would be between 0 and 3.3°C warmer in the 2070s compared to the 1990s, and the 2018 summer would be considered average, rather than cool by the 2090s.
- **Water availability.** Water deficits would affect less than 15% of water resource zones, and it is likely that adaptation measures could manage most of the increased risk from flooding and water scarcity.
- **Sea-level rise and flooding**. The range of sea level rise for the UK's capital cities would be reduced to 11–70 cm by 2100. The population exposed to a significant risk of flooding in 2050 would be around 2.6 million, lower than in a 4°C world.

Lower levels of climate change are also expected to bring some opportunities and benefits to the UK:

- Outdoor activities may become more attractive, helping to promote healthier lifestyles.
- Cold-related deaths would be expected to decline with future warming, these are larger than heat-related deaths in the UK, but are only expected to decline a little due to the effects of an ageing population.
- Growing seasons may lengthen and productivity in agriculture, forestry and fisheries may improve. However, realising these benefits will likely require careful actions to manage soil and water resources.

The evidence base of the effects of limiting warming to 1.5°C instead of 2°C in the UK is growing but still limited. It is expected to develop further over the next few years.

Source: CCC (2016) *Climate Change Risk Assessment 2017 Evidence Report.*

Box 2.2. Climate risks at 1.5°C warming

The recent IPCC Special Report on Global Warming of 1.5°C summarised climate risks at a global average warming of 1.5°C and compared them to higher levels of warming. It assessed a body of new literature that aimed to close a gap identified in the understanding of climate risks by the Paris Agreement.

Key findings from the report included:

- **Half a degree centigrade of global warming matters for climate risks**. Both observations and climate models show clear increases in climate risks for this level of extra warming.
- **Climate extremes.** Temperature extremes are expected to increase by 2-3 times the increase in global average temperature between 1.5°C and 2°C. Around 420 million fewer people would be exposed to extreme heatwaves if warming was kept to 1.5°C than 2°C.
- **Ecosystems.** Risks of species extinction on the land and in the ocean are lower at 1.5°C than 2°C. For example, the fraction of global land area that would change ecosystem type due to climate change factors at 2°C (13%) would be roughly halved if warming was kept below 1.5°C (7%).
- **Distribution of risks.** The additional increase in climate risk between 1.5°C and 2°C warming would affect poor and vulnerable people most of all. Poverty and disadvantage have increased with recent warming and are expected to increase for many populations as average global temperature increases from 1°C to 1.5°C and higher.
- **Irreversible changes.** Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could possibly be triggered by warming between 1.5°C and 2°C. Keeping warming as low as possible reduces the risk of triggering these large-scale irreversible shifts.

The IPCC Special Report highlighted that the climate impacts under pathways that temporarily overshoot 1.5°C before returning warming to below 1.5°C by the end of the century have greater climate risks than those that permanently stay below 1.5°C. These differences mean that there is not a single '1.5°C warmer world'.

- Pathways with substantial (>0.1°C) temporary overshoots of 1.5°C have very similar probabilities of peak warming reaching levels with very high climate risks (e.g. a 4°C warmer world) as pathways that limit warming to below 2°C with >66% probability.
- Risks of triggering irreversible changes in the climate system are largely a function of the maximum level of warming reached, for instance some ecosystems are particularly sensitive to heat-stress (such as warm water corals) and may be wiped out at the higher level of peak warming, but may survive if warming is kept below 1.5°C at all points.

Overall, the IPCC concluded that climate risks at a global warming of 1.5°C would be significantly lower than at 2°C, while at the same time being significantly greater than the level currently being experienced.

Source: IPCC (2018) *Special Report on Global Warming of 1.5°C.*

(d) Global action to cut emissions faster and deeper would help to achieve UN Sustainable Development Goals

International efforts to combat climate change sit alongside the broader international efforts to reach the United Nation's Sustainable Development Goals (SDGs).[61]

- The SDGs consist of 17 separate global goals or targets that were agreed by governments, including the UK, in 2015, prior to the Paris Agreement. They include ending poverty in all its forms, zero global hunger and affordable and clean energy for all.
- Governments are aiming to achieve the SDGs by 2030.
- Many SDGs are directly or indirectly affected by the state of the global climate system. For instance, the 'Life below Water' goal to achieve healthy and sustainable oceans is affected by the warming and acidification of the oceans due to climate change, whilst the 'Clean water and Sanitation' goal will be affected by changing risks of droughts and floods.

Increases in climate risks are expected to fall predominantly on the most vulnerable parts of society. Keeping warming to lower levels would therefore help efforts to achieve the SDGs.

- Poorer and more vulnerable parts of society are expected to be more exposed to impacts from a number of climate risks. For instance, poor quality housing and a lack of access to effective health care can mean that these groups are more impacted by extreme weather events.
- Under a world warming more than 2°C, it is expected that over 2.7 billion people would be exposed to multiple severe climate risks (e.g. land, water or energy risks). The areas with the largest fraction of population exposed are Asia, Africa and Latin America.[62] This number could be nearly halved to 1.5 billion if warming could be limited to 1.5°C.

Efforts to reduce emissions and remove GHGs from the atmosphere could come into conflict with achieving the SDGs if not implemented carefully. This could particularly be the case for land-based GHG removal, such as the very large-scale use of bioenergy with carbon-capture and storage (BECCS), which may create conflicts with other uses of land such as food production. This can be reduced by using a range of technologies to remove GHGs from the atmosphere and supporting global development patterns that reduce the need for GHG removal. Overall, the IPCC concluded that limiting warming to 'well below 2°C' and pursuing efforts to limit warming to 1.5°C is expected to have more synergies than trade-offs with efforts to achieve the SDGs and would help to achieve them.[63]

[61] United Nations (2015) *Sustainable Development Goals*, https://sustainabledevelopment.un.org/?menu=1300
[62] Byers, E. et al. (2018) Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environmental Research Letters*, 13 (5), 055012.
[63] IPCC (2018) *Chapter 5: Sustainable Development, Poverty Eradication and Reducing Inequalities.*

3. International ambition to tackle climate change - the Paris Agreement

This section provides a brief introduction to the Paris Agreement and the elements of the agreement that are relevant to understanding its implications for global emissions reduction pathways.

(a) The UNFCCC process and the Paris Agreement

The United Nations Framework Convention on Climate Change (UNFCCC) is the overarching environmental treaty that brings countries together to tackle climate change. The Paris Agreement, adopted at the 21st conference of parties to the UNFCCC (COP21) in December 2015, represents the first global climate agreement signed under the UNFCCC bringing together nation states under a single set of rules to address the threat of climate change.

- The agreement was the result of a long process to agree an international climate framework for after 2020 (the end date for the voluntary second commitment period of the Kyoto Protocol). It represents the long-term successor to both the Kyoto Protocol and the 2010 Cancun Agreements.
- The agreement came into force on 4 November 2016 after 55 countries had ratified it, representing over 55% of global emissions.
- The agreement was ratified by the UK on 17 November 2016. 185 countries had ratified as of the start of April 2019.
- The rulebook for the agreement was completed[64] at COP24, held in Katowice, Poland, in November 2018.

Further details of the Paris Agreement relevant to the UK share of global effort and actions that UK can take to aid the global effort are provided in Chapters 3 and 4.

(b) The Paris long-term temperature goal

The overall objective of the UNFCCC is 'stabilising greenhouse gas concentrations in the atmosphere at a level that would **prevent dangerous anthropogenic interference in the climate system**'. Current understanding is that the increase in the global average temperature is a good indicator of overall climate risk.[65]

The Paris Agreement contains a long-term temperature goal in which Parties commit to ***'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change'***.

- This long-term temperature goal was designed as an explicit strengthening of the Cancun Agreements' goal to hold the rise in long-term temperature 'below 2°C'.

[64] With the exception of concluding the negotiations regarding international collaboration in meeting mitigation goals and market-mechanisms, which was pushed to COP25.
[65] Assessments of climate-change related risks at various levels of global average warming incorporate expected geographical differences in the pattern of warming across the globe. This includes features such as greater warming in Arctic regions and greater warming over land compared to the ocean, as well as non-temperature impacts such as ocean acidification.

- It emerged following an official UNFCCC review of the adequacy of the long-term target before 2015, which examined the possibility of strengthening it to 1.5°C.[66]
- Throughout this report we use a definition of 'global average temperature' consistent with that used as a working definition in IPCC-SR1.5, which distinguishes human-induced warming from that caused by natural factors.[67]

The levels of warming referred to in the Paris Agreement represent long-term average levels (e.g. over 30 years) and not warming in a particular year, which will vary around the long-term average due to natural climate cycles. A year, or even a period of years, with the observed global average temperature above 1.5°C would not necessarily indicate that human-induced warming has exceeded the lower level of the Paris Agreement long-term temperature goal.

Interpreting the long-term temperature goal

Uncertainty in the climate response to emissions of GHGs means that it is only possible to say an emissions pathway would keep warming below a given level with a particular probability. Judgements are therefore required regarding acceptable levels of certainty of keeping warming below the levels in the Paris Agreement long-term temperature goal to set compatible long-term emissions targets.

In this report we interpret global emissions pathways with at least a **66% chance of limiting peak warming to below 2°C**, and a median warming of 1.6-1.8°C, as a *minimum* level of global ambition to limit warming **to 'well-below' 2°C.** We interpret pathways with at least a **50% chance of limiting peak warming to 1.5°C**[68] as consistent with a global ambition of limiting the temperature increase to **1.5°C**.

- This definition allows us to use the global pathways from IPCC-SR1.5 that are grouped as '>66% below 2°C' and '>50% of low or no overshoot of 1.5°C' as representative of the bounds of effort that are compatible with the Paris Agreement.
  - This classification incorporated IPCC-AR5 estimates of uncertainty in climate sensitivity, the radiative forcing on the climate and carbon-cycle feedbacks.
- This interpretation for the minimum level of ambition consistent with 'well-below' 2°C implies a range of median expectation for peak warming of 1.55 - 1.83°C based on the

[66] UNFCCC (2015) *Report on the structured expert dialogue on the 2013–2015 review*.
[67] This definition uses a mixture of ocean surface warming and near-surface air temperature warming over land. Global surface air temperature over both land and ocean is often used in the climate modelling community to represent global average temperature, particularly for future projections. Pre-industrial levels are defined as being represented by the average level over the 1850-1900 period.
[68] We allow for small (<0.1°C) overshoots within our definition in order to reflect scientific uncertainty regarding the shape of the distribution of future climate outcomes for a given emissions pathway. This was done in IPCC-SR1.5, which used two simple climate models to assess the consequences of emissions pathways for the climate (MAGICC and FaIR). The simple climate model that projected lower future warming (FaIR) indicated that median peak warming could be 0.1-0.2°C lower than simulated under the MAGICC climate model, suggesting that scenarios which are categorised with a peak warming slightly in excess of 1.5°C (based on MAGICC) may in fact keep warming below 1.5°C with 50% or greater probability.

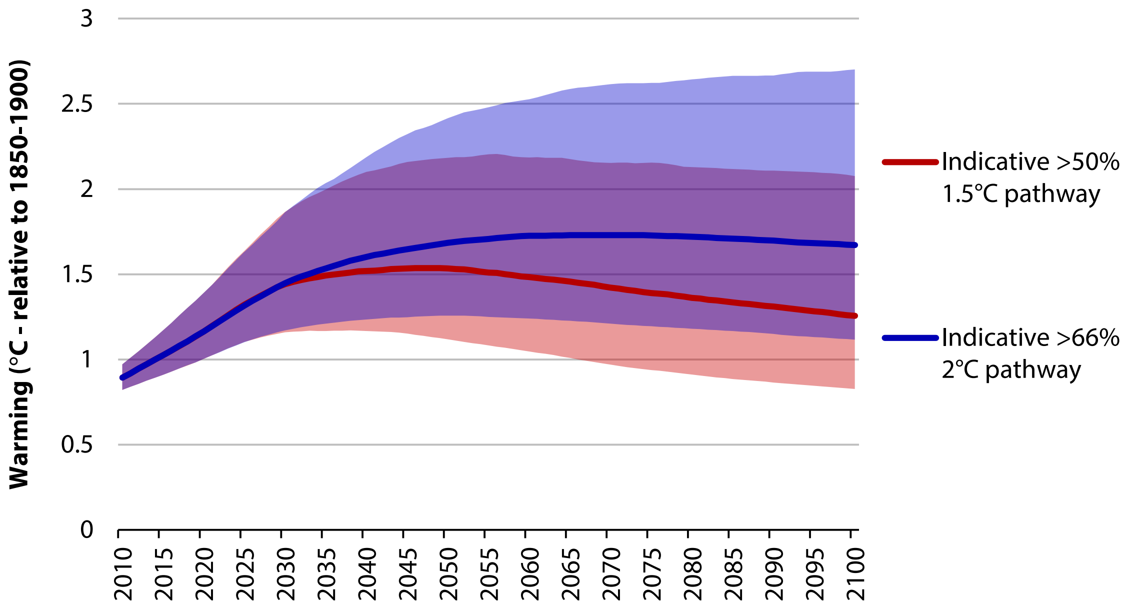
MAGICC model (Figure 2.2).[69] Pathways limiting warming to below 1.5°C with >50% probability have a probability of exceeding 2°C between 6 - 14%.[70]

- This interpretation is similar to the Committee's interpretation in our 2016 report *UK climate action following the Paris Agreement*, although at that time pathways were not available that kept warming below 1.5°C without a temporary overshoot with a greater than 50% probability.

Temperature peak and decline

Peaking and then declining global temperature is a feature of many global emissions pathways, including some that limit peak warming below 1.5°C with no or low overshoot (Section 5). This would require large-scale net removal of CO_2 from the atmosphere (Section 4).

Figure 2.2. Projected warming for emissions pathways estimated to achieve the Paris Agreement long-term temperature goal



Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.

Notes: Indicative pathways consistent with this report's interpretation of the long-term temperature goal of the Paris Agreement. Solid lines indicate the median temperature outcome with shading indicating the 5th - 95th percentile uncertainty assessed by the MAGICC simple climate model. These uncertainty plumes do not show uncertainty from the choice of emissions scenario. These uncertainty plumes also do not include the effect of possible Earth System feedbacks such as permafrost thawing. The particular pathways shown here are the SSP2-1.9 and SSP2-2.6 scenarios from the AIM/CGE 2.0 model.

[69] Using the FaIR simple climate model, also used in IPCC-SR1.5, would suggest a range of median peak warming of 1.27-1.57°C for these same emissions pathways.

[70] This does not incorporate the effect of possible 'Earth system' feedbacks, such as permafrost melting which could increase the upper end of the range of possible warming over the long-term.

In our assessment, it currently remains unclear whether decreasing global temperatures following peak warming would be desirable:

- If removal of CO_2 is implemented predominantly with large-scale use of removal methods depending on the availability of land, such as bioenergy with carbon capture and storage (BECCS) and afforestation, the very large areas of land required could create conflicts with other land-uses such as food production.
- Substantial investments in adaptation may be required to reduce climate impacts at peak warming anyway, regardless of whether temperatures then decline again.
- The cost effectiveness of additional investments in very large-scale deployment of carbon removal technologies to reduce global temperature after it peaks is not currently clear.

Although reducing global temperature after peak will reduce some climate risks, pathways that temporarily overshoot a particular level of warming have higher climate risks than those that permanently stay below it (Box 2.2). For instance, risks of triggering irreversible change in the climate system (such as ice sheet collapse) would be greater.

We therefore take a prudent approach and consider the Paris Agreement long-term temperature goal as referring to **peak levels of warming** for the purpose of setting a long-term emissions target for the UK.

(c) Balancing sources and sinks in the second half of the century

The Paris Agreement supports achieving the long-term temperature goal through a commitment to **'global peaking of greenhouse gas emissions as soon as possible'** and subsequently to reach a **'balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century'**.

- Whilst not being explicit about the metric of aggregation, this 'balance' is generally assumed to refer to net-zero GHGs emissions at a global scale.
- 'Anthropogenic' refers to both the sources and the sinks of emissions.[71] This excludes the use of natural carbon sinks that would occur independent of human actions to achieve this ebalance. This is required to be consistent with the scientific literature that has examined the connection between net-zero human CO_2 emissions and limiting long-term human-induced warming.

Throughout this report we use a working interpretation of this global 'balance' as net-zero GHGs aggregated using currently standard methodologies for defining 'CO_2 equivalence' (Box 2.4). An effective UK contribution to achieving this global 'balance' is discussed in Chapter 3.

[71] Fuglestvedt, J. et al. (2018) Implications of possible interpretations of 'greenhouse gas balance' in the Paris Agreement. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376 (2119), p.20160445.

4. Defining 'net-zero' emissions

A net-zero target could be set for CO_2 only or could include emissions of additional GHGs. This section looks at the effects of different definitions of net-zero emissions on global temperature.

Global net-zero emissions of ***long-lived*** greenhouse gases and stable or falling emissions of short-lived greenhouse gases are needed to stop global temperature increasing.

- **Long-lived greenhouse gases** accumulate in the atmosphere, so continued emissions of these gases leads to continually increasing warming. In order to stop global temperature increasing, global emissions of these gases must be brought to near net-zero. Warming created by long-lived gases is not naturally reversible on the timescale of decades-to-centuries. Therefore, reducing this warming requires the removal of long-lived gases from the atmosphere. CO_2 and other long-lived gases (such as N_2O) can be aggregated as 'CO_2 equivalent' whilst still relatively accurately capturing their effects on global temperature.
- **Short-lived greenhouse gases** such as methane affect the climate in qualitatively different ways to CO_2, with constant rates of emission leading to an approximately constant level of raised global average temperature but not continually increasing warming (Box 2.3).[72] Aggregation as 'carbon dioxide equivalent'[73] fails to capture this fundamental difference in how emissions of short-lived and long-lived GHGs affect global temperature. However, other constraints such as international comparability (Box 2.4) support the continued use of existing 'CO_2 equivalence' metrics for now.

Global net-zero GHGs[74] is expected to lead to **falling** global temperature if maintained, as net-negative long-lived GHGs offset residual stable or falling emissions of short-lived gases such as methane.

- No mitigation options exist to entirely remove all sources of short-lived gases such as methane (which are produced by agricultural processes, such as in the digestive systems of cattle, and by waste degrading in landfill) over foreseeable timeframes. Therefore reaching net-zero GHGs will require net-removals (or 'negative emissions') of long-lived gases from the atmosphere to compensate for these residual short-lived emissions.
- Net-negative long-lived emissions alongside stable short-lived emissions have a cooling overall effect on global average temperature. The amount of net-negative long-lived gases required to reach net-zero depends on how much short-lived emissions remain. Therefore a range of possible rates of cooling under maintained net-zero aggregated GHGs are possible.

Interpreting the Paris Agreement commitment to achieve a balance of sources and sinks as net-zero GHG emissions therefore implies falling global temperatures before the end of the century, but it does not specify from when or how quickly.

[72] A slow decline of methane emissions is in fact required to produce a constant level of warming, due to the slow thermal adjustment of the climate system. However, this rate of decline is on the order of <1% per year and can be approximated by constant emissions.
[73] Carbon dioxide equivalent is conventionally calculated using the GWP_{100} metric. GWP_{100} (the 100-year horizon global warming potential) equates GHGs based on a measure of the total energy that a single one-off emission of the gas would trap in the climate system over 100 years. It has long been known that this is an imperfect proxy for the effect of the emissions of a gas on global temperatures.
[74] Our scenarios for UK emissions reductions are presented in terms of CO_2 equivalence using the GWP_{100} values from the IPCC 4th Assessment Report, but the implications of using IPCC 5th Assessment Report values are explored in Chapter 5.

Box 2.3. Long-lived and short-lived GHGs

CO_2 is the main GHG emitted by humans:

- Once CO_2 is emitted the land surface and the ocean take up some carbon out of the atmosphere, but a significant fraction remains for centuries to millennia.
- This creates warming that persists in the long-term. Each additional tonne of CO_2 emitted adds more long-lasting CO_2 to the atmosphere and creates more warming, meaning that global temperature increases in proportion to the cumulative total emissions of CO_2. Emissions of CO_2 must therefore be brought to net-zero to stop temperature increasing.

Some other GHGs also have long atmospheric lifetimes and accumulate in the atmosphere causing persistent long-term warming. Nitrous oxide (lifetime of ~120 years) and a number of F-gases (e.g. SF_6 with a lifetime of 3,200 years) fall into this category.

Gases with a considerably shorter atmospheric lifetime, such as methane (lifetime of ~12 years) and some other F-gases (e.g. HFC-32, lifetime ~4.9 years), behave very differently:

- Their relatively short-lifetimes mean that for a *constant* rate of emission, atmospheric concentrations of a short-lived gas quickly increase to the point at which the amount of the gas decaying out of the atmosphere each year is equal to the amount being added through new emissions, keeping atmospheric concentrations constant. This only causes a slow increase in global temperature as the deep oceans warm-up on the timescale of several centuries.
- Maintaining constant emissions of a short-lived gas would therefore *maintain* the existing warming effect. This is unlike CO_2, for which atmospheric concentrations and warming both continue to steadily increase with sustained emissions.
- Offsetting the slow additional increase in warming to keep global temperature constant would only require emissions of the short-lived gas to fall by less than 1% per year. This is unlike for CO_2, for which emissions have to fall to near net-zero. Reducing the rate of emissions of a short-lived gas faster than around 1% year would lead to lower atmospheric concentrations and a decrease in the level of global warming.

Non-CO_2 effects from aviation, which include the emission of nitrogen oxides and contrails, is an additional example of a human effect on the climate system that is also largely short-lived. Finding a way to eliminate these effects (which have an overall warming effect on the climate) before global temperatures peak would contribute to a lower peak warming if done without a compensating increase in CO_2 emissions.

Source: CCC analysis; IPCC (2018) *Chapter 1 - Framing and Context*; Oxford Martin School (2017) *Climate metrics under ambitious mitigation*.

Consequences of a UK net-zero target for the global climate

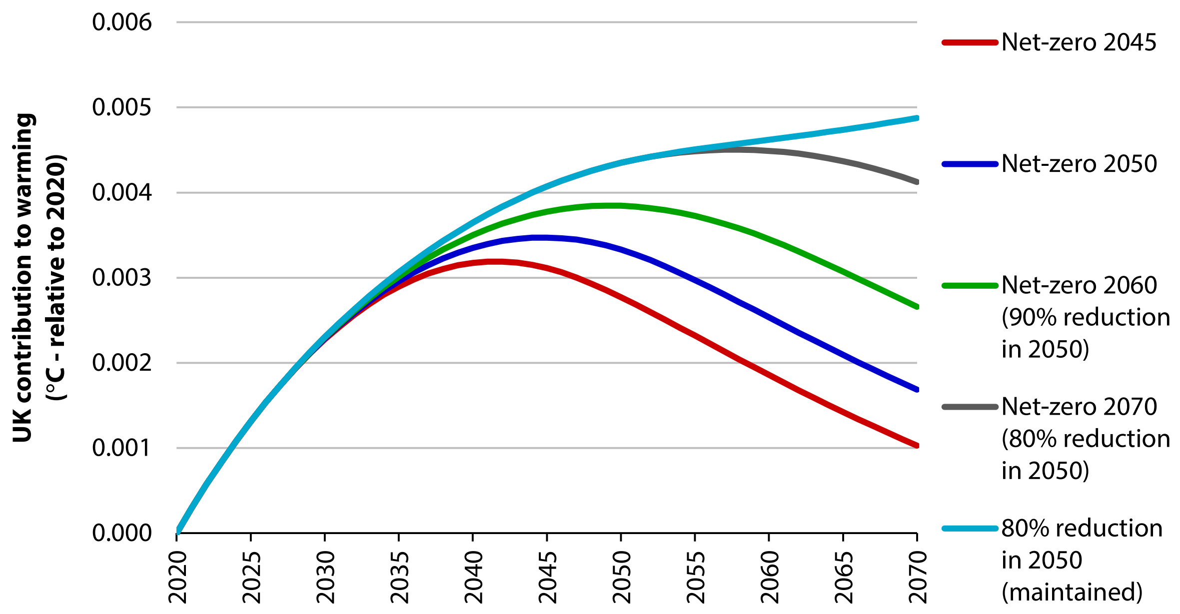
As emissions of GHGs mix relatively uniformly throughout the Earth's atmosphere, UK net-zero targets would have the same qualitative effects on global temperature as at the global level.

- **Net-zero UK emissions of long-lived greenhouse gases would stop the UK contribution to global temperature rise.** Our scenarios for UK emissions reduction in Chapter 5 indicate that net-zero long-lived gases would be reached at around a 97% reduction in aggregated GHGs. This would involve 14 - 16 $MtCO_2e$/yr of net removal of CO_2 from the atmosphere to compensate for around 14 $MtCO_2e$/yr of N_2O emissions and 0 - 2 $MtCO_2e$/yr of long-lived F-gas emissions. Residual emissions of methane and short-lived F-gases would be 28 - 30 $MtCO_2e$/yr.

- **Reaching net-zero GHG emissions in the UK would see the UK contribution to rising temperatures start to reduce prior to the date of net-zero.** Our scenarios for net-zero GHGs involve lower CO_2 emissions (i.e. higher net removals of CO_2) and possibly some further reductions in emissions of N_2O and methane.

An earlier date for net-zero GHG emissions would mean the UK contribution to warming would start to fall earlier and from a lower level. The UK's temperature impact would continue to rise after 2050 under the current target for an 80% reduction by 2050 relative to 1990 (Figure 2.3).

Figure 2.3. UK impact on global temperature under hypothetical future emissions pathways



Source: CCC analysis.
Notes: Emissions of F-gases are excluded from these calculations but their relative contribution to warming is expected to be relatively small compared to the total of the other GHGs. A near-term emissions pathway consistent with the CCC's current cost-effective path for the 4th and 5th carbon budget period is assumed. Contributions to warming are calculated using the climate response functions for calculating emissions metrics in IPCC-AR5. Net-zero GHG emissions are maintained from the time they are achieved. Net-zero GHG emissions is assumed to be reached with additional CO_2 removals beyond the 'Further Ambition' scenario in Chapter 5.

Box 2.4. Implications of the Paris Agreement and the Climate Change Act for greenhouse gas metrics

The aggregation of different GHGs can be done using a variety of 'CO_2 equivalence' metrics. Most commonly used is the global warming potential for a 100-year time horizon (GWP_{100}). This metric is used by the UK GHG inventory.

- GWP_{100} is a measure of the total heat-trapping potential over the next 100 years of emitting 1 kg of a GHG today, relative to emitting 1 kg of CO_2.
- This metric was recommended for use in aggregating greenhouse emissions by the IPCC in its 4th Assessment Report, but the 5th Assessment Report did not recommend the use of GWP_{100} over any other metric.

GWP_{100} equates 1 $MtCO_2e$/yr of sustained methane emissions with 1 $MtCO_2$/yr of sustained CO_2 emissions, but they will have very different effects on global temperature. GWP_{100} over-states the importance of methane for long-term temperature. This is particularly relevant once emissions are constant or falling.

Despite its scientific limitations, the international community decided at COP24 (in 2018) to standardise GHG reporting under the Paris Agreement transparency framework using the GWP_{100} metric.

- This means that future NDCs should all be stated using a common basis to aid aggregation at the global level.
- GWP_{100} values to be used are those from the 5th Assessment Report of the IPCC, which proposed some revisions to values in the 4th Assessment Report. This will require the UK inventory to be updated to use these more up-to-date metric values by the end of 2024.
- The Climate Change Act requires all regulated GHGs to be included in the long-term emissions target and interim carbon budgets with CO_2 equivalence calculated consistently with international reporting practice.

Throughout this report we therefore continue to use existing GWP_{100}-based aggregation of GHGs to maintain consistency with these internationally-agreed frameworks. We explore sensitivities for UK emissions reflecting the revised values proposed in the IPCC 5th Assessment Report in Chapter 5.

Source: CCC analysis; Allen, M.R. et al. (2018) A solution to the misrepresentations of CO_2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *npj Climate and Atmospheric Science*, 1 (1), 16.

5. Global emissions pathways that align to the Paris goal

IPCC-SR1.5 assessed a large body of new scenarios of the climate and the energy system that succeed in limiting warming to the long-term temperature goal of the Paris Agreement. This section examines characteristics of these emissions pathways, which are illustrated in Figure 2.4 and Figure 2.5. The details of the global transition underlying these emissions pathways are found in Chapter 3.

Throughout this section we use 'well-below' 2°C and '1.5°C' to refer to, respectively, the least ambitious and most ambitious ends of our interpretation of the Paris Agreement long-term temperature goal as defined in Section 3.

All emissions pathways consistent with the Paris Agreement share a number of characteristics:

- **Rapid peaking of global emissions.** Pathways that start emissions reductions from 2020 peak CO_2 and aggregated GHG emissions over the next decade (i.e. before 2030, in most cases well before). 1.5°C scenarios have substantially more near-term mitigation than in 'well-below' 2°C pathways leading to lower levels of CO_2 emissions in 2030.

- **Rapid reductions of CO_2 emissions in the following decades to achieve net-zero CO_2 emissions.** *Gross* CO_2 emissions (i.e. before any CO_2 removals from the atmosphere) continue to decline rapidly after 2030 to reach low levels, but do not reach zero. Removals of CO_2 from the atmosphere increase to compensate for these residual gross emissions. Some amount of active (i.e. human-induced) CO_2 removal is required in nearly all scenarios. Net-zero GHG emissions are reached later and only in pathways that peak and then decline global average temperature.
- **Deep cuts in non-CO_2 emissions.** Global emissions of methane, nitrous oxide and F-gases decline significantly between now and 2050. These non-CO_2 reductions are essential to allow more space for cumulative CO_2 emissions whilst staying within the limits of the Paris Agreement long-term temperature goal.

The implications of these pathways for the date of net-zero CO_2 and net-zero GHG emissions is addressed separately in the two subsections below.

Dates of net-zero CO_2 emissions

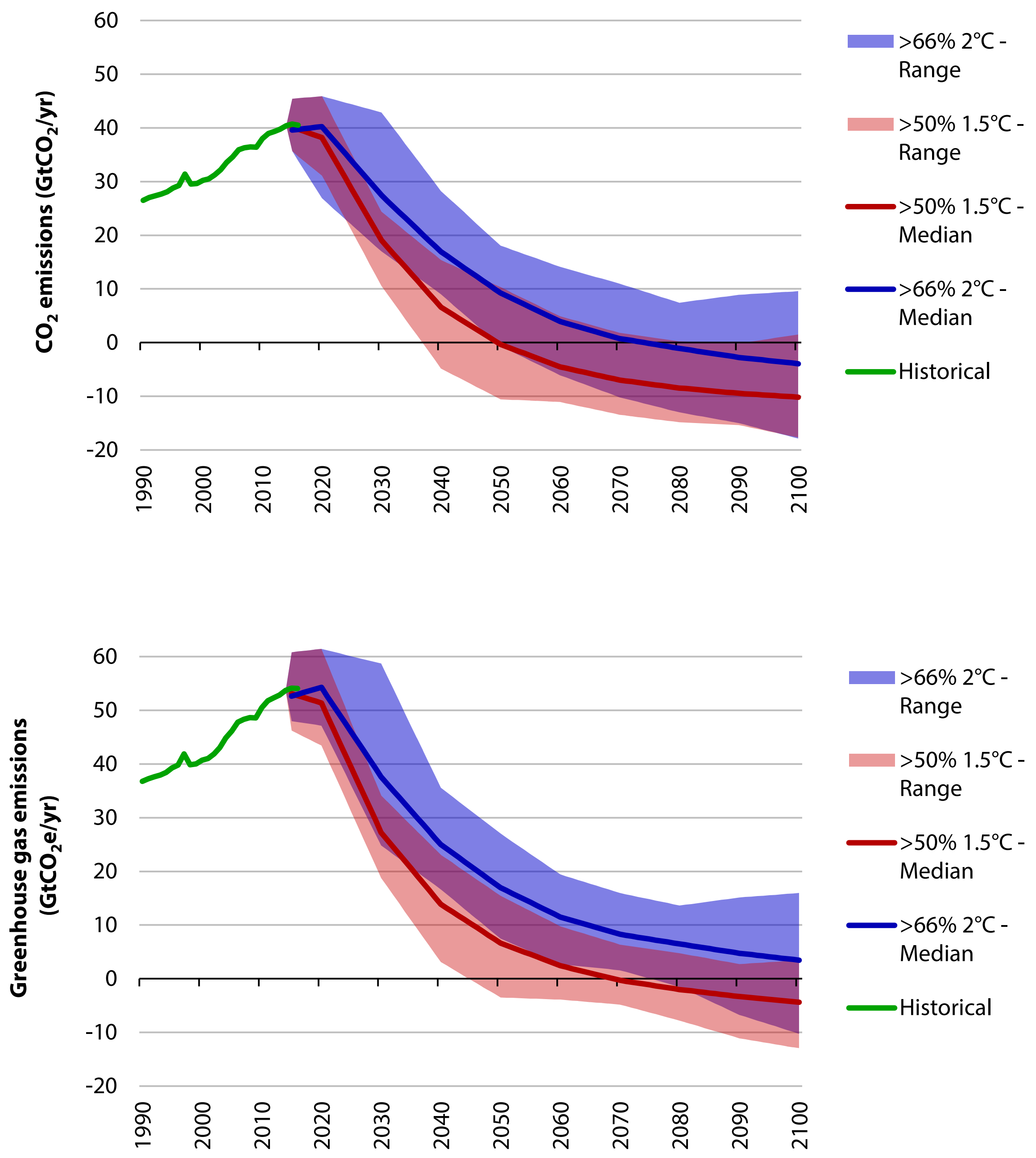
In global pathways that reduce emissions immediately and rapidly, the date of net-zero CO_2 emissions is an imperfect but useful proxy for future cumulative CO_2 emissions, the main determiner of future warming.[75]

Net-zero CO_2 emissions are generally reached **around mid-century** in most 1.5°C scenarios and **around 2075** for 'well-below' 2°C scenarios (Table 2.1). Methane emissions are falling in the decades prior to reaching net-zero CO_2 emissions (Figure 2.5) in most global emissions pathways. This allows warming to peak around the time of net-zero CO_2 emissions (Figure 2.6). However, net-zero long-lived emissions will be needed in the longer term to prevent warming eventually rising again.

Many emissions pathways simulate net anthropogenic removals of CO_2 from the atmosphere after reaching net-zero CO_2 emissions. This net removal largely serves to reduce global temperature from its peak but does *not* affect the level of peak temperature reached.

[75] Deeper emissions reductions in the near-term can actually mean that net-zero emissions are reached later for the same total cumulative CO_2 emissions. For this same reason, global emissions of CO_2 in 2050 are also only an imperfect proxy on the expected level of peak warming reached.

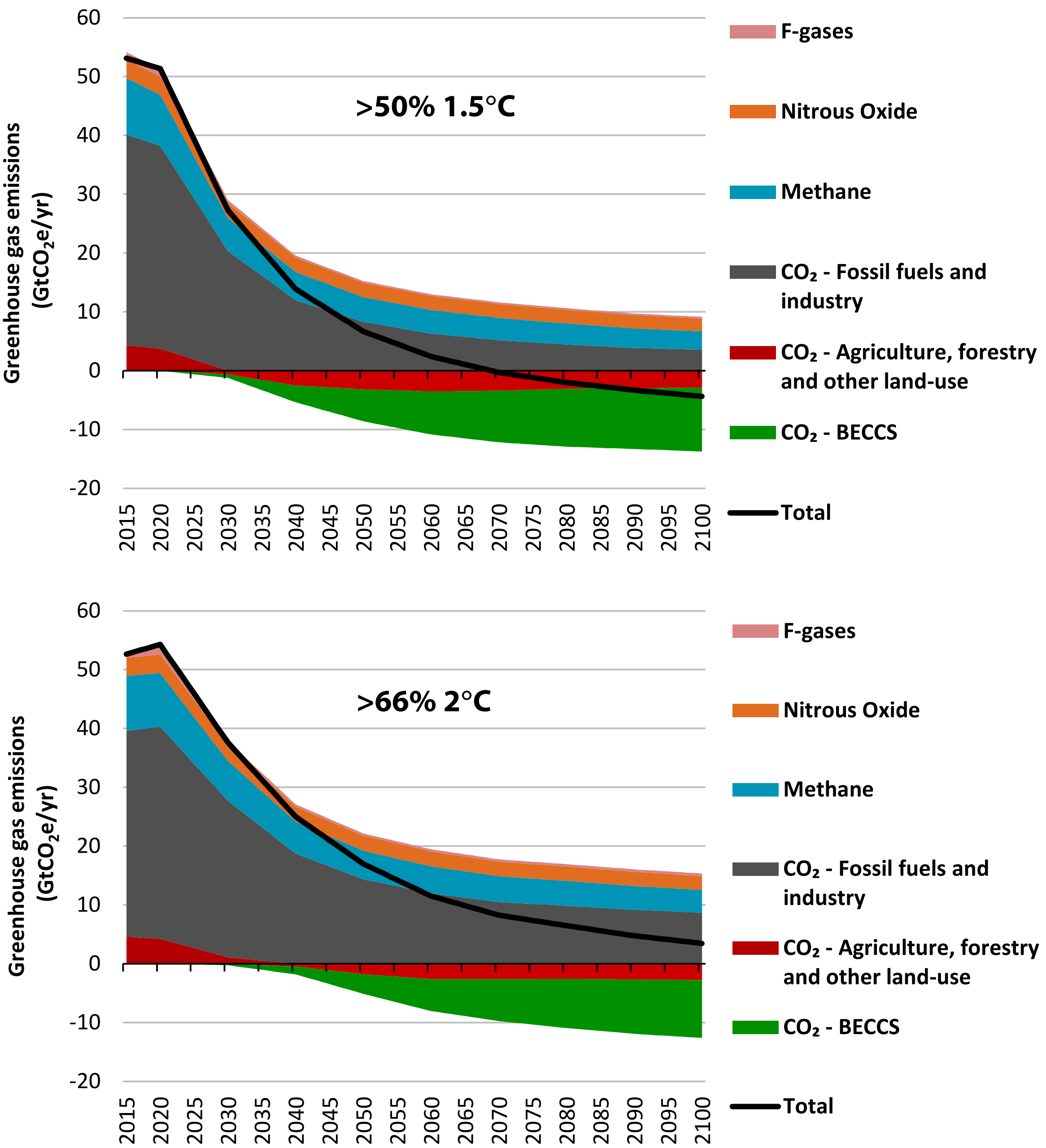
Figure 2.4. Global emissions pathways for CO_2 (top) and aggregated GHGs (bottom) consistent with the Paris Agreement



Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.

Notes: Shading indicates maximum and minimum across the scenario grouping at any point in time. The solid coloured lines are the 'median' scenario (at each point in time) in each scenario group. GHG emissions in the bottom panel are aggregated across all GHGs using the GWP_{100} values from the IPCC 4th Assessment Report.

Figure 2.5. Global emissions pathways split by gas for the average >50% 1.5°C pathway (top) and >66% 2°C pathway (bottom)



Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: Gases are aggregated using GWP_{100} values from the IPCC 4th Assessment Report.

Date of net-zero GHG emissions

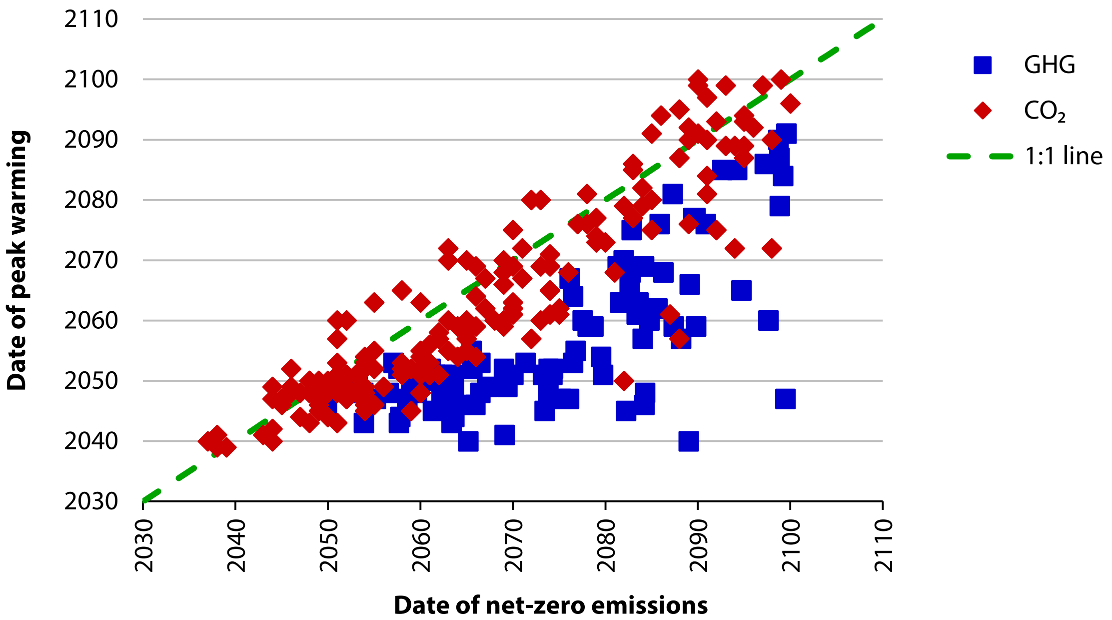
As described in Section 4, reaching global net-zero GHG emissions **is not a necessity** to peak global temperature and is not a feature of all global emissions pathways limiting warming to the long-term temperature goal of the Paris Agreement:

- As net-zero GHGs are associated with cooling global temperatures, only global emissions pathways that peak and then decline global temperatures reach net-zero GHG.
- Pathways that simply stabilise global temperatures generally do not require net-zero GHG emissions.
- The timing of net-zero GHG emissions is therefore not a strong determiner of whether the world succeeds in limiting warming to the Paris Agreement long-term temperature goal.

For those 1.5°C scenarios that do peak and decline temperature they typically reach net-zero GHG emissions **around 15 years later** than reaching net-zero CO_2 emissions.

When expressed on a per person basis, the pathways reduce global GHG emissions from 7 tCO_2e per person currently to -0.4 - 1.7 tCO_2e per person in 2050 for 1.5°C and to 0.8 - 3.2 tCO_2e for 'well-below' 2°C scenarios (Table 2.1).[76]

Figure 2.6. Temperature peaking and date of net-zero CO_2 and aggregated GHG emissions



Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: Each dot represents a scenario from across the entire set of scenarios in the IPCC-SR1.5 database. Scenarios that don't reach net-zero by 2100 are not plotted. If temperature is still rising by 2100 warming at 2100 is plotted. The 1:1 line is shown making equal dates on each axis.

[76] Future global population assumptions are taken as assumed in the scenarios themselves. This spans a range of different population scenarios, from a peak in global population not far above 8 billion around 2050 before declining to 2100, through to a continued increase to over 12 billion by the end of the century.

Why net-zero GHGs may be needed in practice

IPCC-SR1.5 largely focused on global emissions pathways in which reductions in global emissions begin at 2020 or soon after and, by 2030, are significantly below 2020 levels (Figure 2.3). However, current pledges under the Paris Agreement would lead to global emissions close to present-day levels (Chapter 3). If global ambition is not strengthened, net-zero GHG emissions may become a necessity to continue 'pursuing effort' towards 1.5°C:

- The IPCC-SR1.5 estimated that currently projected emissions for 2030 will use up 70 - 95% of the remaining carbon budget for at least a 50% chance of keeping peak warming below 1.5°C.[77] It could then be implausible to reduce global emissions quickly enough to prevent warming exceeding 1.5°C soon after 2030.
- If warming does exceed 1.5°C, then peaking and declining global temperature would be required to return warming to below 1.5°C. This would require large-scale net removals of CO_2 and most likely reaching net-zero GHG emissions at a global level before 2100.

In addition to overshooting 1.5°C, several other considerations may lead to global net-zero GHG being required:

- **Earth system feedbacks** such as permafrost thawing and methane release from wetlands, are expected to slowly release carbon into the atmosphere over decades to centuries. This may be around 100 $GtCO_2$ (2 - 3 times annual global emissions) over the century. Offsetting this warming may require additional removal of CO_2 from the atmosphere in the long-term.
- **Revisions in climate response uncertainty** estimates which make higher warming more likely could mean that maximum feasible rates of global emissions reduction may still lead to overshoots of 1.5°C with a high probability. This may make it necessary subsequently to achieve global net-zero GHG emissions to reduce warming back to below 1.5°C if an overshoot could not be avoided.
- **Redefinitions of global temperature** that have higher warming to-date (and therefore leave less room for further warming within the Paris Agreement limits) could similarly mean that only overshoot pathways could keep warming below 1.5°C with a high probability.[78]

So whilst in theory the long-term goal of the Paris Agreement could be met without reducing all GHGs to net-zero, without a substantial strengthening in global emissions reduction in the near-term net-zero GHGs may be necessary to pursue keeping long-term warming below 1.5°C.

Moreover, the Paris Agreement includes an explicit aim to balance emissions of sinks and sources - implying the world is already aiming for net-zero GHG emissions if interpreted using CO_2-equivalent metrics in current usage (as we do in this report).

[77] IPCC (2018) *Chapter 2 - Mitigation pathways compatible with 1.5°C in the context of sustainable development.*

[78] Using global surface air temperatures at all locations, as opposed to a mixture of surface air temperature over land and ocean surface temperature over water as in the IPCC-SR1.5 would increase estimates of human-induced warming today from around 1°C to 1.1 - 1.2°C. It would also mean that 1.5°C would correspond to a lower level of aggregate climate impacts compared to that assessed in IPCC-SR1.5.

Table 2.1. Characteristics of global emissions pathways compatible with the Paris Agreement long-term temperature goal

	>66% 2°C	**>50% 1.5°C**
Date of net-zero CO_2 emissions	2074 [2050 - 2100+]	2050 [2037 - 2082]
Date of net-zero GHG emissions	2100+ [2078 - 2100+]	2068 [2045 - 2100+]
Gross CO_2 removals at 2050 ($GtCO_2$/yr)	5.3 [0 - 15]	8.0 [3.3 - 17]
Cumulative CO_2 emissions (2020 to date of net-zero CO_2 - $GtCO_2$)	844 [440 - 1241]	480 [319 - 751]
2050 GHG emissions ($GtCO_2e$/yr)	17 [7.5 - 27]	6.5 [-3.5 - 15]
2050 CO_2 emissions ($GtCO_2$/yr)	9.2 [-0.6 - 18]	-0.4 [-11 - 10]
2050 GHG emissions per person ($GtCO_2e$/yr)	1.9 [0.8 - 3.2]	0.7 [-0.4 - 1.7]
2050 N_2O emissions (% of 2020 levels)	80%	75%
2050 CH_4 emissions (% of 2020 levels)	51%	51%
2050 F-gas emissions (% of 2020 levels)	13%	13%

Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: The median across the scenario grouping is shown for all variables. The square brackets show the minimum and maximum across the full range of the scenario grouping. '2100+' means that net-zero is not reached before 2100, the end point of the scenario. GHGs are aggregated using GWP_{100} values from the IPCC 4th Assessment Report.

Chapter 3: An appropriate UK contribution to the global effort

Introduction and key messages

The Paris Agreement is a departure from the structure of previous international climate agreements. Instead of a 'top-down' structure with emissions reductions allocated to each country, the agreement is instead 'bottom-up' with countries determining their own emissions reductions.

It requires countries to set emissions reduction goals that are consistent with its 'highest possible ambition', that are ‘fair and ambitious in light of its national circumstances’, and with regard to the need to raise ambition around the world to achieve the agreement's long-term temperature goal.

This chapter reviews current international action and compares it to action required to meet the Paris Agreement. We consider the UK's appropriate contribution based on capability and equity and on how it can support the required increase in effort across the world.

We conclude that the UK can and should target a domestic emissions reduction that is more ambitious than the average effort required globally to achieve the Paris Agreement's long-term temperature goal. That reflects three key lines of reasoning:

- **Capability.** The UK is well placed to continue to target and achieve emissions reductions that are more ambitious than those required by the world as a whole. It has rapidly reduced per person emissions since 1990. UK emissions per person are now similar to the global average and are on a downward trajectory while global average per person emissions remain broadly constant. The Climate Change Act provides the stable institutional framework needed for the UK to continue to set and achieve long-term emissions reduction targets that are more ambitious than required of the world as a whole.
- **Equity.** An equal per person share of global emissions in 2050 would require a 72 - 93% reduction in UK greenhouse gas (GHG) emissions relative to 1990 for pathways that keep warming 'well-below' 2°C and an 85 - 104% reduction for 1.5°C. However, the UK has a large historical contribution to climate change, is a rich economy compared to the global average, and UK demand for goods and services currently adds to emissions overseas. These are reasons for the UK to go beyond the effort required from the world as a whole.
- **Supporting the global effort.** Setting and achieving more ambitious emissions reduction targets in the UK and other leading countries would have a number of advantages for the global effort. These include easing the pace of deployment of expensive decarbonisation options in developing countries and facilitating technology and institutional development and transfer. Pathways developed for this report that rebalance effort towards existing climate leaders and richer nations appear more plausible than many existing published pathways that imply that most of the required increase in effort would come from middle-income and developing countries.

Whether the world achieves the long-term temperature goal of the Paris Agreement will depend on the actions of other countries alongside the UK. A large-scale shift in investment towards low-carbon technologies is needed and emissions need to stop rising and to start reducing rapidly. Falling costs for key technologies mean that the future will be different from the past: renewable power (e.g. solar, wind) is now as cheap as or cheaper than fossil fuels in most parts of the world.

This chapter is split into five sections:

1. The Paris agreement and international pledges
2. International effort required to achieve the Paris Agreement long-term temperature goal
3. UK capacity to move ahead of the global average effort
4. Equity considerations
5. An appropriate UK contribution to the Paris Agreement

1. The Paris agreement and international pledges

The Paris Agreement was adopted at the UN climate talks in Paris in December 2015. It aims to hold the rise in global average temperatures to 'well-below' 2°C relative to pre-industrial levels and to pursue efforts to limit the increase to 1.5°C (Chapter 2).

This section first sets out the bottom-up structure of the Paris Agreement then considers how consistent current bottom-up commitments are with this long-term temperature goal.

(a) The structure of the Paris Agreement and implications for UK emissions targets

The Paris Agreement has a 'bottom-up' structure. All parties are bound by a single framework and rulebook governing the agreement, but emissions reductions are not allocated through a top-down system. Instead they are determined by individual Parties themselves:

- Parties to the Paris Agreement are required to produce mitigation pledges but the delivery of these pledges is only legally-binding when enshrined in national or territorial law.
- A five-yearly cycle of global stocktakes and new pledge submissions is planned to increase ambition of nationally-determined contributions (NDCs) and move towards achieving the long-term goal of the Agreement. This is known as the 'ratchet mechanism'.
  - Parties will resubmit their first NDCs (covering the period up to 2030) by the end of 2020, with an aim of increasing mitigation ambition. They are also required to submit a 'long-term low greenhouse gas emission development strategy' by the same date.
  - Global stocktakes will assess progress towards the goals of the agreement in a 'comprehensive and facilitative manner'. They aim to help increase NDC ambition and promote international cooperation. The first global stocktake is scheduled to take place in 2023.
  - Parties are obliged to provide new and updated NDCs in the two years following each global stocktake. Successive Nationally Determined Contributions (NDCs) are expected to represent a 'progression over time' and reflect a party's 'highest possible ambition'.

We consider in Chapter 4 the scope for UK adoption of a new net-zero emissions target to influence positively this developing international picture.

Implications of the Paris Agreement for determining an appropriate UK contribution to the global mitigation effort

The 'bottom-up' structure of the Paris Agreement is significantly different from previously proposed structures for a global climate agreement. These largely focused on creating a 'top-down' structure, similar to the Kyoto Protocol, which would allocate agreed emissions reductions to each Party.

The Committee's 2008 recommendation for the UK's current 2050 emissions target, to reduce emissions by 80% below 1990 levels, was set based on the expectation of such a top-down global agreement:

- A set of global emissions pathways were assessed in the Committee's 2008 report that assumed emissions peaking in 2016 and then declining.
- Pathways with approximately **a 50% chance of limiting warming to below 2°C** in 2100 had global average per person global GHG emissions of 2.1 - 2.6 tCO_2e in 2050.[79]
- Assuming the UK would have no more than an equal per person share of global emissions in 2050, and accounting for projected population change, implied at least an 80% reduction in UK GHG emissions relative to 1990 levels in 2050.

A new or revised UK long-term emissions target should reflect an appropriate UK contribution to the global effort under the new 'bottom-up' nature of the Paris Agreement. This will involve satisfying a number of aspects:

- The Paris Agreement requires that emissions reductions are set according to a Party's 'highest possible ambition'.
- Equity and fairness remain core principles of the international process, through the acknowledgement of 'common but differentiated responsibilities' and different 'national circumstances'. Parties are required to communicate how their NDC is 'fair and ambitious in light of its national circumstances'.
- Developed countries are expected to continue to take the lead by undertaking 'economy-wide absolute emission reduction targets'.
- Article 3 of the overarching UNFCCC[80] requires that 'policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost'.

The above criteria will all have to be met by any revised UK long-term emissions target.

(b) Current emissions pledges and the emissions gaps

When the Paris Agreement was adopted in December 2015, intended emissions reduction for the period up to 2030 were acknowledged to fall short of global least-cost pathways estimated to be consistent with global warming of below 2°C.[81] They do however represent an improvement on business-as-usual emissions.

This 'ambition' gap in emissions reduction before 2030 still exists (Figure 3.1):

[79] Updated understanding of the climate system and more ambitious post-2050 emissions reductions in global pathways mean that pathways peaking emissions around 2020 and then reducing annual global emissions to around 2 tCO_2e/person in 2050 are now expected to be consistent with a 50% chance of limiting warming to a lower value (~1.6 - 1.8°C).

[80] The United Nations Framework Convention on Climate Change - the overarching treaty to deal with climate change at the international level.

[81] The pre-amble to the Paris Agreement highlighted a level of global GHG emissions in 2030 of 40 $GtCO_2e$/yr (aggregated using the GWP_{100} metric from the IPCC 2nd Assessment Report) as consistent with pathways resulting in below 2°C warming and referred to an undefined level for 1.5°C to be specified by the IPCC Special Report on Global Warming of 1.5°C. Aggregated Intended Nationally Determined Contributions (INDCs) were projected to lead to 55 $GtCO_2e$/yr in 2030.

- The aggregated global emissions under unconditional NDCs (i.e. commitments to reduce emissions which aren't conditional on the provision of climate finance from abroad) come to 56 $GtCO_2e/yr$ (52 - 58 $GtCO_2e/yr$) in 2030.[82] This would be a 5% growth above 2017 levels by 2030.[83]
- Additional commitments in the conditional NDCs reduce projected emissions in 2030 to 53 $GtCO_2/yr$ (49 - 55 $GtCO_2e/yr$), similar to the 2017 level.
- Pathways consistent with limiting temperature rise to 'well-below' 2°C typically have 2030 global GHG emissions in the range of 38 - 45 $GtCO_2e/yr$. This reduces to around 22 - 30 $GtCO_2e/yr$ in pathways consistent with limiting warming to 1.5°C.[84] In these pathways global GHG emissions would have peaked and be declining rapidly when they reach these levels in 2030.

Alongside this 'ambition' gap an 'implementation' gap exists as current global policies are not sufficient to meet the existing NDCs. Current policies are expected to lead to global emissions around 59 $GtCO_2e/yr$ in 2030, an increase of around 10% over 2017 levels.[85]

Current pledges in high emitting regions

A large fraction of global emissions come from a small number of territories. China, USA, the EU and India are the four biggest emitting parties to the Paris Agreement and contribute 56% of present global GHG emissions between them.[86] There is a mixed picture regarding the extent to which these big emitters are on track to achieve their NDCs:

- **China** remains on track to achieve its NDC (a main target to peak its CO_2 emissions before 2030). However, non-CO_2 emissions are expected to increase and may be up to 25% of the country's total GHG emissions in 2030.[87] Chinese emissions per person are now approximately equal with the EU (Figure 3.2) and are expected to exceed the EU level under current NDCs.
- **The USA** is off-track to achieve its 2025 NDC (a 26 - 28% reduction in GHG emissions relative to 2005 levels), which would still result in emissions per person significantly above other big emitters. Instead, emissions are projected to remain near-to-constant between now and 2030. It is planning to withdraw from the Paris Agreement under the policy of the current administration in November 2020, however the longer-term trajectory of US climate ambition is uncertain with substantial non-federal level action proposed.[88]
- **India** is expected to overachieve its pledged NDC (a 33 - 35% decrease in emissions intensity of GDP by 2030 relative to 2005 levels). This is still expected to lead to rising GHG emissions by 2030, but still with low emissions per person.

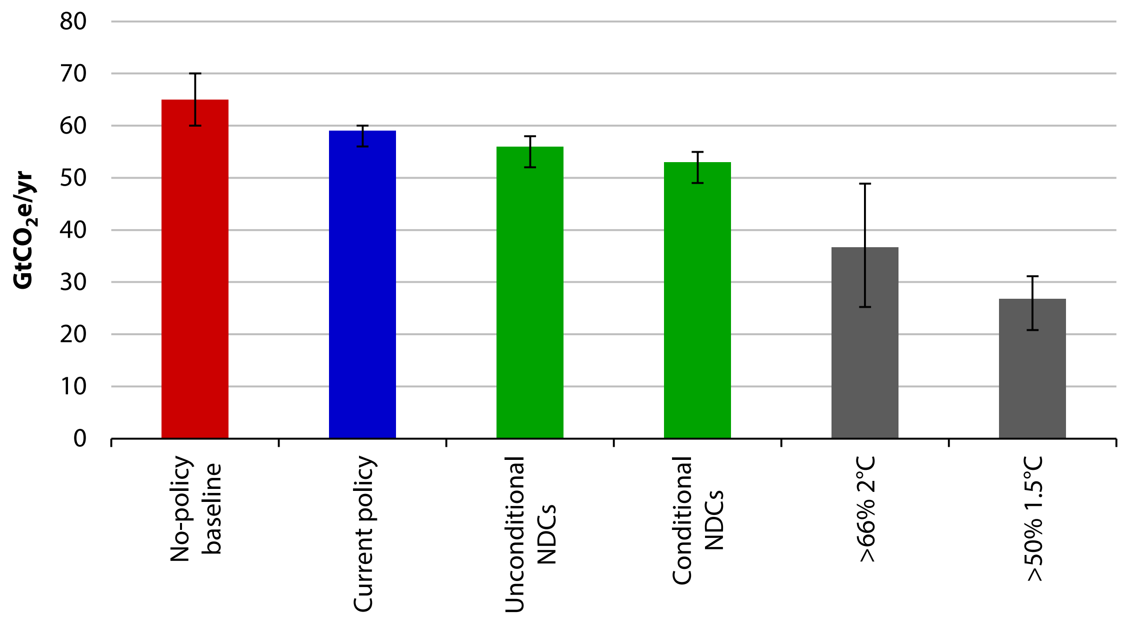
[82] Aggregated using the GWP_{100} values from the IPCC 2nd Assessment Report. Projected emissions under the NDCs are uncertain due to the ambiguous definition and description of NDC commitments (for example uncertainty in baseline emissions which NDCs are expressed relative to) - the quoted range reflects that uncertainty.
[83] United Nations Environment Programme (2018) *Emissions Gap Report 2018.*
[84] See Chapter 2 for the interpretation of the Paris Agreement long-term temperature goal used in this report.
[85] United Nations Environment Programme (2018) *Emissions Gap Report 2018,* - emissions aggregated using GWP_{100} values from the IPCC 2nd Assessment Report.
[86] Excluding emissions from land use, land use change and forestry (LULUCF).
[87] Climate Action Tracker (2018) *Current polices assessment*, https://climateactiontracker.org/countries/china/
[88] Chapter 4 summarises a number of large non-federal initiatives in the USA.

- **The EU** is nearly on track to achieve its NDC (a 40% reduction relative to 1990 levels) with current policies. Additional planned policies agreed in 2018 would likely be sufficient to raise ambition to a 45% reduction in GHG emissions by 2030 relative to 1990 levels.

Alongside these big emitters the rest of the world is a large and growing part of global emissions. G20 countries make up around 78% of global emissions today but around half are currently not on track to achieve their NDCs.[89] International aviation and shipping, which are excluded from national totals, represent around 2.5% of global GHG emissions and continued growing rapidly over recent years.

If the temperature goal in the Paris Agreement is to be met, both ambition and implementation will need to increase across the world.

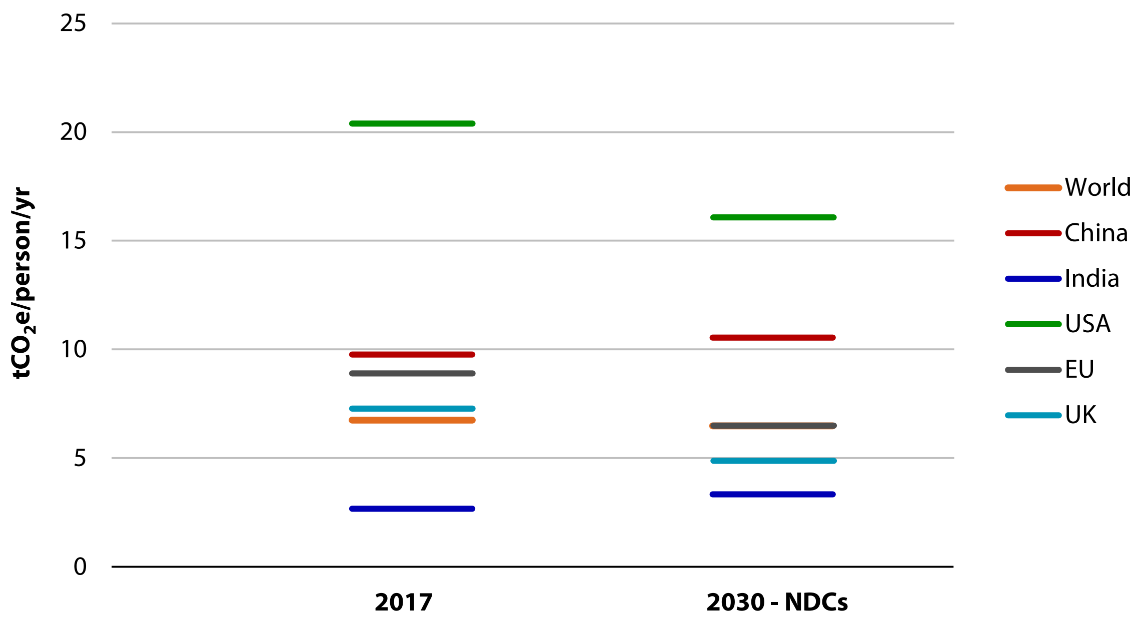
Figure 3.1. Global GHG emissions gaps in 2030



Source: United Nations Environment Programme (2018) *Emissions Gap Report 2018;* Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: Assessment of no-policy baseline, current policy, unconditional and conditional NDCs from UNEP Emissions Gap Report 2018. Aggregated 2030 emissions levels for Paris Agreement compatible scenarios are from the IPCC-SR1.5 >66% 2°C and >50% 1.5°C low or no overshoot categories. GWP_{100} values from the IPCC 2nd Assessment Report are used to aggregate gases. Error bars show the 5th-95th percentile range in all cases with the solid bars marking the median values.

[89] den Elzen, M. et al. (2019) Are the G20 economies making enough progress to meet their NDC targets? *Energy Policy*, 126, pp.238-250.

Figure 3.2. Emissions per person in 2017 and projected under current NDCs



Source: Olivier, J. and Peters, J. (2018) *Trends in global CO_2 and total greenhouse gas emissions*; World Bank Population Estimates (2018), Climate Action Tracker, United Nations Population Projections (2017); CCC (2015) *Advice on the fifth carbon budget*.
Notes: NDCs for China and India are as projected by the Climate Action Tracker. All NDC emissions are for 2030, except for the USA which are for 2025. UK emissions in 2030 under the NDCs are assumed to be equal to the annual level of emissions compatible with the 5th Carbon Budget. Medium variant population projections are used in all cases. GHGs are aggregated using GWP_{100} values from the IPCC 4th Assessment Report.

2. International effort required to achieve the Paris Agreement long-term temperature goal

Understanding of the global transition required to deliver the long-term temperature goal of the Paris Agreement has improved significantly over the last couple of years.

This section looks at several aspects of the required international effort to achieve the Paris Agreement long-term temperature goal:

a) Features of the required global transition
b) Regional contributions to the global effort
c) The future must be very different from the past and it can be

(a) Features of the required global transition

The IPCC Special Report on Global Warming of 1.5°C (IPCC-SR1.5) provided a comprehensive assessment of how the global energy and land-use systems can be transformed to achieve the Paris Agreement (Figure 3.3, Table 3.1). There are three key strands of the global transition that emerge across all scenarios:

- **Energy demand reduction.** Reductions in the demand for energy services and other GHG emitting activities helps reduce future emissions. Changes in future energy demand can come from measures to improve energy efficiency and/or changes in the underlying demand for a service (such as changes in dietary preferences).
- **Decarbonisation of energy supply.** The carbon intensity of energy is reduced to near-zero around mid-century in all scenarios that achieve the Paris Agreement long-term temperature goal. Key to this is a very rapid phase-out of unabated coal and widespread electrification of energy demand, alongside a widespread and rapid roll-out of renewable and other low-carbon power sources.
- **Greenhouse gas removals**. All scenarios require some active removal of GHG from the atmosphere. This enables net emissions to fall faster than gross emissions can be reduced and compensates for residual sources of emissions. Most current emissions pathways only consider bioenergy with carbon capture and storage (BECCS) and afforestation/reforestation as methods of GHG removal.

When these three strands are combined at sufficient scale and speed, global emissions can fall rapidly enough to achieve the global emissions pathways required to meet the Paris Agreement's long-term temperature goal.

Bringing about this global transition will be a major challenge across all three strands:

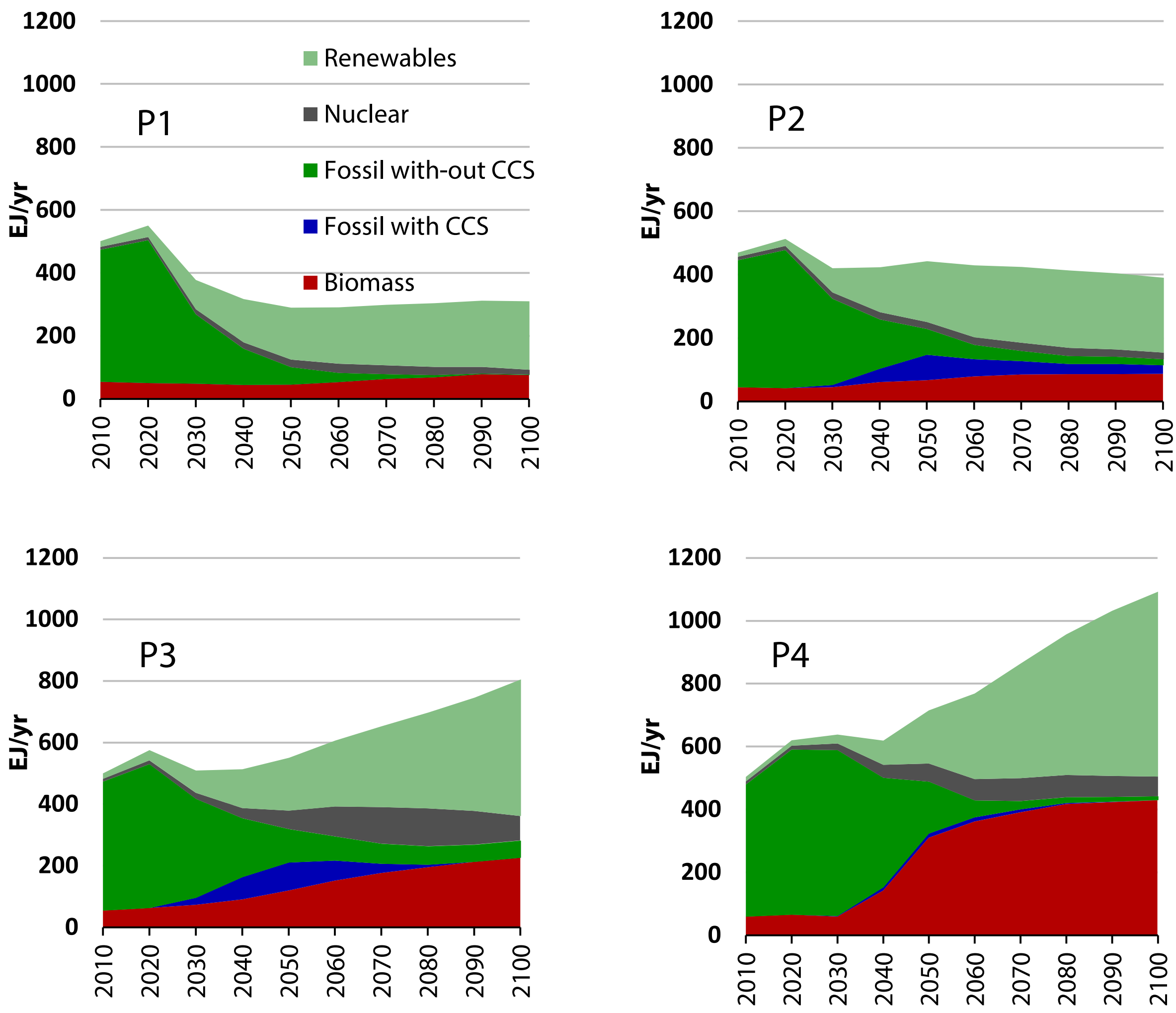
- The energy intensity of the global economy has been decreasing (at around 12% per decade since 1990)[90], but would need to decrease at a faster rate between 2020 and 2050 (17% per decade in 'well-below' 2°C scenarios and 19% per decade in 1.5°C scenarios).[91]
- Although the fraction of electricity generation from renewable sources has recently been growing rapidly the carbon intensity of global primary energy has remained approximately constant since 1990.[92]
- Large-scale engineered removal of GHGs from the atmosphere is rapidly deployed at large-scale from the mid-2020s in many scenarios, however relying entirely on BECCS could require very large amounts of land and may create conflicts with food production and biodiversity.

The IPCC concluded that whilst the scale of the transition[93] would be unprecedented, there has been some precedent for the speed of the required transitions within particular sectors such as deployment of wind and solar power and the take-up of electric vehicles.

Bringing about this transition will require a large shift in investment patterns in the energy sector (Figure 3.4) as well as other parts of the global economy. Some additional investment is required, but most importantly a shift is needed in the pattern of investment away from unabated fossil fuel power and towards low-carbon technologies. Modelled pathways show an increased mitigation cost of restricting warming to 1.5°C compared to pathways for 'well-below' 2°C, but this does not include the benefits from lower climate risks and an increased ability to achieve global sustainable development goals.

[90] BP (2018) *Statistical review of world energy*.
[91] Throughout this chapter we use 'well-below' 2°C to refer to the minimum level of ambition consistent with the Paris Agreement long-term temperature goal, which we interpret as scenarios with >66% probability of keeping warming below 2°C (Chapter 2). '1.5°C' refers to scenarios with >50% of keeping warming below 1.5°C with no or low overshoot.
[92] CO_2 intensity of global primary energy was 98% of 1990 levels based on data from the Global Carbon Project and BP Statistical review of world energy.
[93] Specifically to keep warming to below 1.5°C.

Figure 3.3. Global primary energy in the four archetype 1.5°C scenarios set out by the IPCC



Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.

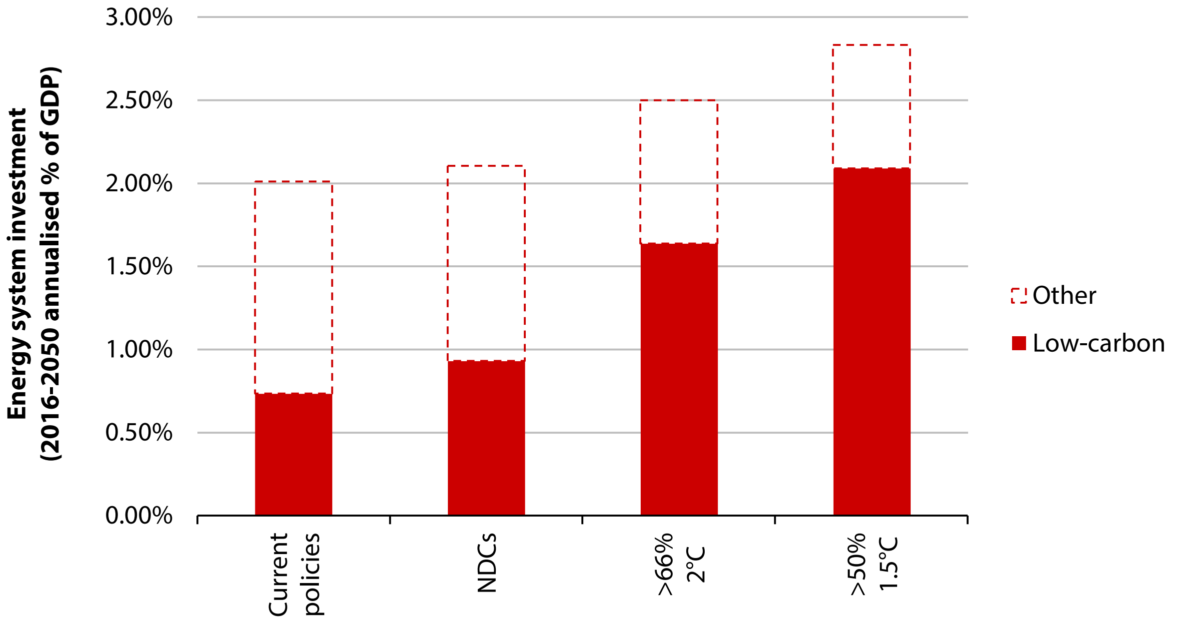
Notes: Total global primary energy demand is shown. Solar, wind, hydropower and geothermal are all grouped in 'Renewables'. Descriptions of the P1-4 scenarios are provided in Chapter 2 of the IPCC-SR1.5. P1-3 keep warming to below 1.5°C with no or low overshoot whilst P4 has a higher overshoot of 1.5°C.

Table 3.1. Energy system transitions in scenarios achieving the Paris Agreement

2050 energy system characteristics	**>50% 1.5°C**	**>66% 2°C**
Final energy demand reduction relative to 2010 (%)	8 [-11 - 22]	26 [12 - 38]
Share of renewables in electricity (%)	78 [69 - 86]	71 [61 - 80]
Primary energy from coal (% relative to 2010)	-82 [-95 - -74]	-66 [-79 - -56]
Primary energy from oil (% relative to 2010)	-55 [-78 - -31]	-24 [-39 - -2]
Primary energy from gas (% relative to 2010)	-25 [-56 - 6]	1 [-34 - 23]
Primary energy from nuclear (% relative to 2010)	163 [91 - 190]	157 [98 - 208]
Primary energy from bioenergy (% relative to 2010)	203 [123 - 261]	168 [112 - 212]
Primary energy from non-biomass renewables (% relative to 2010)	1060 [576 - 1299]	1061 [638 - 1341]
Land area for energy crops (million km^2)	3 [2 - 3]	2 [2 - 2]

Source: Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: Median values across the scenario category is shown, with the bracketed values indicating the interquartile ranges. All values are for the global total.

Figure 3.4. Required energy sector investments under current ambition and under scenarios that are expected to achieve the Paris Agreement long-term temperature goal



Source: McCollum, D.L. et al. (2018) Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nature Energy*, 3(7), p.589.
Notes: Bars represent the average across 6 models from the CD-LINKS project. They are a subset of the group of pathways assessed in IPCC-SR1.5. Effort consistent with current polices and NDCs is extrapolated to 2050. Low-carbon investment includes investments in fossil-based carbon capture and storage (CCS).

(b) Regional contributions to the global effort

Existing published scenarios for regional effort

Scenarios of the global transition to meet the Paris Agreement are generally produced by integrated assessment models of the climate and energy system (IAMs - Box 3.1). These reduce emissions where and when they are assumed to be cheapest to keep within overall limits on cumulative CO_2 emissions.

These published scenarios give an indication of the relative 'technical emissions reduction potential' of different regions. However, the exclusive focus on 'least-cost' (according to the technical parameters of the modelling) gives a regional breakdown of effort that is potentially at odds with the principles of the Paris Agreement:

- In 'well-below' 2°C scenarios, 2050 CO_2 emissions per person for the EU and USA are similar to those already expected under existing long-term commitments (Figure 3.5). In contrast, 2050 CO_2 emissions per person are significantly below current trajectories in several developing and middle-income regions. This is potentially at odds with the principles of the Paris Agreement ratchet mechanism.

- Developing regions generally have lower CO_2 emissions per person than in developed regions even in the long run. This is in contrast to 'equity-based' allocations (see Section 4) that generally require much greater effort from developed countries.
- Scenarios that keep warming below 1.5°C show much less regional variation in CO_2 emissions per person, with all regions reaching net-zero CO_2 emissions around 2050. This is due to the very small compatible global carbon budgets that requires emissions reduction near the assumed limit of technical potential in all regions.

This regional breakdown of effort requires a challenging scale-up of more expensive 'deeper decarbonisation' options in developing regions. For example:

- Scenarios require that carbon capture and storage (CCS) deployment starts immediately with substantial deployment in all regions by the 2030s. In 2018 only 18 large-scale CCS facilities were in operation around the world (with a further 25 under development), concentrated in only six countries.[94]
- GHG removals with BECCS increase rapidly in many regions, particularly in Latin America where 2050 BECCS removals per person are over 75% of the OECD and EU level. Only one large-scale BECCS operation sequestering over 1 $MtCO_2$/yr is currently in operation around the world.[95]
- The relative increases in investment are greater in developing regions than developed ones. For example, the increase in investment required in China is simulated to be nearly twice that of Europe between now and 2050 to keep warming to below 1.5°C.[96] Achieving this investment scale-up will likely require efficient cooperation between countries through functioning international markets.

These simulations highlight a potentially large emissions reduction potential in many developing regions. However, factors not typically captured within these scenarios, such as a lack of strong mitigation policies or a lack of access to capital in many developing regions, could be significant barriers to deploying these deeper decarbonisation options as rapidly as simulated.

These additional barriers indicate that a plausible global pathway to achieve the Paris Agreement may well require greater emissions reductions in developed regions than implied by many existing published scenarios.

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[94] Global CCS Institute (2018) *Global Status of CCS*. Operational projects are in the US, Canada, China, Norway, Brazil and Australia.

[95] Illinois Industrial CCS Project.

[96] Zhou, W. et al. (2019) A comparison of low carbon investment needs between China and Europe in stringent climate policy scenarios. *Environmental Research Letters*.

Box 3.1. Integrated Assessment Models – value and limitations

Integrated assessment models (IAMs) are state-of-the-art coupled models of the global energy, agriculture, land-use and climate systems.

- They simulate the reduction of GHG emissions where they are least expensive across the whole century in order to achieve a specified climate goal at least cost.
- IAMs require external assumptions such as future population and GDP growth, as well as present technology costs and how these will develop over time.
- IAMs usually aggregate countries into a small number of regions (typically 10 - 20) due to computational constraints. They tend to show that emissions reduction costs are lower in developing regions, reflecting in part differences in economic output per person and wage rates.
- IAMs often implicitly assume that there is a global planner with perfect foresight and control across all future years and all parts of the world, in order to minimise the cost of achieving the climate goal.

IAMs are useful for mapping possible transitions that are compatible with limiting warming below a given level. They can also be used to test a number of questions regarding climate policy:

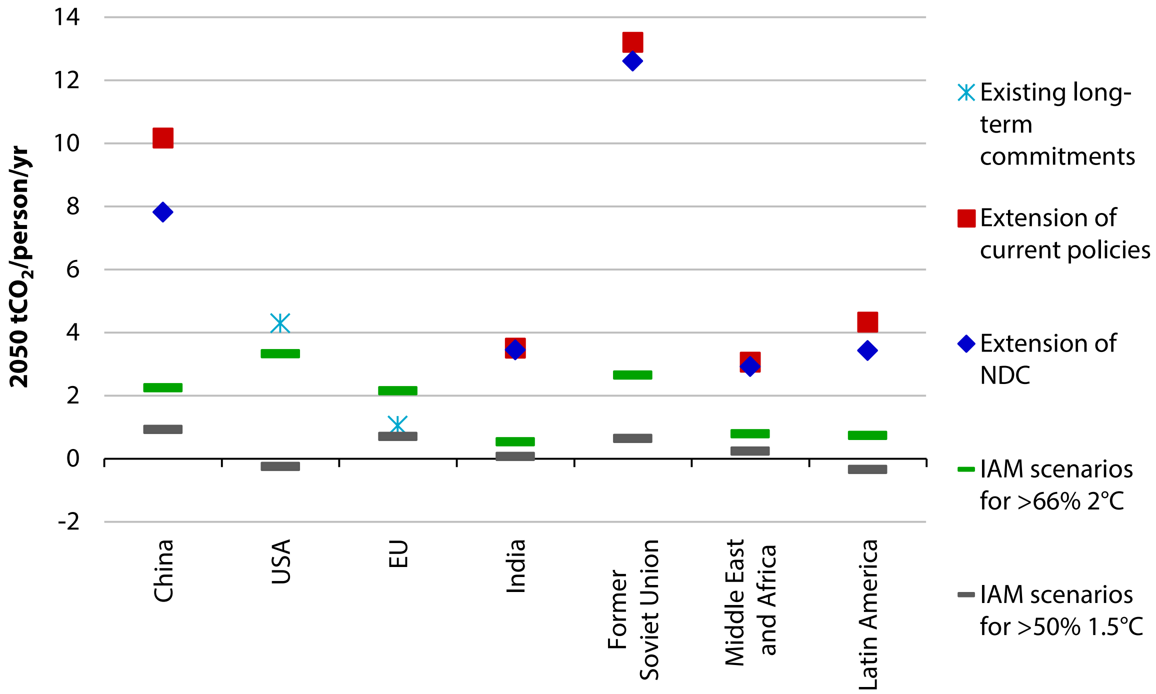
- They are most-often used to provide 'cost-effective' global transition pathways to keep expected warming below a given level with least overall cost.
- They can be used to understand the relative cost of different emissions reduction activities around the world and the compatibility of current commitments with modelled 'cost-effective' pathways.

At the same time, IAMs have a number of acknowledged limitations:

- They generally do not incorporate many non-economic barriers to mitigation action (such as consumer behaviour) which can often be as important as technical ones.
- Mitigation options that reduce the demand for energy and GHG-intensive activities are commonly represented in less detail and have received less attention within IAMs than supply-side solutions.
- IAMs have recently been criticised for being too conservative on future price declines of renewables, as well as failing to reflect how innovation in some low-carbon sectors can spill over to accelerate innovation across the global economy.
- IAM pathways often rely heavily on the use of very large amounts of low-carbon harvested biomass in the energy system. Such large amounts may not be sustainable in the real world.

Source: CCC analysis; Farmer, J.D., Hepburn, C., Mealy, P. & Teytelboym, A. (2015) A third wave in the economics of climate change. *Environmental and Resource Economics*, 62 (2), pp.329-357.

Figure 3.5. 2050 CO_2 emissions per person in IAM scenarios compared to current trajectories and commitments



Source: McCollum, D.L. et al. (2018) Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nature Energy*, 3(7), p.589.
Notes: Marked points represent the mean per capita emissions across a range of different IAMs, a subset of the scenarios assessed in IPCC-SR1.5. The current policies and NDC scenarios continue the same average emissions reduction effort between now and 2030 in that scenario to 2050. Only emissions from CO_2 emissions from fossil fuel and industry are displayed. 'Existing long-term commitments' applies the same percentage reduction in CO_2 emissions (relative to the base period) as required for all GHGs. Expected changes in population are accounted for.

Exploring 'leadership-driven' scenarios

Relying on existing scenarios to determine appropriate contributions to the global effort would not satisfy the full range of considerations required by the Paris Agreement, such as developing countries taking the lead and considerations of equity. It also would run counter to the emerging reality that several developed countries and the EU are already considering setting targets more ambitious than their currently stated ambition (Chapter 4), which would push targeted ambition in these countries further beyond scenario simulated values, particularly for the 'well-below' 2°C end of the Paris Agreement ambition.

The Committee commissioned work from University College London (UCL) to extend the integrated scenario literature by exploring **'leadership-driven'** scenarios of the global effort that reflect better the reality of current and emerging mitigation ambition around the world (Box 3.2).

These 'leadership-driven' scenarios generally contain several groupings of regions (Figure 3.6):

- **Developed regions.** In accordance with their emerging long-term commitments, these regions achieve or go beyond net-zero CO_2 emissions by 2050.[97]
- **Large emerging economies.** Countries in these regions, such as China, peak their emissions very soon (improving on their NDCs) and reduce them rapidly in the next two decades. They do not need to reach net-zero CO_2 emissions until after 2050 but generally do so before the end of the century. Efficiency, low-carbon power and electrification must all have major roles, supplemented by CCS.
- **Developing regions.** These regions 'leapfrog' to low-carbon development paths. Emissions remain low on a per capita basis, but do not need to reach net-zero CO_2 until well after 2050, and many do not reach net-zero before 2100.

This 'leadership-driven' scenario involves a larger concentration of 'harder' decarbonisation options in the developed regions of the world. For example:

- CCS deployment per person in 2050 would be over four times greater in the developed regions (2.0 tCO_2/person/yr) than the average for the rest of the world.
- Developed regions take up a much larger share of the burden of CO_2 removal from the atmosphere, with removals of CO_2 from the atmosphere over seven times greater in developed regions (1.7 tCO_2/person/yr) than the average of the rest of the world.
- Per person CO_2 emissions from the developed regions would be lower in 2050 than all other parts of the world (Figure 3.6), consistent with stated and emerging emissions reduction intentions and aligned to IAM results for scenarios that would keep warming to 1.5°C.

This 'leadership-driven' scenario appears to represent a more plausible global pathway that is better aligned to the principles of the Paris Agreement. It would also bring several advantages for strengthening the global mitigation effort:

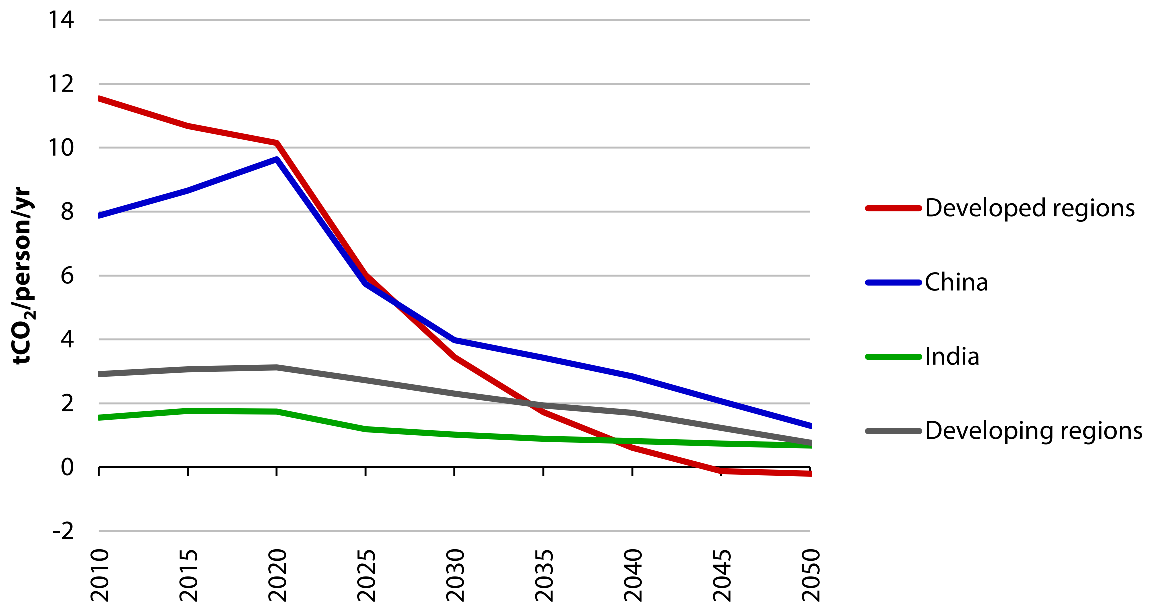
- **Demonstrating a pathway to achieve net-zero emissions.** Countries with lower historical contributions to climate change look to developed countries with large historical contributions to take a lead in making the changes required globally to deliver on the goals of the Paris Agreement. Doing so can help build the knowledge and skills required to achieve net-zero emissions in the rest of the world.
- **Technology development.** Deployment of renewables in developed countries has helped drive down their cost, enabling large-scale deployment in regions such as China and India. Ambitious mitigation targets in developed countries can help establish the new industries required and drive down the cost of currently more expensive technologies needed to reach net-zero CO_2 emissions including carbon capture and storage, hydrogen, low-carbon heating and technologies to remove CO_2 from the atmosphere.
- **Developing the necessary policies, institutions and business models.** The innovation requirements to make the necessary emissions reduction are not only technical. Developed countries like the UK typically have strong institutional capacity and are well placed to take a lead in areas needing innovation in supporting mechanisms, such as for CCS and GHG removal.
- **Building markets and sustainability standards for greenhouse gas removal.** GHG removal will likely be required to some extent in the long run to achieve the goal of the Paris Agreement. Ensuring effective markets to provide removals are developed whilst not

[97] This is imposed as a feature of the scenario implementation.

compromising efforts to achieve other UN goals to end hunger and protect biodiversity could enable GHG removals to be deployed safely around the world.

'Leadership-driven' scenarios still require rapid and deep mitigation in all regions of the world, especially as future population and GDP growth is expected to be concentrated in the more developing parts of the world.[98] In particular, to keep warming to the more ambitious end of the Paris Agreement long-term temperature goal without overshoot will require *all* regions of the globe to reduce emissions as fast as technically possible in all sectors of the economy in order to stay within the very small remaining cumulative CO_2 emissions budget.

Figure 3.6. CO_2 emissions per person (2010-2050) in an example modelled 'leadership-driven' scenario consistent with limiting global warming to 'well-below' 2°C



Source: UCL (2019) *Modelling 'leadership-driven' scenarios of the global mitigation effort*.
Notes: CO_2 emissions per person are shown. This scenario constraints the remaining global carbon budget to 800 $GtCO_2$ between 2018 and 2100, consistent with the broader group of >66% 2°C scenarios assessed in IPCC-SR1.5. 'Developed regions' show the average across the 'high-ambition' grouping described in Box 3.2. Developed regions include: Africa, Central and South America, Middle East and other developing countries in Asia.

[98] Population growth leads to a larger share of 2018 - 2050 cumulative emissions (approximately 80%) from these developing regions than indicated by their share of the global emissions today (70%).

Box 3.2. Modelling 'leadership-driven' scenarios consistent with the Paris Agreement long-term temperature goal

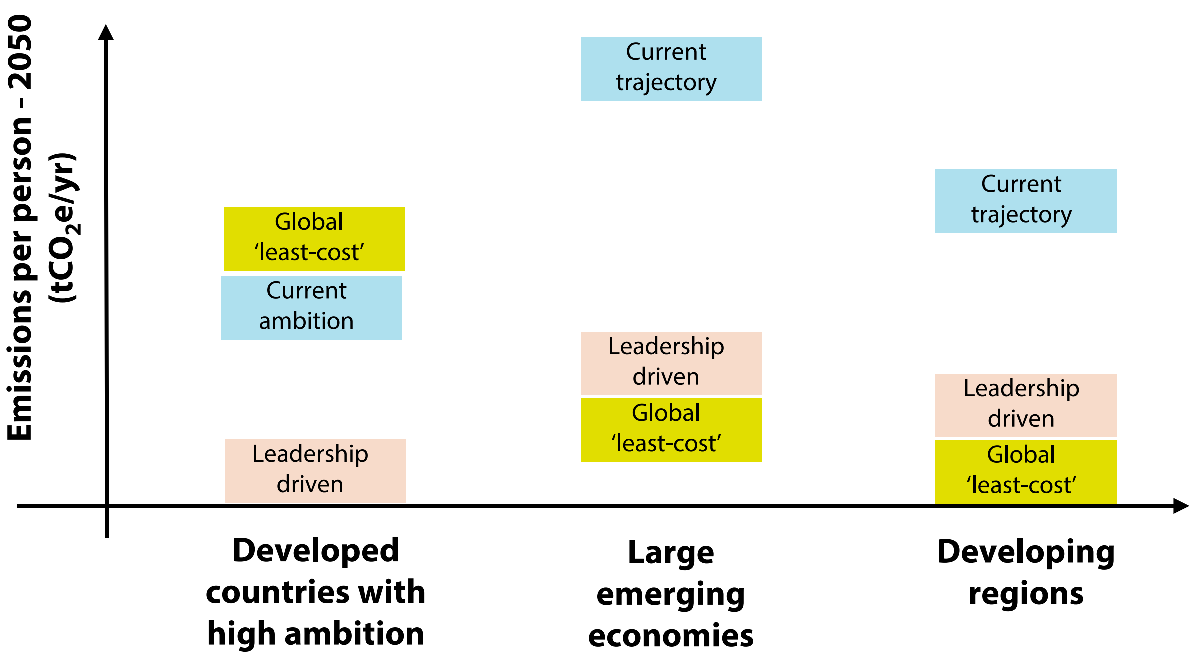
The Committee commissioned UCL to develop a **'leadership-driven'** scenario of the global mitigation effort. This scenario reflects the reality of where the most ambitious emissions reduction commitments are being set, and is more representative of the Paris Agreement structure (Figure B3.2). The results are summarised in the UCL report published alongside this report.

A number of constraints were imposed on the model including:

- A set of 'leadership' regions comprising the UK, Australia, Canada, Europe, Japan, Mexico, South Korea and the USA. Together they represent 30% of global emissions. This grouping includes countries that are currently showing potential for setting ambitious emissions reduction targets, or are key global players that have responsibility and capability to undertake ambitious emissions reductions, such as the USA and Australia. These regions are required to reach net-zero CO_2 by 2050.
- The global availability of low-carbon harvested biomass was restricted to the Committee's 'high' estimate of global sustainable low-carbon biomass in our November 2018 report *Biomass in a low-carbon economy* (i.e. 110 EJ/yr). This is a significantly lower level than in many other IAM scenarios.

These scenarios provide a view of a global transition more aligned to the current international picture. Whilst the details of the real-world transition that emerges will inevitably be different to the scenarios here, they provide a useful indication of a possible global path that is consistent with the Paris Agreement and with leadership from developed regions.

Figure B3.2. Schematic of global effort in 'leadership-driven' global pathways



Source: CCC analysis; UCL (2019) *Modelling 'leadership-driven' scenarios of the global mitigation effort*.

Source: UCL (2019) *Modelling 'leadership-driven' scenarios of the global mitigation effort*.

(c) The future must be very different from the past and it can be

The previous sections have shown that achieving the long-term temperature goal of the Paris Agreement will require challenging transitions in all regions of the global economy.

Many elements of these transitions are becoming more feasible than was envisaged only a few years ago. This is particularly true in the power sector where there is the potential for a rapid transition away from fossil power towards renewables, a key initial part of the global transition:

- Reductions in the carbon intensity of electricity are expected to provide around half of the global abatement in 2050 for 'well-below' 2°C scenarios and around 35% for 1.5°C scenarios.
- Latest cost data and prices emerging from auctions for renewable power contracts show that renewable generation can or will produce electricity at the same cost, or cheaper, than fossil fuel alternatives in most parts of the world (Figure 3.7). This has happened faster than expected, with major international forecasts for projected renewable capacity regularly revised upwards over recent years.[99]
- Estimates of realistic technical potential for renewable generation also indicate that it should be possible to meet future electricity demands in almost all parts of the world provided challenges associated with the integration of large amount of variable renewables are dealt with.[100] Increasingly evidence and experience, including in the UK, suggests that will be possible.[101]

Outside the power sector there are positive indications of a global road transport transition. The global deployment of electric vehicles (EVs) has increased dramatically over recent years, particularly driven by a surging uptake in China which now accounts for over 40% of the world's EVs, increasing from just 10% in 2013.[102] This is due to the emerging cost-competitiveness of EVs with internal combustion engine-driven cars due to falling battery costs.

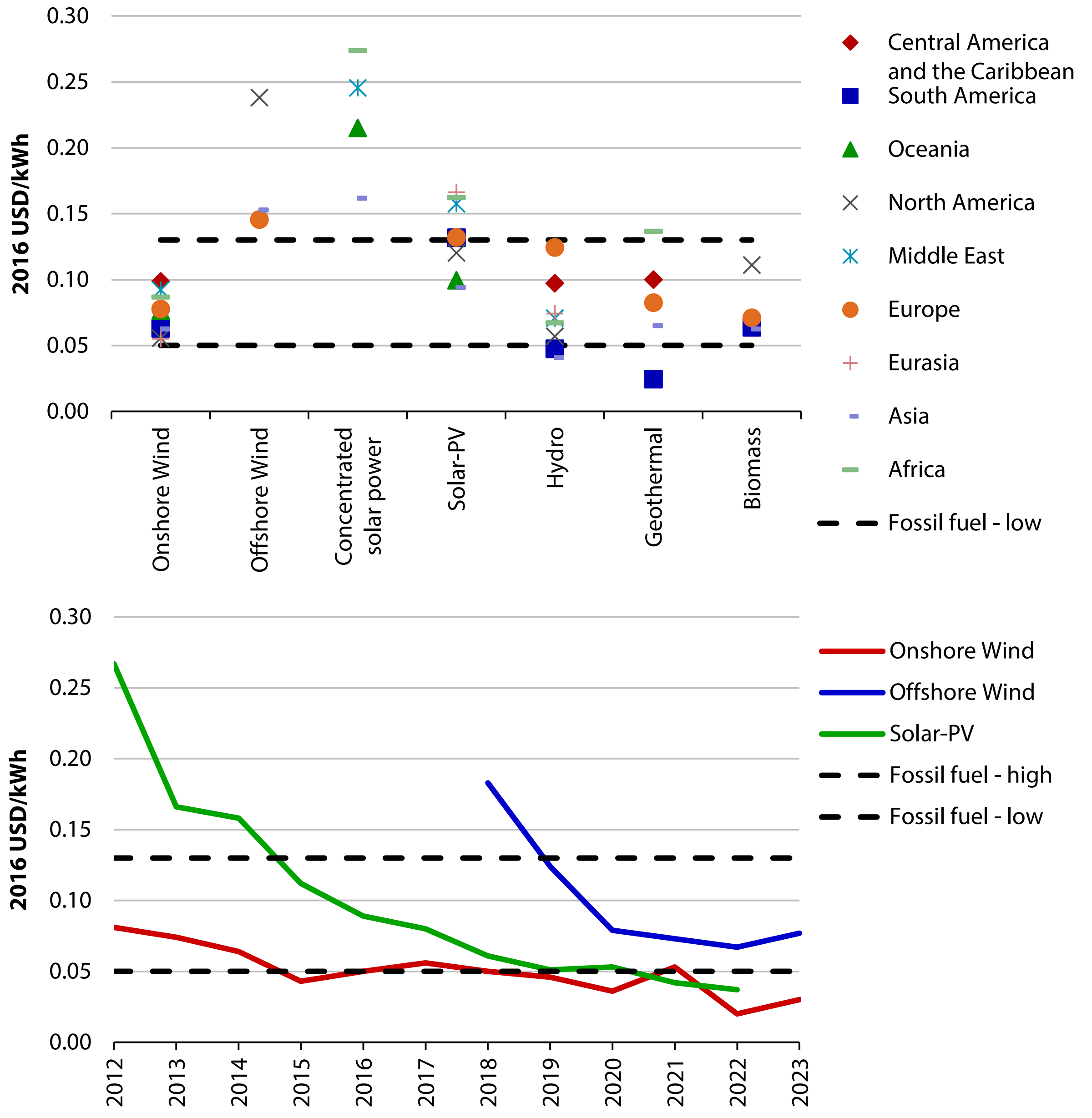
While this emerging transition can be expected to continue and accelerate across the world, this alone will not be sufficient to achieve a 'well-below' 2°C world. Mitigation options that are likely to remain expensive and create an on-going cost will still be required to decarbonise other sectors.

- In our 'leadership-driven' global scenario, there is still a need for CCS in developing regions, particularly to decarbonise industry. Carbon capture requires energy so will therefore always incur an ongoing cost, even if leadership by developed regions can bring down the cost.
- Similarly, some amount of GHG removals in developing regions of the world is likely to be required to compensate for residual sources of emissions that cannot be mitigated.

As well as a domestic strategy to help develop these technologies and effective policy regimes, the UK's international strategy should aim to support their wider deployment. We explore some of the routes for UK leadership and international collaboration in Chapter 4.

[99] BP *Energy Outlook 2011-2019*.
[100] Deng, Y.Y. et al. (2015) Quantifying a realistic, worldwide wind and solar electricity supply. *Global Environmental Change*, 31, pp.239-252.
[101] For example, the UK System Operator (National Grid) recently indicated that they are planning to run the UK grid for parts of the year with zero carbon emissions as soon as 2025.
[102] IEA (2018) *Global EV Outlook*.

Figure 3.7. Levelised costs of renewable power generation around the world (top) and global average auction prices by commissioning date (bottom)



Source: IRENA (2018) *Renewable Power Generation Costs 2017*; IEA (2019) *Renewable Energy 2018*.
Notes: Scatter points represent the capacity-weighted average levelised electricity cost generated in that region over 2016 and 2017. Auction strike prices since 2017 have lower costs, particularly for solar-PV and offshore wind. Auction results indicate the continuing trend of falling prices, but are not directly comparable to levelised costs (e.g. apart from the UK, European auction results for offshore wind do not cover costs of grid connection).

3. UK capacity to move ahead of the global average effort

Section 2 identified possible benefits to the global effort from 'leadership-driven' scenarios to achieve the Paris Agreement's long-term temperature goal, where a group of developed countries pursue more ambitious emissions reductions than the global average. This section considers how well the UK is placed to contribute to this effort and is informed by work the Committee commissioned from Imperial College London (ICL) which is published alongside this report.[103]

Evidence on the UK's economic structure and trends, its past progress and the potential for continued rapid decarbonisation relative to other countries around the world suggest that the UK *is* well-placed to go ahead of the global average. The following three sub-sections consider each of these factors in turn.

Economic structure and trends

The UK has an economic output per person of more than two and a half times the global average. Despite this, UK territorial GHG and CO_2 emissions per person are close to the global average.[104] In 2017, UK GHG emissions[105] per person were estimated to be 7.6 tCO_2e/person, compared to a global average of 7.2 tCO_2e/person (including emissions from land-use change and international aviation and shipping emissions).

A number of reasons underlie this:

- The UK's economic structure is highly service-based, more so than the world as a whole: the UK's industrial share of its economic output is around 18%, significantly lower than the world average of 25%. This contributes to the UK having the lowest energy intensity of GDP of all major developed countries.
- Although the UK's absolute industrial output is higher than the global average, its industrial output is largely concentrated in higher value, less energy- and emissions-intensive activities. This results in significantly lower industrial emissions per person than the global average.
- Alongside low energy intensity of GDP and relatively high GDP, the UK's emissions intensity of final energy is similar to the global average.
- UK emissions per person of non-CO_2 gases from the agricultural sector are similar to the global average.

More broadly, the UK's higher economic output suggests more capacity to act to reduce emissions, particularly for actions that initially could be expensive.

Looking forward, expected population and economic growth in the world as a whole are higher than for the UK. These imply a lower business-as-usual emissions growth for the UK than the world in aggregate, which may make deeper emissions reduction relatively easier to achieve.

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[103] ICL (2019) *The UK's contribution to a Paris-consistent global emissions reduction pathway*.
[104] The UK has a substantial imported emissions footprint on top of this. These 'consumption' emissions are discussed in Section 4.
[105] Aggregated using GWP_{100} values from the IPCC 4th Assessment Report.

Past progress in decarbonisation

Over recent years the UK has been amongst the most rapidly decarbonising countries, far outstripping the global average. Since 1990 the UK has reduced its per capita emissions from roughly double the global average to be in line with the global average now (Figure 3.8).

- The UK's energy sector CO_2 emissions per person have been reduced by more than 5%/yr on average over the 2011 - 2016 period. Over a similar period global energy CO_2 emissions per person declined by less than 0.5%/yr and show an increase if updated to include projected 2018 data.
- The UK's energy demand has also been steadily reduced, with a 1%/yr reduction over the last decade.
- The underlying improvement in the carbon intensity of economic output in the UK (around 2%/yr) over this period have been greater than both the world and the EU as a whole.
- The UK also achieved an average 3.5%/yr reduction in the carbon intensity of its final energy, compared to only 0.5%/yr for the world. This was largely driven by a reduction in the carbon intensity of electricity generation, with a rapidly growing low-carbon share of the generation mix (growing by 3.7 percentage points per year over 2011 - 2016). This has led to a world-leading 10%/yr reduction in the carbon intensity of the UK's electricity generation over the same period.

Progress outside of the electricity and industrial sectors has been similar to the global average but slower than in other parts of the EU:

- Average UK decarbonisation rates per person in the buildings (0.8%/year) and transport (0.2%/year) sectors over the period 2011 - 2016, are similar to the global averages of 0.7%/yr and 0.2%/yr respectively.
- In both of these sectors, decarbonisation rates in the UK have been outstripped by other similar economies. For instance, over the same period the EU achieved rates of decarbonisation in these sectors of 1.6%/yr and 2.4%/yr respectively.
- Agricultural non-CO_2 emissions are at a similar level (per person) to the global average, but have been approximately constant over 2011 - 2016 while the world has been decreasing by about 4%/yr over the same period.

The challenge for the UK is therefore rather different to the challenge for the world as a whole. The UK needs to continue per capita emissions reductions at a similar rate to those achieved in the last several decades. The world as a whole needs to stop emissions rising and rapidly move to a position where they are falling as quickly as in the UK.

Future potential for continued rapid decarbonisation ahead of the global average

With sustained effort, there is potential for global decarbonisation over the next decade to proceed as rapidly as it has previously in the UK, as would be required to achieve the Paris Agreement temperature goal:

- Immediate step-changes in global action are required to achieve pathways consistent with the long-term temperature goal of the Paris Agreement. Those must involve global per person emissions reductions similar to those achieved since 1990 in the UK (Figure 3.8).
- Decarbonisation of the power sector could be a substantial contributor to this, as it was in the UK.

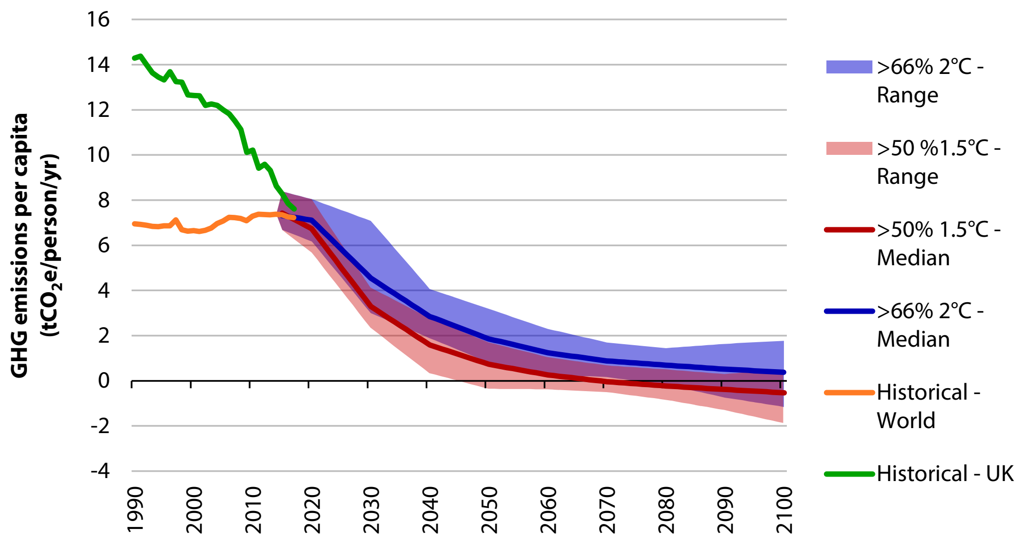
– In one sense the challenge is easier now due to the emergence of cheap renewable power around the world (Figure 3.7).

– In another sense it is harder. Global demand for energy is projected to increase by 12 - 21% between 2016 and 2030[106], whereas UK primary energy declined by around 5% per decade between 1990 and 2017. Whilst this implies a larger challenge, it could still be met if all new power generation comes from low-carbon sources (as it has in the UK for the last decade or so).

Continuing to achieve rapid per capita decarbonisation rates in the UK will require tackling sectors beyond power. Other countries are demonstrating that it is possible to decarbonise sectors where only limited progress has been made in the UK thus far:

- In Norway, 47% of all new vehicle sales were plug-in electric in the 12 months to September 2018, with Sweden achieving a 7.5% share of new sales, due in part to support through the tax regime and other incentives. By contrast, in the UK electric vehicles made up just over 2% of new car sales in the 12 months to September 2018.
- Heat-pump deployment has been significantly greater in many other European countries than in the UK. Sales of heat pumps of all kinds in 2017 exceeded 240,000 in France, but were less than 20,000 in the UK.[107]
- CCS deployment has begun in six other countries, with Norway having the largest per person annual rate of CO_2 capture (~350 kg/person/yr).[108]

Figure 3.8. Evolution of global and UK per capita emissions over time



Source: CCC analysis; Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027; Olivier, J. & Peters, J. (2018) *Trends in global CO_2 and total greenhouse gas emissions*.
Notes: UK GHG emissions per capita include land-use change emissions and emissions from international aviation and shipping. Land-use emissions from the Global Carbon Project are included in 'Historical - World'.

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[106] BP (2019) *Energy Outlook 2018*; McKinsey (2019) *Global Energy Perspective 2019*.
[107] European Heat Pump Association (2017) *Heat pumps – key technology to achieving Europe's energy and climate goals: 2017 Market development and outlook*.
[108] Drax (2018) *Energy Revolution: A Global Outlook*.

Our detailed assessment of the opportunities for further emissions reduction in the UK in Chapters 5, 6 and 7 support the view that the UK can continue to reduce emissions and can reach net-zero GHG emissions earlier than required for the world overall.

The UK's established policy frameworks position it well to make these reductions:

- The Climate Change Act provides a long-term stable governance structure for UK climate policy. The five-year carbon budgets under the Act ensure that the UK Government undertakes near-term action that is commensurate with economically efficient pathways to the long-term goal.
- The UK scores well on measures of institutional capacity, regulatory quality and government effectiveness measures[109], reflecting a relatively strong capacity for UK Government, businesses and other actors to pursue ambitious emissions reductions in a stable and supportive policy environment.

If the UK does continue to cut emissions in line with other leading countries and ahead of the world overall, this would support the global effort. As it has in the power sector, the UK could pioneer and demonstrate effective policy mixes for other sectors and share the learning from these with other countries as they tackle similar challenges shortly afterwards.

4. Equity considerations

This section looks at the implications of considerations around equity and fairness for UK emissions targets as well as the relevance of emissions imported through goods and services.

Section 1 highlighted the importance of equity and fairness as considerations for determining national emissions reductions under the Paris Agreement. Parties are explicitly required to communicate how their pledges (i.e. NDCs) are 'fair and ambitious'.

We consider three aspects of equity in this section: 'consumption' emissions, average incomes and historical emissions.

Consumption emissions

The UK imports additional GHG emissions through our consumption of goods and services. These emissions do not appear in the UK GHG inventory, which in line with emissions accounting across the world is conducted on a territorial basis (i.e. it only counts emissions that directly arise from activity within the UK) to prevent any double counting of emissions at the global level (Box 3.3). This also more closely maps to levers available to the UK to reduce emissions.

Estimates published by Defra (the Department for Environment, Food and Rural Affairs) indicate that UK consumption emissions were significantly higher than comparable territorial emissions reported in the UK GHG inventory. That reflects the high carbon intensity of our imports, which are more likely to be industrial products, than our exports, which are more likely to be services.

It also partly reflects the UK's good progress in reducing its own emissions.

- Actions like closing coal and switching to renewable power generation in the UK will tend to reduce territorial emissions by more than consumption emissions (since under consumption

[109] World Bank (2018) *World Governance Indicators Dataset*.

accounting some of the credit will lie with countries that import UK products that use the low-carbon power supply).

- In contrast, improvements in carbon intensity in other countries will help to cut the UK's consumption emissions, but not affect its territorial emissions.

Even if the UK reduces its own territorial emissions to net-zero, consumption emissions will only reach net-zero once the rest of the world's territorial emissions are also reduced to net-zero. At that point the UK can expect to pay slightly more to cover the costs of low-carbon production of the goods it imports.

High consumption emissions in the UK could be seen as a reason for the UK to go further on emissions reduction, since it has a larger impact on global emissions than its territorial emissions suggest.

Box 3.3. UK consumption emissions

Under the Climate Change Act and the UNFCCC emissions are reported on a 'territorial' basis. This includes all the emissions and removals of GHGs that physically occur within the geographical bounds of the UK. This is consistent with internationally-agreed rules to prevent double counting of emissions.

'Consumption-based' emissions reporting (often referred to as the UK's carbon footprint) aims to capture the emissions resulting from the consumption of goods and services within the UK, wherever their production occurs.

- This includes most of the UK's territorial emissions, except for emissions associated with goods and services exported from the UK.
- It also includes emissions associated with producing imported food and energy-intensive products such as steel and cement. The UK is a net importer of emissions through its international trade.

The Government monitors consumption emissions on an annual basis but there are no legislated targets associated with consumption-based emissions.

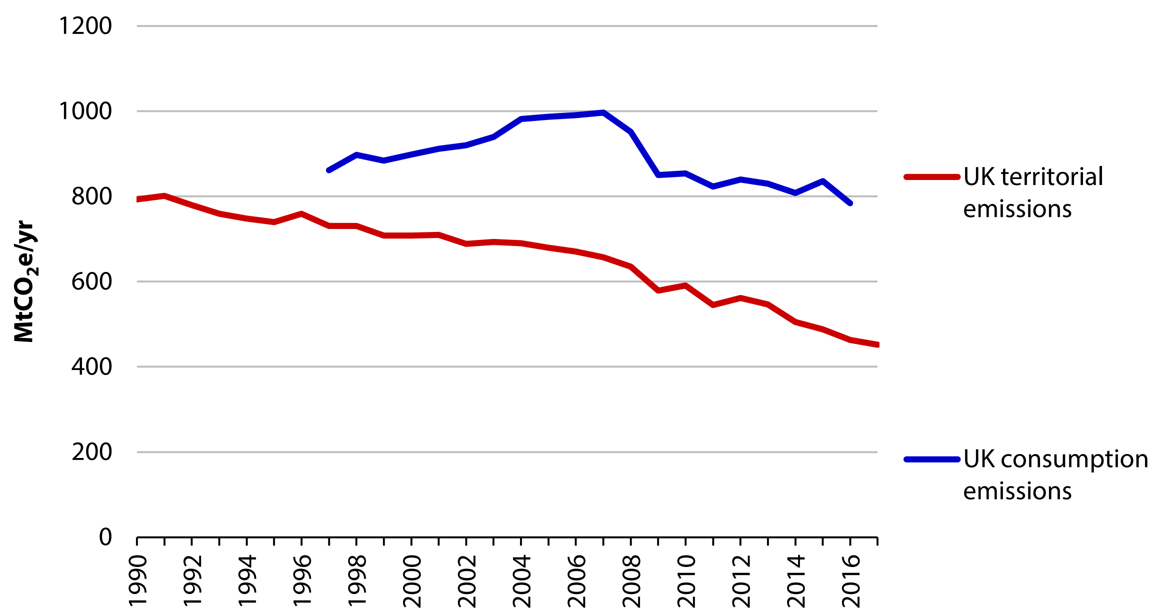
- Consumption emissions estimates have greater uncertainty than territorial emissions inventories as calculating them requires modelling using large amounts of economic data to track the flow of goods and services across countries along a product's entire supply chain.
- Statistics published by Defra show that the UK's consumption emissions are 69% greater than its territorial emissions estimated under the UK GHG inventory (for 2016).
- Consumption-based emissions rose 16% from 1997 to 2007, but have since declined to 91% of their 1997 levels (Figure B3.3).
- Imported emissions have grown as a fraction of the UK's total GHG footprint as territorial emissions have declined rapidly.

Previous CCC analysis indicates that these territorial emissions reductions have not simply been off-shored as they have largely been associated with reductions in the carbon intensity of energy produced in the UK. Consumption emissions have increased in spite of, not because of, falls in the UK's territorial emissions.

In pursuing a net-zero emissions target, it is important that the actions to reduce UK territorial emissions do not simply off-shore these emissions to other parts of the world. Furthermore, actions that the UK can take to reduce its consumption emissions could be as effective in tackling climate change as actions to reduce territorial emissions. We reflect that in our scenarios in Chapter 5, which for example include resource efficiency and waste reduction, and identify actions that will reduce both UK territorial and imported emissions.

Box 3.3. UK consumption emissions

Figure B3.3. Historical consumption emissions in the UK



Source: CCC analysis; Defra (2019) *UK's carbon footprint*; BEIS (2019) *Final UK greenhouse gas emissions national statistics: 1990-2017*.

Notes: UK territorial emissions are expressed using IPCC 5th Assessment report GWP_{100} values (without carbon cycle feedbacks) with F-gas emission excluded. This is to allow a like-for-like comparison to the UK consumption emissions statistics. International aviation and shipping is not included in UK territorial emissions totals.

Average incomes

The UK is a rich economy. It is the world's fifth biggest economy and the 25th richest on a per person basis, with GDP per person over two and a half times the global average.[110] That can be argued on equity grounds to imply that the UK should bear more of the costs of the transition to a low-carbon global economy.

Historical emissions

As the birthplace of the industrial revolution the UK has large historical emissions. This means that the UK has a large per person contribution to past human-induced warming of the climate system:

- Estimates of historical GHG emissions back to the start of the 19th Century indicate that approximately 2 - 3% of the global warming attributable to human GHG emissions arose from UK territorial emissions.[111]

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[110] World Bank (2018) *World Bank Development Indicators Database*.

[111] CCC analysis and updated from Skeie, R.B. et al. (2017) Perspective has a strong effect on the calculation of historical contributions to global warming. *Environmental Research Letters*, 12 (2), p.024022.

- When accounting for the UK's share of current global population (under 1%), this puts the UK as one of the largest per person contributors to present climate change, behind Canada, the USA and Russia and approximately equal with Germany.

High historical contributions to emissions and warming are often cited as reasons for countries like the UK to reduce emissions faster than the world as a whole. How much faster depends on the emissions included (i.e. only CO_2 or all GHGs), the starting date for the historical comparison and the time horizon over which it is evaluated.

Equity approaches to effort sharing

A range of possible equity-based methodologies to share out the future global mitigation effort have been proposed focusing on different aspects of equality, responsibility and capability. These generally require the UK to do more than an equal per capita share (Box 3.4 and Figure 3.9).

- Methodologies which consider the UK's historical emissions ('Equal cumulative per capita') or high average income ('Capability') would require emissions reductions close to or even in excess of reaching net-zero GHG emissions (a 100% reduction relative to 1990 levels) for limits on global warming in line with the Paris Agreement.
- Considering both the UK's relative wealth and large historical emissions ('Greenhouse development rights') would require 2050 GHG emissions reductions significantly greater than 100% relative to 1990 levels (over 150% reduction relative to 1990 levels in a 1.5°C scenario). Under this allocation the UK would be removing GHGs from the atmosphere overall to compensate for its high historical emissions and would need to reach net-zero GHG emissions considerably before 2050.

As the UK has a relatively small share of current global GHG emissions but large historical emissions and a high average income, the upper end of equity-compatible targets would likely require UK emissions reductions significantly in excess of feasible domestic emissions reductions. It is important to note that these effort-sharing methodologies do not explicitly prescribe emissions reductions to occur domestically in the UK but could be achieved in-part by the UK undertaking and/or paying for emissions reductions elsewhere in the world, for example through climate finance or purchase of carbon offsets (see Chapter 4).

Box 3.4. Equity-based approaches to sharing the global mitigation effort

A variety of different equity frames have been used by countries to justify how their NDCs are 'fair and ambitious' as required under the Paris Agreement. These approaches can be categorised by three main principles:

- **Responsibility**: This category would require countries that have contributed most to historical warming and past emissions to undertake the most ambitious future reductions.
- **Capability**: This equity category requires countries that are the most able to undertake emissions reductions (for example those that are richer) to take a larger share of future emissions reductions.
- **Equality**: This category includes approaches focused on equal per capita rights to emit (such as 'contract and converge' methodologies).

Some allocation methodologies involve elements of more than one of the above categories. For instance, the **greenhouse development rights** approach uses both GDP and historical cumulative

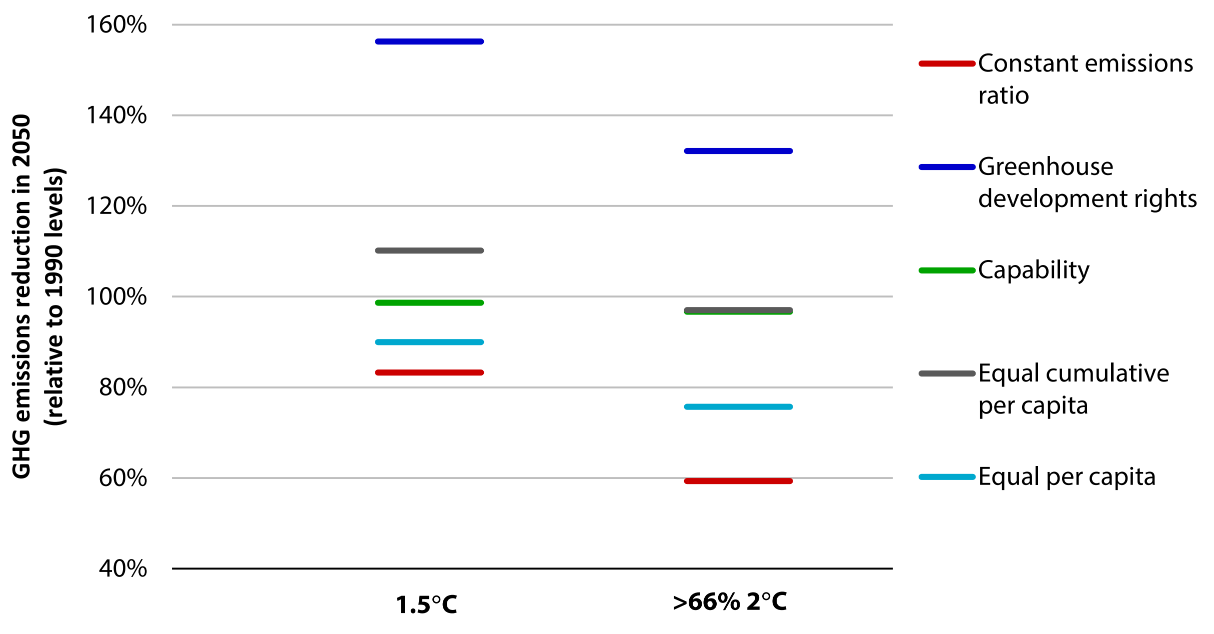
Box 3.4. Equity-based approaches to sharing the global mitigation effort

emissions to allocate future emissions reductions, and has a minimum threshold of economic development for burden-sharing to apply.

Due to the range of methodological choices such as the start date for responsibility, or whether to include all gases or just CO_2, each individual equity approach can produce a range of results. Figure 3.9 illustrates results for the UK from a particular study and demonstrates the general point that approaches which assign weight to historical responsibility and capability require the UK to go further to achieve its 'fair-share' emissions reductions.

Source: CCC analysis; Winkler, H. et al. (2018) Countries start to explain how their climate contributions are fair: more rigour needed. *International Environmental Agreements: Politics, Law and Economics*, 18 (1), pp.99-115.

Figure 3.9. Alternative equity-based allocations for a 'fair-share' UK emissions target in 2050



Source: du Pont, Y.R. et al. (2016) National contributions for decarbonizing the world economy in line with the G7 agreement. *Environmental Research Letters*, 11(5), p.054005.
Notes: Allocations use a subset of global emissions pathways considered by IPCC-SR1.5, which have per capita emissions reductions slightly lower than the median of the full set of pathways (Table 3.2) but well within their range. Reductions are for all GHGs and expressed as a percentage of 1990 levels of emissions. 'Constant emissions ratio' is not generally considered an 'equity-based' way of allocating the global mitigation effort as it preserves the right of existing high emitters to emit more in the future (grandfathering) - but is included here for comparison. 'Equal cumulative per capita' and 'Capability' are very close in the >66% 2°C scenario and are visually indistinguishable.

5. An appropriate UK contribution to the Paris Agreement

The Paris Agreement defines the level of warming that the world is aiming for. Chapter 2 reviewed the latest climate science on the global emissions reductions that would be consistent with achieving this goal. It concluded that the world needs to reach net-zero CO_2 by around 2050 to keep warming to 1.5°C (with >50% probability) and around 2075 for the minimum ambition of the 'well-below' 2°C goal. Ultimately, to stabilise global temperatures, the world will need to reach net-zero long-lived GHG emissions alongside stable or falling emissions of short-lived climate pollutants.

However, this does not give a definitive answer to the question of what level of emissions the UK should aim for in the long run.

Our conclusion from the analysis in this chapter is that the UK should aim for emissions reductions **more ambitious** than the world as a whole:

- The UK is positioned to reach lower GHG emissions per person than the world as a whole and faster.
  - The UK has already reduced GHG emissions per person to the global average, having been double the global average in 1990.
  - UK emissions have been reducing for decades, whilst global emissions continue to rise.
  - Projected population and energy demand growth are higher for the world as a whole than for the UK.
  - The UK has an effective governance system in place in the Climate Change Act and a strong track record of effective policy-making.
  - The UK is a relatively rich nation, with GDP per person two and a half times the global average.
- Equity arguments suggest the UK should go further than the world as a whole: we have high historical and 'consumption' emissions and are a richer developed nation.
- A group of developed countries setting and achieving more ambitious emissions reduction targets would have a number of advantages for the global effort. These include easing the pace of deployment of expensive decarbonisation options in developing countries and facilitating technology and institutional development and transfer. Pathways developed for this report that rebalance effort towards existing climate leaders and richer nations appear more plausible than pathways that allocate effort based purely on theoretical cost optimisation.

Table 3.2 shows the global average GHG emissions per person in 2050 for scenarios that are expected to achieve the temperature goal of the Paris Agreement and the equivalent reductions implied for the UK from 1990 levels that the UK should go beyond. A net-zero GHG target for the UK (i.e. a 100% reduction in emissions) would go beyond pathways that limit temperature rise to 'well-below' 2°C and would be towards the high end of the range for reductions consistent with a limit of 1.5°C.

Whether the world successfully limits temperature rise to the Paris Agreement's long-term temperature goal will depend on actions in the rest of the world alongside the UK. For example:

- Temperature rise could be limited to 'well-below' 2°C if:

– The UK and other high-ambition countries deliver their 'highest possible ambition', reaching at least net-zero CO_2 emissions by 2050 and net-zero GHG emissions around 2050 where possible. That would go beyond the global average effort needed to keep warming to 1.5°C with over 50% probability. Chapters 5 - 7 of this report set out what would be required in the case of the UK to achieve this.

– Middle-income countries like China peak their emissions very soon and reduce quickly, but do not reach net-zero CO_2 emissions until after 2050. Efficiency, low-carbon power and electrification must all have major roles, supplemented by, for example, CCS.

– Developing countries 'leapfrog' to low-carbon development paths, particularly for the energy sector, and shift from deforestation to afforestation. Emissions remain low on a per capita basis, but do not need to reach net-zero CO_2 until after 2050, if at all.

- For 1.5°C, countries like the UK would still need to deliver their 'highest possible ambition', and other regions of the world would also need to reach net-zero CO_2 emissions by around 2050.
- A substantial increase in global near-term emissions reduction ambition will be needed alongside these longer-term emissions reductions to limit cumulative future long-lived GHG emissions to relatively low levels and to keep warming to levels in the Paris Agreement long-term temperature goal.

This chapter concludes that the UK should reduce emissions beyond the level required for the world as a whole. Chapter 4 considers the UK's role as a climate leader internationally and considers how an ambitious net-zero emissions target in the UK would support increased ambition in the rest of the world.

Table 3.2. GHG emissions per person compatible with the Paris Agreement temperature goal

	Well-below 2°C	**1.5°C**
Global 2050 GHG emissions per person (tCO_2e/year)	0.8 - 3.2	-0.4 - 1.7
Equivalent reduction in total UK GHG emissions from 1990 for same per capita emissions - the UK should go beyond the global average	72% - 93%	85% - 104%

Source: CCC analysis; Huppmann, D. et al. (2018) A new scenario resource for integrated 1.5°C research. *Nature Climate Change*, 8 (12), 1027.
Notes: Ranges shown correspond to the minimum and maximum across the full range of the IPCC-SR1.5 scenario groupings with a >66% probability of warming below 2°C (well below 2°C) and a >50% probability of 1.5°C. Gases are aggregated using GWP_{100} values from the IPCC 4th Assessment Report. Population change in the UK is accounted for using 'Principal' long-term projection from the Office of National Statistics.

Chapter 4: Supporting increased global ambition

Introduction and key messages

Chapter 3 set out the global effort needed to meet the long-term temperature goal of the Paris Agreement and an appropriate contribution from the UK towards it. This chapter considers opportunities for wider climate leadership from the UK, which can help support other countries in reducing their emissions.

International collaboration forms an important part of the Paris Agreement. It is in the UK's interest given that global action tackles climate change, reducing the exposure of the UK (and the world) to rising climate risks. It can also help the UK to achieve its own emissions targets, for example by ensuring that strong governance is in place to develop genuinely sustainable supplies of biomass.

Our key messages in this chapter are:

- **The UK has played a key role in driving climate action internationally to date and is well placed to keep playing a leading role:**
  - The UK has led by example in cutting emissions, demonstrating that it is possible while growing the economy. The Climate Change Act 2008 (the Act) and UK approaches to low-carbon policy more generally have provided positive examples that have been adopted elsewhere.
  - The UK has also been an active player in reaching international agreements, supporting mitigation and adaptation effort in other countries, building capacity and knowledge, improving governance and rules for financial markets including disclosure of climate-related risks and in meeting its climate finance commitments in a productive and responsible manner.
- **To continue being a credible leader, the UK should set a net-zero GHG target by 2050 at the latest**. Emerging commitments are showing that an increasing number of other climate leaders are adopting net-zero greenhouse gas (GHG) targets by 2050 or earlier. To stay part of this leading group the UK must set a more ambitious target than the world overall and one that at least aligns to plans from other climate leaders. This would imply reaching net-zero GHG emissions by 2050 at the latest.
- **The UK should seek to maximise the international impact of any new target that is set and use it as an opportunity for further positive international collaboration.** This should be targeted at the UK's areas of comparative advantage and aimed at increasing emissions reduction ambition as well as helping countries onto a sustainable development path.
- **The Paris Agreement includes several routes to collaboration**, both through centralised and bilateral mechanisms, and including carbon markets. These could play a role to help deliver some of the more challenging decarbonisation options which may be required to reach net-zero emissions globally.

We set out our analysis in four sections:

1. Routes to collaboration under the Paris Agreement and UN bodies
2. Current UK activities to support global efforts to tackle climate change
3. Ratcheting effort up: emerging long-term commitments and increases in ambition
4. Priorities for UK support towards increased global effort to reduce emissions

1. Routes to collaboration under the Paris Agreement and UN bodies

The Paris Agreement is a broad international climate framework and has a considerably wider focus than greenhouse gas emissions mitigation. It sets a long-term goal with three main strands:

- **Mitigation:** holding 'the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.
- **Adaptation:** increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production and following a 'country-driven approach'.
- **Finance:** making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

Voluntary cooperation between parties was recognised as crucial to reach the goals set out in the Paris Agreement. This identifies several routes to international collaboration, building on and going beyond existing obligations under the UNFCCC. The cooperative approaches set out in the Agreement reflect a broader shift from a 'top-down' to a 'bottom-up' structure (Chapter 3), where bilateral agreements between Parties could play an important role:

- **Climate finance.** *Article 9* calls for developed countries to support developing ones by mobilising finance from a range of sources. The support should 'seek a balance' between adaptation and mitigation actions, and take into account country-driven strategies and the priorities and needs of developing countries.
- **Technology sharing.** *Article 10* recognises the central role of innovation in achieving mitigation and adaptation goals, and encourages cooperation and technology sharing. It expects developed countries to provide financial support and to strengthen cooperative action to disseminate technology in developing countries.
- **Capacity building.** *Article 11* encourages cooperation across all Parties to enhance the capacity and ability of developing countries to take effective climate change action. Capacity building includes the development, dissemination and deployment of technology, access to finance and increased education and awareness.
- **Transfer of mitigation outcomes.** *Article 6* provides the option for countries to use 'internationally transferred mitigation outcomes' (ITMOs) towards their commitments to reduce emissions (Box 4.1). It prompts efforts to ensure environmental integrity, transparency, robust accounting, and support for sustainable development.

Beyond the Paris Agreement, there are further collaboration mechanisms under the UN. These are particularly relevant to emissions reduction from international aviation and shipping:

- The responsible bodies for this are dedicated UN agencies, respectively the International Civil Aviation Organization (ICAO) and International Maritime Organisation (IMO).
- Both agencies have recently reached agreements which represent a first step in limiting the sectors' contribution to global emissions (see Box 4.2 on the Carbon Offsetting and Reduction Scheme for International Aviation, CORSIA).

The UK has been an active participant in negotiations at the UNFCCC, ICAO and IMO.

Box 4.1. 'Carbon units' and the transfer of international mitigation outcomes under the UN framework

Throughout this report we refer to domestic or international 'carbon units'.

- This is the language that the Climate Change Act 2008 uses to indicate a unit of one of the following categories: a reduction in an amount of GHG emissions, a removal of an amount of GHGs from the atmosphere or an amount of GHG emissions allowed under a [trading] scheme.
- In a wider context the term 'credits' is often used. The term 'offsets' is also used, particularly in the international context when emissions occurring in a certain geographic location are being compensated by a reduction or a removal elsewhere. The Paris Agreement refers to 'internationally transferred mitigation outcomes' (ITMOs).
- For this discussion it is also important to distinguish carbon units used for compliance with an emissions reduction target (such as allowances under the EU Emissions Trading System, EU ETS), from those generated and exchanged in voluntary markets.

The Kyoto Protocol allowed the international transfer of carbon units by initiating the Clean Development Mechanism (CDM). There are several issues which impacted the effectiveness of the CDM. The main criticisms are a failure to incentivise truly additional emissions reductions, lack of transparency in governance, as well as a more general failure on its contribution to sustainable development objectives.

The Paris Agreement includes two mechanisms to facilitate ITMOs, outlined in Article 6, which allow a portion of a party's commitments to be achieved through actions abroad:

- The direct transfer of an ITMO between two willing parties for the purpose of accounting towards their respective nationally determined contribution (NDC).
- An international market-based mechanism to facilitate the transfer of emissions reductions from project-based mitigation activities around the world to purchasing nations. This mechanism is intended to be the Paris Agreement's successor to the CDM.

Negotiations are still ongoing and rules are expected to be finalised at the 25th Conference of the Parties (COP25) at the end of 2019:

- Agreement on a set of rules to facilitate the international transfer of mitigation outcomes could not be reached at COP24 in 2018 when the rest of the Paris Agreement rulebook was agreed. Finalising these rules has been postponed to COP25.
- In the design of the new framework parties are building on the lessons learned from the implementation of the CDM. Negotiations have given particular attention to rules to avoid double counting, which is essential to ensure that mechanisms for international collaboration are robust.
- However, as under the Paris Agreement trading only has to be 'consistent' with guidelines developed by subsequent COPs, this failure to agree rules is not a barrier to parties beginning to consider cooperation to achieve their NDCs and longer-term targets.

Overall, the transfer of carbon units will likely continue to be used internationally as a mechanism to promote cost-efficient abatement and to mobilise finance. Article 6 could provide a more robust framework addressing some of the key shortcomings in the CDM, both through its new centralised mechanism and by allowing parties to cooperate bilaterally towards meeting their NDCs.

Source: Marcu, A. (2016) *Carbon Market Provisions in the Paris Agreement (Article 6)*; AEA, et al. (2011) Study on the Integrity of the Clean Development Mechanism (CDM). Final report; Carbon Market Watch (2018) The Clean Development Mechanism: Local Impacts of a Global System; UNFCCC.
Notes: The CDM allows projects generating emissions reduction in developing countries to earn certified emissions reduction units (CERs) which may be traded in emissions trading schemes. 2% of the proceeds from CERs went to the Adaptation Fund established under the Kyoto Protocol. COP24 agreed that a share of proceeds from the Article 6 market-based mechanisms would be used to continue that Adaptation fund.

Box 4.2. Collaboration to reduce emissions from international aviation

Aviation contributes to both CO_2 and non-CO_2 warming effects. If its greenhouse gas emissions were left to increase, by 2050 they would constitute approximately 10% of the global cumulative carbon budget compatible with limiting temperature increase to 1.5°C or below (Note 1).

The body in charge of developing an approach to mitigating emissions from international aviation is the UN's International Civil Aviation Organisation (ICAO).

Emissions from aviation can be limited through improvements to fuel efficiency, constraints on demand growth and switching to alternative fuels. However, deep emissions reductions in the aviation sector will be more difficult to achieve compared to other sectors (see Technical Report, Chapter 6). Current trends suggest a large share of emissions from aviation will have to be compensated through reductions elsewhere or through emissions removal from the atmosphere.

In 2016 ICAO members agreed the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA):

- This will run from 2021 to 2035, though it will be voluntary until 2026. It creates an obligation for carbon-neutral sectoral growth from 2020. Any unabated emissions above 2020 levels will have to be offset through the purchase of emissions reduction units.
- The mitigation gap that CORSIA needs to cover has been estimated at between 1.6 and 3.7 $GtCO_2e$ over its operational period (2021-2035), meaning it may represent the single largest source of demand for emission offsetting after 2020 (Warnecke et al, 2018). As such, the integrity of eligible carbon units under CORSIA is critical for it to genuinely contribute to global mitigation efforts.
- A final set of eligibility criteria for emissions units has recently been approved by the ICAO Council. These include key elements such as 'no double counting' (emission reductions should only be counted once towards mitigation commitments) and 'permanence' (carbon units should represent permanent emissions reduction). The responsibility to select eligible projects on the basis of those criteria is assigned to a Technical Advisory Body made up of member-state experts.

Uncertainties around the availability and cost of robust carbon units in the longer term (Note 2) and broader developments in international carbon units markets may impact the effectiveness of the CORSIA scheme. Should this be the case, the wider cooperation mechanisms under Article 6.2 of the Paris Agreement could provide an alternative route for more robust standards through bilateral agreements.

Despite the challenges, CORSIA offers a route to limit post-2020 aviation emissions. It can provide an interim measure allowing new solutions to become available and support the development of a global market in carbon units, particularly for GHG removal technologies. However the emissions cap at 2020 levels, committed until 2035 only, is not compatible with achieving net-zero emissions globally. The ICAO should set a long-term objective for aviation emissions consistent with the Paris Agreement and align CORSIA to this.

Source: ICAO (2016) *Assembly Resolution A39-22/2;* EDF (2018) *Carbon prices under carbon market scenarios consistent with the Paris Agreement: Implications for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*; Warnecke, C., et al. (2019) *Robust eligibility criteria essential for new global scheme to offset aviation emissions*; ICAO (2016) *ICAO Environmental Report 2016.*
Notes: (1) Based on 543 $GtCO_2e$ of global carbon budget consistent with the IPCC's 1.5°C scenario (CCC analysis), and 56 $GtCO_2e$ of projected aviation emissions between 2015 and 2050 (2016 published Carbon Brief analysis).
(2) E.g. a recent study by the US' Environmental Defence Fund (EDF) modelling carbon prices under alternative scenarios estimates prices between $7.6 (current NDC ambition) and $70 (2°C compatible) in 2035.

2. Current UK activities to support global efforts to tackle climate change

The UK has been leading climate action internationally both by acting as a positive example and in carrying out various international activities. This section looks at both aspects, covering:

(a) Governance and capacity building
(b) Diplomacy and negotiations
(c) Technology development and sharing
(d) Climate finance
(e) Carbon markets

(a) Governance and capacity building

The UK Climate Change Act 2008 (the Act) has been a model of climate legislation for many countries worldwide. The UK has also been a driving force in green finance initiatives (Box 4.3), and is engaging in various capacity building activities aimed at strengthening institutions abroad.

The Act made the UK the first country in the world to set a legally-binding long-term emissions target within a comprehensive climate law covering both mitigation and adaptation.

- A crucial part of the framework established by the Act is that it links the long-term target to nearer-term policy requirements. The Act requires that five-yearly carbon budgets are set on the path to the long-term target and that the Government bring forward policies and proposals to meet both. The Committee on Climate Change (CCC) was set up as an independent advisory body and must report annually on progress to Parliament.
- This framework remains among the strongest in the world and has allowed the UK to be influential on climate action internationally. Since the Act's passage in 2008, several other countries have adopted comprehensive climate legislation,[112] and some like Mexico (2012) and Sweden (2017) have explicitly drawn on the Act as an example for domestic laws.[113] More recently, France has established the High Council on Climate Action (HCAC), an independent body with a similar role to that of the CCC.[114] The Act has also been identified as 'one of the factors that enabled the UK to play a leading role in the Paris Agreement process'.[115]
- The Committee's own experience is that there has been significant demand for knowledge sharing from other countries. The Committee and its staff have shared experiences with delegations from numerous countries to support capacity building, including Canada, China, France, Germany, Japan, New Zealand, the Philippines, Portugal, Sweden, South Korea and Taiwan.

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[112] These include, from the most to the least recent: Peru and Benin (2018); Paraguay and Pakistan (2017); Kenya (2016); Malta, Ireland, Papua New Guinea, Finland and Taiwan (2015); Honduras and Mozambique (2014); Micronesia, Guatemala and Burkina Faso (2013); Iceland (2012); France (2010); Brazil, Nicaragua and Philippines (2009).
[113] Mexico adopted its General Law on Climate Change in 2012 and Sweden adopted its Climate Act in 2017.
[114] The Tyndall Centre (28 November 2018) *'Corinne Le Quére becomes Chair of France's first climate change committee'.* Available at: https://www.tyndall.ac.uk/news/corinne-le-qu%C3%A9re-becomes-chair-frances-first-climate-change-committee.
[115] Fankhauser, S., Averchenkova, A. and Finnegan, J. (2018) *10 Years of the UK Climate Change Act.*

Box 4.3. Green finance

'Green' finance refers to private investment being channelled into sustainable projects and infrastructure (i.e. with positive environmental and/or climate benefits), and to environmental risk being factored into financial decision-making. It includes 'green bonds', i.e. bonds that are earmarked for projects with positive impacts on sustainability.

The UK has taken a leading role in the growth of green finance internationally and is a 'front-runner in some aspects, in terms of raising the profile of the issue' according to a 2016 UNEP Inquiry.

- The UK's targeted regulatory regime has helped facilitate major growth in green assets, with the UK holding 80% of the EU's 'alternative finance' market as of 2016.
- The UK's Green Investment Bank, established in 2012, was the first institution in the world of its kind. It played a major role in unblocking financing for renewable energy projects and has since been privatised.
- In 2017, the UK Government endorsed the recommendations from the Task Force on Climate Related Financial Disclosures (TCFD), which was set up by the G20's Financial Stability Board (FSB). These recommendations aim to mainstream risks and opportunities posed by climate change into financial disclosures. Following these recommendations, the UK established the Green Finance Taskforce in 2017 and a new Green Finance Institute, and committed to publish a Green Finance Strategy (expected in spring 2019).
- Internationally, the UK has worked towards accelerating green finance through further initiatives, for instance it co-chaired the G20 Green Finance Study Group with China in 2015, suggesting options to G20 members on how to scale up green finance globally. The Bank of England, a founding member of the Network for Greening the Financial System (NGFS), produced pioneering work to identify financial risks and opportunities from climate change which has been an example to other financial institutions.
- Some areas need further progress. Export finance is not aligned with climate goals, and often supports high-carbon investments. The UK Environmental Audit Committee recently launched an Inquiry investigating the scale and impacts of UK Export Finance's investments and subsidies to fossil fuels in developing countries. It will look at possible alternatives and Government plans to tackle this.

Given its past successes in this area and the global importance of its financial institutions, the UK is particularly well placed to drive further progress in green finance internationally.

Source: UNEP Inquiry (2016) *Building a Sustainable Financial System in the European Union*; Nannette Lindenberg (2014) *Definition of Green Finance;* The Green Finance Task Force (2018) *Accelerating Green Finance;* ICMA (2018) *The Green Bond Principles;* UN Environment: https://www.unenvironment.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-financing; UK Parliament: https://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/inquiries/parliament-2017/uk-export-finance-17-19/

Other examples of successful capacity building include: the contribution of UK scientists to international climate science and the IPCC's work; strengthening sustainable governance; monitoring reporting and verification (MRV); the UK's work on supply chains (e.g. to halt deforestation, including through the UNFCCC programme on Reducing Emissions from

Deforestation and Forest Degradation, REDD+);[116] and other more recent initiatives such as the UK Partnering for Accelerated Climate Transitions programme (PACT).[117]

(b) Diplomacy and negotiations

The UK has been a consistent positive voice in driving international climate agreements and has had a positive influence in the wider international context.

- The UK negotiated as part of the EU in the **UNFCCC talks**, often leading for it. The UK is widely considered to have played a leading role in the negotiations for the Paris Agreement.[118]
- The UK was also amongst the initiators of the **High Ambition Coalition**. This is a group of developed and developing countries sharing the highest level of ambition in the international climate talks. The Coalition is considered to have 'played a key role in shaping the Paris Agreement'.[119, 120]
- The UK has been an influential voice on international aviation and shipping issues within the **ICAO** and **IMO** (Section 1). For instance, the UK was a strong proponent of the recently approved criteria on 'additionality' and 'no double counting' for CORSIA carbon units, and it led a group of countries pushing the IMO to adopt more ambitious goals.
- The UK jointly launched, with Canada, the **Powering Past Coal Alliance (PPCA)** in November 2017. The Alliance provides knowledge-sharing and expert support to its members to help move away from unabated coal power. Increasingly, medium-sized coal users such as Mexico are joining the Alliance and the UK is also involved in early stage dialogues with some of the larger coal users, such as South Africa and Germany.
- The UK has taken a proactive approach to mainstream climate talks through **other channels** including the Foreign and Commonwealth Office (with its highly-regarded network of climate attachés),[121] the G7 and G20, the UN Security Council and other 'soft diplomacy' routes. The UK has also recently committed to lead on Resilience for the UN Secretary General's summit in September 2019.

The UK's diplomatic influence has been strengthened by its strong track record of cutting emissions while growing its economy (Chapter 1, Figure 1.3), and by its strong legislative framework (i.e. the Climate Change Act).

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[116] See for example: PWC (2011) *Funding for forests: UK Government support for REDD+.*
[117] The UK PACT programme is part of BEIS' International Climate Finance portfolio providing targeted climate finance support on the basis of bilateral relationships to support institutional change, and assist countries with infrastructure and capital building. Its projects run over a period of two years and the current two-year projects have £60 million available funds.
[118] See for example Fankhauser, S., Averchenkova, A. and Finnegan, J. (2018) *10 Years of the UK Climate Change Act.*
[119] The European Commission (12 December 2018) *COP24: EU and allies in breakthrough agreement to step up ambition.*
[120] It is worth noting that the majority of the 14 countries which to date have adopted a net-zero emissions goal (Table 4.1) are part of the Coalition.
[121] UK Parliament (2010) *The Role of the FCO in UK Government. Written evidence from the Foreign and Commonwealth Office.*

(c) Technology development and sharing

At the global level, the decarbonisation challenge now appears considerably more tractable due to the rapid decrease in the costs of renewable power in recent years (Chapter 3).

The UK has made a significant contribution to this technological progress through its offshore wind sector. It has consistently been the largest global market (over one third of the global installed capacity in 2017 was in UK waters[122]) and costs have fallen to the point that projects are being contracted across Europe with no or minimal subsidy. UK institutions that contributed to falling costs are also engaged in international collaboration, for example the Offshore Renewable Energy Catapult has been helping address technical and engineering challenges in the Chinese market.

UK industry and research centres are engaged in international collaboration on a number of other low-carbon technologies and knowledge areas. The impact of those initiatives is difficult to evaluate but qualitative evidence suggests positive results (Box 4.4).

Box 4.4. UK collaboration in low-carbon technologies

- **CCS technology**. The UK has been sharing knowledge on carbon capture and storage (CCS) with various countries including China, Mexico and the EU. This includes providing support on practical aspects of delivering large-scale commercial CCS projects (e.g. under the Front End Engineering and Design contracts); leading an international working group to accelerate deployment of CCS and participating in Mission Innovation (a global initiative working to accelerate clean energy innovation); and overseas collaboration through the UK CCS Research Centre (e.g. with Canada, Australia, the Netherlands, China and the USA).
- **Batteries.** This is a growing sector and companies in the chemical and automotive battery sector have the potential to supply valuable material needed to build batteries domestically in the UK. The Government is supporting this through investments in research on batteries for applications like electric vehicles (EVs), for instance through the Faraday Battery Challenge, which has been set up with a £246 million fund as part of the Industrial Strategy.
- **Solar photovoltaic.** A number of UK research institutions are leading on the development of solar photovoltaic, including international collaborations with other countries such as India and Egypt (e.g. Swansea University lead the SUNRISE project exploring solar power in rural Indian villages).
- The **UK Research and Innovation** body UKRI provides funds to several collaboration initiatives, with £7 billion worth of funds across its partnerships and areas of research. It includes the Global Challenges Research Fund (GCRF), which funds sustainable development initiatives with transformational impact, including on climate change.
- **Other examples** of knowledge sharing in developing, middle and higher income countries include: the development of innovative biomass supply chains, the sharing of microgrid technologies (used to distribute solar power in remote locations) and Hydrogen energy (e.g. collaboration with Canada and UK's participation in EUROfusion, a European collaboration research project to develop fusion power reactors).

[122] Global Wind Energy Council: https://gwec.net/global-figures/global-offshore/

More broadly, global supply chains have been critical in driving down the cost of clean energy technologies - from solar panels to LEDs and batteries. The UK has contributed to this through its open markets and well-established financial institutions.

Building on past examples, the UK is well-placed to drive the development and diffusion of technologies internationally and keep driving costs down. The Government has taken some first steps to support this, and is investing in research and innovation as part of its Industrial Strategy.

(d) Climate finance

Climate finance is a form of sustainable finance and is one of the cooperation mechanisms in the Paris Agreement that can be used to fund technology development and transfer, governance and capacity building.

- Together with other developed countries, the UK committed in 2009 to raising $100 billion annually, from both public and private sources, for climate action in developing countries. The pledge applies until 2025, when a new higher target is expected to be set.
- These funds are delivered through a wide range of channels, including multilateral and bilateral funds (e.g. the UNFCCC's Green Climate Fund), lending by multilateral development banks (MDB), and privately managed funds.

In the UK, climate finance funds are part of the Overseas Development Budget (ODA) and are gathered through the International Climate Fund (ICF).

- The ICF is jointly managed by BEIS, Defra and DfID and its funds are evenly spent on mitigation and adaptation activities.
- It accounts for nearly 8% of the ODA budget which is set as a constant 0.7% share of GDP and grew from £8.45 billion in 2010[123] to £14.1 billion in 2017.[124]
- The Government spent £3.9 billion on climate finance activities over 2011-2015 (around £0.8 billion per year), and has recently committed to spending £5.8 billion between 2016 and 2021.
- While climate finance to date has been delivered mostly through multilateral funds and development banks, this is increasingly shifting towards a focus on bilateral agreements.

A recent performance review by the Independent Commission for Aid Impact (ICAI) was broadly positive. It found the UK makes 'strategic choices' enhancing the coherence of the ICF structure, and increasingly contributes to generating transformational impact.[125] The low visibility of its contributions however reduces the impact of its demonstration and influencing objectives.

UK climate finance has been supporting a number of projects and programmes globally. While it is not always possible to quantify the emissions savings these deliver, there is evidence of positive impacts to date.

- Funded programmes include technical and institutional capacity building, both for mitigation and adaptation (from solar power to mangrove restoration); purchasing carbon

[123] Fitzsimons, E., Rogger, D. and Stoye, G. (IFS) (2012) *UK development aid.*
[124] DfID (2018) *Statistics on International Development. Final UK Aid spend 2017.*
[125] ICAI (2019) *International Climate Finance: UK aid for low-carbon development. A performance review.*

units to tighten national emissions trading caps (e.g. through the CDM), [126] and payments attached to policies generating emissions savings.

- The programmes contributed to emissions savings, installation of clean energy capacity and improved access to clean energy. They also contributed to lowering the costs of certain low-carbon technologies, for example through the concentrated solar power (CSP) programme in Morocco.[127]
- In the past, climate finance was mainly directed to single projects or programmes, as a reflection of the wider UNFCCC cooperation structure under the CDM. The focus is increasingly shifting towards supporting nation-wide programmes and country long-term strategies (e.g. under the Partnering for Accelerated Climate Transitions programme, PACT).

Other countries leading on climate action have taken a number of different approaches to climate finance (Box 4.5).

Box 4.5. Examples of international climate finance approaches by other leading countries

- **Japan - the Joint Crediting Mechanism (JCM).** This is a project-based bilateral offset crediting mechanism initiated by the Government of Japan, aiming to facilitate the diffusion of low-carbon technologies. The credits generated under the JCM are shared between Japan and the project host country and count towards their respective GHG emission reduction targets, but cannot currently be traded outside of the scheme. Project registries help avoid double counting of associated emissions savings. The JCM is seen as one of the possible cooperative approaches stipulated in Article 6 of the Paris Agreement.
- **France - the French Development Agency (AFD).** France contributes to ICF through its development agency, for which climate change is one of the five key priority areas. Contributions are now expected to increase from €3 billion a year in 2015 to €5 billion a year in 2020. The AFD has already achieved a target set in 2013 for at least 50% of the supported projects to have a climate co-benefit.
- **Germany's climate finance emphasises bilateral cooperation.** A large share of federal climate finance funds is channelled through bilateral cooperation for development (approximately 85% in 2015-2016, compared to 15% through multilateral funds). International climate finance and traditional development programmes have the same structure - but contribute to climate activities to different degrees (referred to as 'climate-relevant' development cooperation). To ensure transparency, the Government publishes a database which collects information on Germany's climate finance from various sources.
- **Norway's International Climate and Forest Initiative (NICFI)** was established in 2008 and is currently scheduled to run until 2020; it is largely managed by Norway's Agency for Development Cooperation (NORAD). The Initiative has established a series of large-scale partnerships with key forest countries, with 3 billion Norwegian Krones committed per year (around £0.3 billion).

Source: Asian Development Bank (December 2016) *Joint Crediting Mechanism: An Emerging Bilateral Crediting Mechanism;* the French Government (11 December 2018) *France increases its contribution to climate funding; German Climate Finance*: http://www.germanclimatefinance.de/; *NORAD*: https://norad.no/en/front/thematic-areas/climate-change-and-environment/norways-international-climate-and-forest-initiative-nicfi/

[126] Note that international carbon units purchased through ODA funds cannot be counted towards emissions reduction targets.
[127] IRENA reports that auction prices in Morocco have gone from nearly 0.3 USD/kWh for 2016 to less than 0.15 USD/kWh for 2020. Source: IRENA (2018) *Renewable Power Generation Costs in 2017.*

(e) Carbon markets

Carbon markets support international climate change efforts both by allowing access to cost-efficient abatement options and as a source of finance. There is some evidence that shows trading contributes to lower abatement costs and incentivises innovation.[128] However, in order to incentivise low-carbon investment, carbon prices need to be sufficiently high.

The UK's engagement in carbon markets primarily occurs through the EU Emissions Trading System (EU ETS), of which the UK was one of the key architects:

- The EU ETS covered around 40% of EU Emissions as of 2016,[129] and is the second largest carbon market globally after China (where carbon trading began many years after the EU).
- The UK played a key role in the set up and design of the system and its rules, including running a UK ETS from 2002 as a pilot for the EU scheme, which started in 2005.
- Of the 11,000 operators covered by the scheme, 1,000 are located in the UK accounting for about 10% of EU ETS emissions.[130]
- Over the 5 years between 2013 and 2017, the UK was a net buyer of 105 million EU ETS emissions allowances.[131] Traded allowances to date included the purchase of a limited amount of international carbon units. This will no longer be allowed in the next EU ETS phase (from 2021 onwards).

The effectiveness of the EU ETS in the past has been limited by an over-supply of allowances, which has resulted in a low carbon price. Various mechanisms have been put in place to ensure higher carbon prices:

- At the EU level, the EU ETS cap has been set to fall over time, and the issue of over-allocation was addressed with two key measures: 'backloading' and the Market Stability Reserve (MSR).[132] Following these reforms, the price of allowances has gradually increased reaching a level of 22€/tonne in March 2019 compared to 7€/tonne in March 2012.[133]
- The UK introduced a price floor for emissions allowances in 2013. This currently adds £18/tonne to the EU ETS price and it has been a key driver of the 83% drop in UK coal-fired power generation from 2013 to 2017.[134] The UK also established mechanisms (e.g. compensations and exemptions) to deal with competitiveness issues affecting the most energy-intensive industries.

There is uncertainty about the future of emissions trading in the UK following exit from the EU. The Committee has previously stated a preference for the UK to remain within the EU ETS.[135]

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[128] E.g. Cludius, J. et al. (2019) *Cost-efficiency of the EU Emissions Trading System: An Evaluation of the Second Trading Period.*

[129] According to published EEA data, EU GHG emissions in 2016 were around 4.4 $GtCO_2e$ and verified emissions under the EU ETS were 1.7 $GtCO_2e$.

[130] EEA EU (10 July 2018) *Emissions Trading System Data Viewer.*

[131] BEIS (2018) *Final UK greenhouse gas emissions national statistics: 1990-2017.*

[132] 'Backloading' is a short-term measure postponing the auctioning of 900 million allowances from 2014-16 until 2019-20. The MSR is a long-term measure with mechanisms to regulate the amount of allowances in circulation. Source: DG CLIMA, https://ec.europa.eu/clima/policies/ets/reform_en

[133] Source: Sandbag Carbon Price Viewer, last accessed in April 2019. Available at: https://sandbag.org.uk/carbon-price-viewer/

[134] BEIS (2019) *Energy Trends.*

[135] Several non-EU countries are members of the EU ETS (e.g. Norway, Iceland and Lichtenstein).

The UK has also been a buyer of a limited amount of certified emissions reductions (CERs) under the CDM (Box 4.1) and other voluntary offsetting schemes. It has done so through various channels including through operators under the EU ETS (which will no longer be possible after 2020); international climate funds (e.g. to tighten caps and then writing these off); individual consumers and businesses (including from voluntary schemes other than the CDM).

The UK has contributed more widely to support global carbon pricing mechanisms, including through various World Bank initiatives. These include the Partnership for Market Readiness (PMR), the Pilot Auction Facility (PAF) and the more recent Transformative Carbon Assets Facility (TCAF), which uses result-based payments. In doing so, the UK shared its expertise from the EU ETS to help others to set up their own markets.

With its mature carbon market and related know-how, the UK is well-placed to further drive improvements in carbon markets globally.

3. Ratcheting effort up: emerging long-term commitments and increases in ambition

This section describes long-term commitments and increases in ambition by other climate leaders - both state and non-state actors - which are rapidly emerging. These suggest that in order to maintain its role as climate leader, the UK should as a minimum align to the commitments being set and considered by other leading countries and the EU.

Since the Paris Agreement was signed a number of commitments have begun to emerge to help increase global mitigation ambition prior to 2030, however only a few of these have been translated into domestic frameworks:

- Three countries (Argentina, Indonesia and Morocco) have adopted more stringent targets in converting their Intended Nationally Determined Contributions (pledged before the Paris Agreement was signed) into NDCs.[136]
- Six countries (Morocco, Nepal, Sri Lanka, Pakistan, Uruguay and Venezuela) announced new supplementary commitments and actions when revising their NDCs (WRI, 2018).
- Other updates to NDCs have increased the transparency of national mitigation commitments, for instance by specifying the level of emissions that will result if their NDCs are achieved (Argentina, Canada, Morocco and Uruguay), the anticipated emissions savings from their actions (Belize) or by providing information of how their NDCs will be implemented and monitored (Benin, Morocco, Pakistan and Sri Lanka).
- While most countries have an economy-wide emissions reduction target in their NDC, only a few of these have been translated into domestic frameworks. Currently, only six countries have set economy-wide targets beyond 2030 in their NDCs and only 16 countries and the EU have done so in their laws and policies.[137, 138]

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[136] According to 2018 published analysis by the World Resources Institute (WRI), Argentina and Indonesia have clarified their target definition, leading to a projected additional reduction in 2030 of around 100 $MtCO_2e$ across both countries. Morocco increased its commitment from a 13% reduction relative to 'business-as-usual' to a 17% reduction. Available at: https://www.wri.org/blog/2018/04/insider-whats-changing-countries-turn-indcs-ndcs-5-early-insights

[137] Alina Averchenkova (2019) *Legislating for a low carbon and climate resilient transition: learning from international experiences*.

[138] Michal Nachmany and Emily Mangan (2018) *Policy brief: 'Where are we going?' Aligning national and international climate targets.*

Countries have also begun to signal their intentions regarding raising their pre-2030 NDC ambition by the end of 2020.

- The High Ambition Coalition have signalled their intention to raise their NDC ambition by the end of 2020.[139]
- The Marshall Islands (also part of the High Ambition Coalition) became the first country to submit a revised NDC, firming up its indicative target to reach a 45% reduction of GHG emissions below 2010 levels by 2030 (compared to its pre-Paris commitment to reach a 32% reduction by 2025). Although the Marshall Islands represent only a minimal share of global emissions and GDP,[140] they - along with other members of the Alliance of Small Island States - are likely to suffer some of the largest impacts from climate change and so have an important voice in global climate talks.

Since the signing of the Paris Agreement, the USA has announced its intention to withdraw from the Paris Agreement, and has ceased implementation of its existing NDC. This withdrawal will not be complete until the 4 November 2020, the day after the next US presidential election. Despite this, ambition has continued at a non-federal level, with a number of alliances pledging to implement the ambition of the USA NDC.

- *We are Still In*, *America's Pledge* and *United States Climate Alliance* all represent coalitions of sub-federal state actors that have committed to undertake ambitious climate action.
- 19 states have made quantifiable GHG reduction or renewable energy commitments. 16 US state governments have stated their will to pursue the objectives of the Paris Agreement under the US Climate Alliance. This includes California (with an economy of similar size to the UK) which has used an executive order to commit to reduce emissions to net-zero by 2045. Taken together, the various US coalitions of states, cities and businesses supporting the Paris Agreement make up around 37% of US GHG emissions.[141]

Longer-term commitments from other countries have also been emerging, including a number that aim at a net-zero emissions goal, as reflected in Table 4.1 below.

- 11 countries have produced a mid-century, long-term low greenhouse gas emission development strategy that has been submitted to the UNFCCC. Under the Paris Agreement all other countries must submit a mid-century strategy before the end of 2020.
- Through the 2050 Pathways Platform, 19 countries and 32 cities have committed to develop long-term, low-emissions, climate-resilient development strategies.

Net-zero commitments vary in terms of their definition, the date for reaching net-zero emissions, and the institutional strength of the commitment to achieve the target (Table 4.1). These commitments have been made by a range of countries, both developed and developing. The EU and other rich developed countries have set or considered targets for net-zero GHG emissions by 2050 or before.

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[139] European Commission: https://ec.europa.eu/clima/sites/clima/files/news/20181211_statement_en.pdf
[140] In 2017, the Marshall Islands accounted for 0.12 Mt of CO_2 emissions, compared to nearly 41.2 Gt of global CO_2 emissions. Its GDP in 2017 was around $200 million compared to nearly $81 trillion of global GDP.
[141] America's Pledge (2018) *Fulfilling America's Pledge.*

- **The European Commission** has proposed a vision for a net-zero GHG Europe by 2050. This includes LULUCF sinks[142] but does not include any use of international carbon units. This is not yet a legislative proposal, but has been supported by the EU Parliament.
- **Sweden** became the first country in 2017 to legislate for a net-zero GHG target. It commits to reach net-zero emissions by 2045, with at least an 85% reduction relative to 1990 levels[143] occurring domestically and up to 15% coming from international carbon units, enhanced land-sinks or other engineered GHG removals. Contributions from international aviation and shipping are not included within this target unlike for the UK's current 2050 target under the Climate Change Act.
- **France** has a climate action plan with a net-zero GHG target of 2050 proposed by the Government, and is working on a bill to come before its parliament in the spring.

More widely, ambitious commitments by several non-state actors have also been emerging. These include: businesses (e.g. Siemens' commitment to carbon neutrality and Unilever's ambition to eliminate fossil fuels from their operations - both by 2030); cities (e.g. C40 Cities' pledge to enact policies ensuring new buildings operate at net-zero carbon by 2030 and all buildings by 2050[144]); and regions (e.g. several Australian provinces have introduced some form of net-zero emissions goals).

Overall therefore emerging direction is towards climate leaders setting targets for net-zero GHGs by or before 2050.

Table 4.1. Emerging net-zero commitments in other countries

	Net Zero: CO_2 or GHGs	**Date to achieve target by**	**Formality**	**Additional information**
Net-zero targets under consideration				
European Union	GHGs	2050	Commission Proposal	Proposal includes detailed scenarios to meet target without use of international carbon units. Includes land use
France	GHGs	2050	Bill - not yet legislated	Provides scenario to meet target without use of international carbon units
New Zealand	To be decided	2050	Bill - being drafted	High agricultural emissions make an all-GHG target challenging

[142] In 2015, average LULUCF sinks in the EU were -0.6 tCO_2/person, greater than in the UK (at -0.1 tCO_2/person). Estimates based on: the World Bank (2019) *Population, total*; the ONS (2018) *Population estimates*; the EEA (2018) *Greenhouse gas data viewer*; BEIS (2019) *Final UK greenhouse gas emissions national statistics 1990-2017*.
[143] Excluding its existing large land-based sink for defining both 1990 levels of emissions and percentage reductions from this baseline.
[144] C40 Cities is a knowledge-sharing network of 94 of the world's largest cities, representing over 650 million citizens, one quarter of the global economy and 2.4 $GtCO_2e$ of emissions. These committed to take 'bold climate action' on mitigation, adaptation and wider sustainability, and to put in place plans to deliver their contribution to limiting warming to 1.5°C. Source: https://www.c40.org/.

Table 4.1. Emerging net-zero commitments in other countries

	Net Zero: CO_2 or GHGs	Date to achieve target by	Formality	Additional information
Net-zero targets that have been adopted				
Sweden	GHGs	2045	Legislation	Allows up to 15% offsetting, excludes aviation and shipping
Denmark	Unclear	2050	Legislation	Legislated target is for a 'low emission society', strategy document specifies 'climate-neutral society'
Norway	GHGs	2030	Parliamentary Agreement	Allows use of international carbon units
California	Unclear	2045	Executive Order	Minimal further details published
Net-zero targets and aspirations that are not legally binding				
A number of other countries have mid-century or earlier net-zero targets and ambitions. They are contained in NDCs and strategy documents, but aren't legally binding. Countries include: Ethiopia ('in the long term'), Costa Rica (CO_2 by 2021, GHGs by 2085), Bhutan (already carbon neutral), Fiji (by 2050), Iceland (by 2040), the Marshall Islands (GHGs by 2050), and Portugal (by 2050).				

Source: CCC analysis.
Notes: Costa Rica and Bhutan have large land sinks and include land use emissions in their targets. Sweden excludes its current land sink from its target, although additional removals can count towards the 15% offsetting. Norway's 2017 Climate Change Act includes a target to become a 'carbon neutral society' by 2050 (quantified as a 80-95% reduction in GHG emissions from 1990 levels); recently the government accepted the Parliament's recommendation to bring the date forward to 2030, allowing offsetting through the use of carbon units.

4. Priorities for UK support towards increased global effort to reduce emissions

This section largely draws on the work of our International Advisory Group (Box 4.6). This is a group of independent experts from the public sector, business, academia and NGOs. It has been formed to support and critically evaluate the Committee's work on the international background to UK action. Specifically, the group's work focused on areas of priority for the UK to best support global effort in implementing the Paris Agreement.

The Group's summary findings and recommendations are published alongside this report. The Committee agrees with the rationale for acting and areas of priority that the Group has identified. These are summarised in sections 4(a) and 4(b).

(a) Why setting an ambitious UK net-zero target matters

Other climate leaders - countries and various non-state actors - have set or are considering net-zero GHG targets by 2050 or before. Were the UK to pursue a later date or a weaker target it would undermine these discussions, most notably for the European Union, who are aiming to agree in 2020 a net-zero GHG target for 2050. It would also undermine broader UK climate leadership as it may not be seen as a credible contribution towards the Paris Agreement goals.

This was one of the key conclusions of our advisory group: that the UK should set a more ambitious target than the world as a whole. This is also reflected in the evidence and conclusions presented in Chapter 3.

- The world will need to reach net-zero CO_2 emissions by around 2050 at the latest if the Paris aspiration of limiting warming to 1.5°C is to be met. Chapter 3 concluded the UK would need to set a target at least that ambitious to show clear consistency with the full range of the Paris Agreement. Our scenarios in Chapter 5 show that for the UK to reach net-zero CO_2 emissions it would need to reduce GHG emissions by over 95% compared to 1990 levels.
- The UK's capability mean it is well-placed to reach net-zero emissions before the world as a whole. Equity arguments also point to the UK going further. A 100% cut in GHG emissions by 2050 is the minimum effort required to demonstrate clear consistency with the Paris goals and that the UK is taking a lead as a richer developed nation with high historical emissions.

The Committee therefore agree with the conclusions of the International Advisory Group that if the UK is to remain credible as an international leader on climate change it must as a minimum pursue net-zero GHG emissions by 2050. Setting this target will strengthen UK climate leadership and help encourage others to adopt ambitious targets. However, a weaker target could be damaging in terms of undermining attempts to increase ambition from other countries.

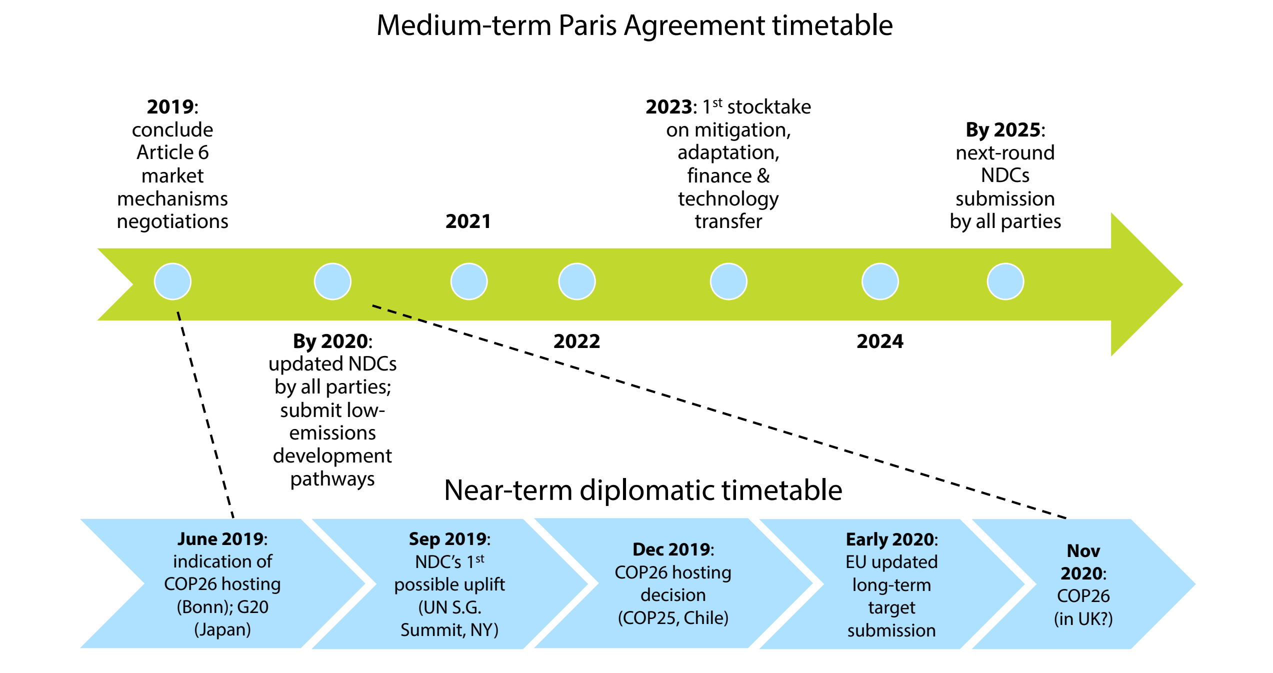
An ambitious domestic net-zero target should be leveraged with wider actions in order to maximise its impacts. These would also support developing countries in shifting to sustainable development pathways, and contribute to developing removals markets required in the longer term (Chapter 3). The UK is well placed to provide further support to this global effort.

(b) Areas of priority for UK action

The priority for the UK should be to focus on actions that will have the largest impact in the transition to a low-carbon economy globally, while at the same time being consistent with the achievement of sustainable development goals (SDGs) and building on the areas where it has particular advantages.

The timing is good for supporting the global ratcheting of effort (as shown by the timeline in Figure 4.1). The forthcoming UN Climate Action Summit in September, the global ratchet mechanism under the Paris Agreement, and the Conference of the Parties in 2020 (COP26) amongst others provide opportunities to influence global ambition. The UK can use these opportunities to encourage other leading countries to reach net-zero emissions on a similar timeline and to act together.

Figure 4.1. Timeline for global ratcheting of effort



Source: CCC analysis.

The areas of priority for UK action identified by the Advisory Group are summarised below (further details can be found in Box 4.6). The UK should:

- **Lead by example.** This includes: keep cutting emissions without undermining economic growth (this will require progress to move beyond the power sector and expand to the rest of the economy); scrutinise public investments; shift away investments from high-carbon infrastructure; further increase investments in low-carbon technologies and contribute to their diffusion.
- **Leverage its diplomatic and political influence**, including through: leading the way on sustainable finance; maintaining open markets, and promoting international trade that is compatible with climate goals and investment in low-carbon solutions; mainstream climate considerations into foreign and security policy; contribute to strengthening governance (e.g. for biomass and removals) and broader understanding on climate change based on the best available evidence; influencing negotiations.
- **Make targeted use of climate finance to nudge developing countries onto low-carbon development paths**, by: building on past success in this area to develop projects with transformational impacts; continuing the move to a greater relative emphasis on bilateral projects, which maximise both impacts and visibility; playing a leadership role in the Multilateral Development Banks; intensifying the 'excellent work so far on supply chains' (e.g. to halt deforestation).
- The Advisory Group also identified a positive case for contributing to the positive development of international carbon markets. They considered that a **limited use of international carbon units** by the UK may be needed as a contingency in the long term, but should be limited to greenhouse gas removals.

Box 4.6. The International Advisory Group's recommendations on climate leadership and signalling

The International Advisory Group (AG) is a group of independent external experts, formed to support and evaluate the international aspects of the CCC's long-term target review. The group considered how additional UK action could best support the global effort to implement the Paris Agreement. The findings and recommendations from the AG are published separately alongside this report.

The AG unanimously recognised that the UK has been a global leader in tackling climate change to date, and there is a strong case for this leadership to continue.

On the date for setting a net-zero target, AG members concluded that:

- 'The UK should set a clear and ambitious net zero emissions target to reflect its policy commitments and legal obligations … A net zero goal would be a powerful signal to UK and international business helping to drive down the cost of the transition.'
- 'The UK should set an earlier date for its net zero target than the world as a whole' in view of considerations of historic emissions, capability, leadership, and politics which are ignored by cost optimisation models.
- 'The latest date for the UK's net zero target which would be internationally credible and maintain the UK's leadership position would be 2050 … Other like-minded jurisdictions are proposing 2050 (e.g. the EU; France; California) or even earlier (Sweden)'.
- 'Setting an earlier date than 2050 would have even more impact internationally … There may be options for credibly setting such an earlier date … A 2045 net zero GHG target could be influential in ensuring the EU adopts the ambitious climate neutrality goal proposed by the Commission'.

Alongside setting an ambitious and timely net-zero target, the AG have identified broader options available to the UK to influence further global progress. These are gathered in four broad areas, in which the UK has successfully intervened in the past: leadership by example, leverage on its existing diplomatic influence, make targeted use of climate finance, and international negotiations.

The AG also recognised that there is a strong case for the limited use of international carbon units in the long term. These should not be a substitute to ambitious domestic action and they will likely be expensive; they should be limited to negative emissions, and associated risks should be mitigated by setting strict standards. The AG also acknowledged that in the short term carbon markets can be a practical solution for industries like aviation and shipping which currently have limited technical means to abate their emissions.

Notes: The members of the group were Mike Barry (Marks and Spencer), Peter Betts (independent consultant, Chair of the AG), Bernice Lee (Chatham House), Nick Mabey (E3G), Prof Julia Steinberger (University of Leeds) and Prof Jim Skea (Imperial College London). Committee Member Corinne le Quéré also joined the group meetings.

The UK has expressed its interest in hosting the 2020 UN climate talks (COP26), which are a vital next step in the Paris Agreement process. Setting a bold net-zero GHG target would strengthen the UK's position to act as a powerful host in those talks and as an influential convener of increased global effort.

(c) The role of international carbon markets

Although the UK should aim to meet the new recommended target without use of carbon units (or 'credits'), it should also take positive actions to ensure that effective markets and rules for carbon units are developed.

The UK can take steps to ensure that it can access genuinely additional carbon units in the long term. Some purchase of carbon units is likely to be supportive of required global actions under the Paris Agreement and could help meet UK targets cost-effectively.

- **It should be possible to access genuinely additional carbon units.** The international transfer of mitigation outcomes is foreseen under the Paris Agreement (Article 6.4). Article 6.2 also allows for bilateral arrangements between countries, which would allow the UK to set its own criteria for effective carbon units if Article 6.4 is not satisfactorily negotiated.
- **Some carbon units could support required global action.** The scenarios we set out in Chapter 3 involve a large amount of expensive effort (e.g. CCS and removals) in developing and middle-income countries. These are likely to need an ongoing income stream, which carbon markets and transfers of carbon units could provide.
- **Some use of carbon units could prove cost-effective.** Our recommended UK target goes beyond the required global effort. That opens the possibility that even if the UK does a little less and buys carbon units from elsewhere it would still be doing at least as much as the world overall. Our scenarios in Chapter 5 also involve a significant amount of emissions removals, some of which may be cheaper to deploy in other parts of the world (e.g. where there is more land, solar or biomass resource).

Any use of international carbon units for target compliance should be conditional on their integrity and robustness:

- The UK should set out clear principles to ensure these reflect an amount of emissions abatement that is at least equivalent to what would have been otherwise achieved through domestic effort.
- They should support genuine and permanent emissions reductions or removals, and ensure these are compatible with environmental and sustainable development objectives. General principles for the integrity of international carbon unit purchases are set out in Box 4.7.

In the shorter term, the UK should support the development and improvement of international markets for the purchase of carbon units. This would develop the option to use these in the future if needed. Even if carbon units are not needed to meet UK goals, some purchase could be valuable as part of the UK's broader collaboration (e.g. some UK climate finance is already directed through carbon credit markets, with the units then written off).

The UK is well placed to support development of effective carbon units markets in various ways:

- **Rule setting** in the context of the UNFCCC. The UK has already been influential in negotiations on Article 6 and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).
  - For instance, the recently approved criteria for eligible carbon units in CORSIA include rules on 'additionality' and 'no double counting' which were strongly advocated by the UK.
  - The UK can influence decisions on the centralised mechanism under Article 6.4 of the Paris Agreement (Box 4.1). It can also set stricter rules through bilateral agreements under the decentralised mechanisms of Article 6.2.
- **In-country capacity building**. At the practical level, carbon markets require skills and know-how (e.g. for MRV and validation). Countries involved in markets will need to build these domestically. The UK should keep providing its support. This can be done through

international mechanisms such as the Partnership for Market Readiness (PMR) and bilateral partnerships.

- **Directly support improvements in systems design,** including through pilot projects. The UK already does so through existing platforms. The Transformative Carbon Assets Facility (TCAF) is an example of this.
- **Selling carbon units**, for example by developing a domestic market for GHG removals.

In the short term international carbon units can be valuable outside of compliance markets as a tool to mobilise finance. This is particularly relevant to encourage ambition in middle-income countries on options such as carbon capture and storage (CCS) and GHG removals.

- These do not have the clear short-term benefits of other low-carbon options (e.g. renewables and electric vehicles) in cutting costs and improving air quality.
- Middle-income countries would not benefit from climate finance and broader climate development support which are rather directed to developing countries.

We therefore recommend that although the UK should aim to meet the recommended net-zero target in 2050 without use of carbon units if possible, it should also take positive actions to ensure that effective markets and rules for carbon units are developed.

We continue to consider the trading in emissions allowances under the EU ETS (and potential links to other emissions trading systems) as separate from the wider use of international carbon units for compliance referred to in this section. The emissions trading system should maintain its current role, as a tool for cost-efficient abatement which also minimises competitiveness impacts on industry (Chapters 6 and 7).

Box 4.7. Criteria for robust carbon units purchase

Our recommendation that the UK should establish clear principles and rules to identify robust carbon unit purchases and maximise their integrity reflects their importance:

- Clear and effective principles and rules will be required for any use of international units (or 'credits') to qualify for target compliance. The Climate Change Act requires the Committee to advise on whether carbon units from particular schemes can be used towards targets in the Act.
- By setting a benchmark, these principles and rules could also positively contribute to the wider development of international markets for carbon units.
- Principles should draw upon 'lessons learned' from past experience and as much as possible avoid the shortcomings which affected the CDM and other existing schemes.

Drawing upon our stakeholder consultations and a targeted literature review, we identified the following broad principles:

- **Equivalence.** Any international carbon unit should have a clear long-term climate benefit, at least as large as the effect of a unit of CO_2 removal in the UK.
- **Additionality.** The activities generating carbon units should drive genuinely additional emissions reductions (i.e. that would not have happened in the absence of such activity).
- **Permanence.** The activities generating carbon units should lead to permanent reduction or removal of GHGs from the atmosphere.
- **Sustainability.** The activities generating carbon units need to support wider sustainability objectives:
  - They should do **no-net harm as a minimum**, preserve and enhance environmental integrity, be compatible with sustainable development goals and not disadvantage local communities.
  - They should ideally deliver environmental and social **co-benefits** (e.g. ecosystem services, support to local economic development).
  - As such, they should ensure **land and biomass** are used sustainably.

In order to be implemented, criteria will require a robust and transparent **governance framework,** addressing accounting and measurement issues, as well as monitoring and verification:

- Article 6.2 states that Parties shall 'apply … robust accounting'. Governance should ensure robust measurement and accounting of emissions as well as of other impacts the activities generate.
  - This includes a rigorous calculation of emissions savings and the clear assignment of ownership rights for carbon units.
  - Crucially, accounting rules will need to ensure emissions savings are **not double-counted**.
  - Accounting rules should also consider differences in NDCs (e.g. whether these are with or without an economy-wide cap, or expressed in non-GHG metrics) and deal for example with trade of units across multiple years (i.e. different vintages).
- The governance system should be **transparent** and should ensure robust **monitoring and verification** through independent auditing.

Some possible **practical approaches** to implement these principles are described below.

- Having a **list of eligible projects.** Limiting the purchase of units to certain types of activities can help mitigate specific risks, for example:

Box 4.7. Criteria for robust carbon units purchase

- Limiting the purchase of carbon units to engineered greenhouse gas removals (GGRs) could help achieve 'equivalence'. A (low-carbon) removal elsewhere would have a long-term climate benefit at least as large as the effect of a unit of CO_2 removal in the UK. For engineered approaches like direct air capture, which are inherently scalable and not restricted by availability of land, this would not reduce the capacity of the host country to reduce its own emissions.
- Excluding certain types of projects such as large hydropower or wind projects can mitigate the risk of not delivering 'additional' reductions. Some certification standards (e.g. the Verified Carbon Standard) and countries (e.g. Norway) are already doing so.

- Select **partnerships** can help setting high quality standards. For example, this can be done on the basis of:
  - **Level of ambition.** Purchasing within the scope of a country's NDC (i.e. only covered activities/sectors) and from countries with ambitious NDCs can help ensure the quality and additionality of carbon units (note that outside of NDCs, carbon units could still be used as a tool to mobilise finance).
  - **Bilateral partnership.** These can help ensure the agreement of clear and robust criteria between exchanging parties, such as to avoid double counting. For example, the KliK Foundation in Switzerland (which fulfils an obligation to reduce emissions on behalf of the Swiss motor fuel importers) restricts funding to activities in countries that have a bilateral treaty with Switzerland ensuring that specific quality requirements on emission units are met.
- Similarly, setting clear and detailed **rules** for selecting carbon units can also help ensure higher standards. It is hard to identify now what the right rules would be in the long-term.
  - There are however examples of this sort of approach, such as the German Federal Government's initiative to offset travel emissions from its staff through the purchase of CDM emission units. This sets out detailed criteria for the selection of activities eligible for funding and evaluation of quality of project bids (e.g. based on contribution to sustainable development objectives).
  - Rules could encourage activities with the largest transformative potential.
  - A technical body could be tasked with either setting or interpreting the rules (e.g. CORSIA's Technical Advisory Body), however its independence would need to be ensured.

The negotiations on Article 6 present an opportunity for the international community to set up a robust and credible centralised market mechanism. However, depending on the outcome of the negotiations the UK may need to set up more ambitious rules and implement these through bilateral agreements (under the Paris Agreement Article 6.2). The international guidance under UNFCCC may not be detailed enough to guarantee robust principles are effectively implemented.

These criteria are only a starting point and cannot be fully defined at this stage given the Paris Agreement mechanisms are not yet fully defined. They can be developed further as the development of Article 6 becomes clearer.

Source: German Federal Government (2018) *Purchase of Certified Emission Reductions (CERs) from the Clean Development Mechanism (CDM) for greenhouse gas offsetting of business trips of the German Federal Government;* The KliK Foundation: https://www.international.klik.ch/en/Home.182.html

Chapter 5: Reaching net-zero emissions in the UK

Introduction and key messages

In this chapter we assess whether it would be technically feasible to reduce UK greenhouse gas (GHG) emissions to net-zero if there were a well-designed policy framework in place to deliver it. We conclude that it is technically feasible by 2050 but highly challenging.

We address the practical delivery challenges that a net-zero GHG target for 2050 could pose in Chapter 6, and the costs and benefits of meeting it in Chapter 7.

Our key messages in this chapter are:

- **The foundations are in place.** The UK has already set carbon budgets and begun to develop policies on the path to an 80% reduction in GHG emissions by 2050. This chapter identifies a set of **Core** measures that would broadly deliver that target, have relatively low costs and delivery barriers, and that Government policy has begun to address. These include: energy efficiency, the shift to low-carbon power, roll-out of electric vehicles and some low-carbon heating, some use of carbon capture usage and storage (CCUS) and electrification in industry, tree planting and on-farm measures, diversion of waste from landfill and phasing out of fluorinated gases.
- **To reach net-zero GHG emissions would require all these measures and much more.**
  - Our **Further Ambition** scenario reaches a 96% GHG reduction by 2050 compared to 1990 levels. A significant low-carbon hydrogen economy will be needed to help tackle the challenges of industry, peak power, peak heating, heavy goods vehicles, and shipping emissions. CCS will have a larger role, including in industry and at scale in combination with biomass. Major changes are needed to how we use and farm our land.
  - Some currently **Speculative** options would also be needed to get to a 100% reduction (i.e. to net-zero GHG emissions). Options include: further changes in demand (e.g. in aviation and diets) alongside more radical shifts in land use; extensive use of emerging technologies to remove CO_2 from the atmosphere and safely store it (e.g. 'direct air capture'); or successful development of a major supply of carbon-neutral synthetic fuels (e.g. produced from algae or renewable power).
- **Delivering net-zero GHGs by 2050 is technically feasible but highly challenging.** In assessing whether reaching net-zero GHG emissions is feasible we also consider realistic timeframes for the transition. Achieving net-zero emissions domestically prior to 2050 does not currently appear credible for the UK as a whole.
- **Wales** has less opportunity for CO_2 storage and relatively high agricultural emissions that are hard to reduce. On current understanding it could not credibly reach net-zero GHGs by 2050.
- **Scotland** has proportionately greater potential for emissions removal than the UK overall and can credibly go further, to reach net-zero GHG emissions before 2050.

It is impossible to predict the exact mix of technologies and behaviours that will best meet the challenge of reaching net-zero GHG emissions. The analysis in this chapter is not intended to predict or prescribe the future technology mix, but it gives an understanding of what a sensible mix might look like and allows us to assess the potential challenges and costs in delivering it.

The analysis draws on extensive new research commissioned for this project, along with previous Committee analysis including our recent reports on Biomass, Land Use, and Hydrogen, as well as a review of the wider literature.

We set out the analysis that underpins our key messages in the following five sections:

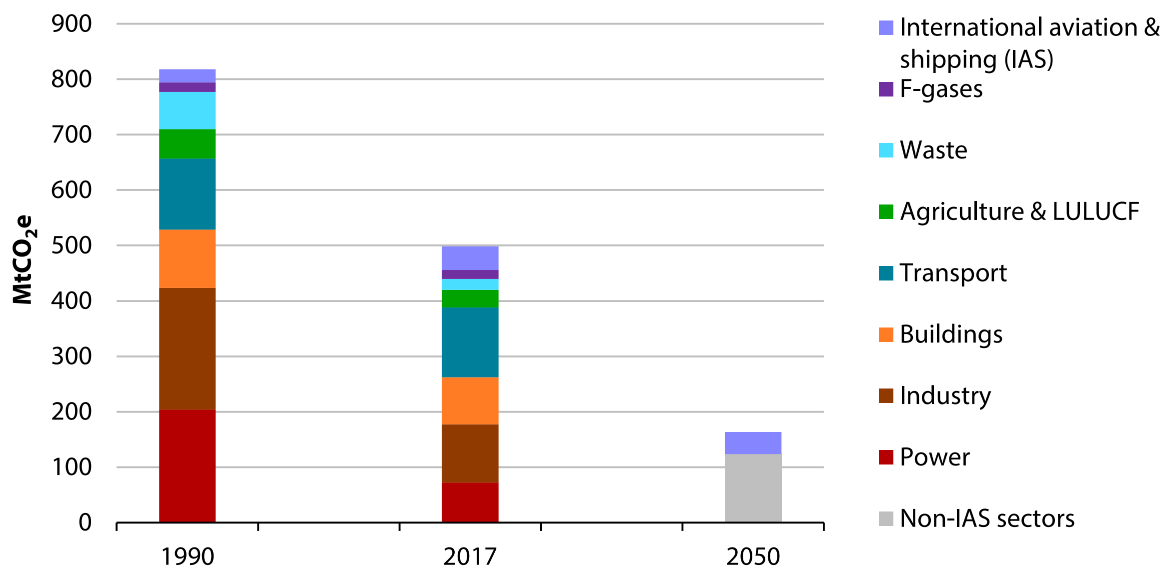
1. The scale of the challenge
2. Options for deep decarbonisation in the UK
3. Getting to net-zero UK GHG emissions
4. Feasible timing for the net-zero transition
5. Implications for Scotland, Wales, and Northern Ireland

1. The scale of the challenge

UK emissions in 2017 were 503 $MtCO_2e$, including emissions from international aviation and shipping. This is 39% below 1990 levels, around halfway towards the currently legislated 2050 target of at least an 80% reduction in GHG emissions compared to 1990 levels (Figure 5.1).

Since 1990, GHG emissions have fallen at an average rate of 12 $MtCO_2e$ per year. Continuing this rate of reduction would meet the 80% target for 2050. However, current policies will not be sufficient to deliver this (see Chapter 6). In addition, an increase in the speed of emissions reduction (e.g. to around 15 Mt per year) would be needed to reduce GHG emissions to net-zero by 2050.

Figure 5.1. The scale of the emissions reduction challenge for the existing 80% 2050 target



Source: BEIS (2019) *2017 Greenhouse Gas Emissions, Final Figures*; CCC analysis.
Notes: IAS stands for international aviation and shipping. Figure based on the current emissions inventory and does not reflect forthcoming revisions to peatland emissions or global warming potentials (see Box 5.1).

We are already meeting some of our energy and economic needs with low-carbon technologies. Half of UK electricity generation in 2017 was from low-carbon sources, including renewables and nuclear. This low-carbon electricity generation helps lower emissions in other sectors where electricity is consumed (e.g. in buildings and industry).

In other sectors very little economic activity is currently met with low emissions:

- **Surface transport.** Less than 0.5% of kilometres driven are by low-carbon vehicles (e.g. electric or plug-in hybrid cars); biofuels have around a 2% share.
- **Heating.** Less than 5% of energy used for heating homes and buildings comes from low-carbon sources.
- **Industry.** Less than 5% of industrial energy demand is met by low-carbon sources.
- **Aviation.** There are no commercially available low-carbon planes, so all flights currently rely on fossil fuels.

Revisions to the UK emissions inventory are expected in the next five years, reflecting an improved understanding of how to measure emissions (e.g. to take into account emissions released from peatland). These will increase estimated emissions, both for the present day and back to 1990 (Box 5.1). We take these expected changes into account in our analysis for reaching net-zero emissions.

Box 5.1. Future changes in accounting for the emissions inventory

Future changes to the emissions inventory include the addition of emissions from peatland and revision of the Global Warming Potentials (GWPs) used to aggregate greenhouse gas emissions:

- **Peatland.** The current inventory only captures about 1.3 $MtCO_2e$ of emissions from peatlands, but all sources of peatland emissions will be included in the inventory from 2020. Work by the Centre for Ecology & Hydrology (CEH) for the BEIS Wetland Supplement project,[145] which will be used as the basis for the emissions inventory, estimates net annual emissions from all peatland sources of 18.5-23 $MtCO_2e$ in 2017 and a similar amount in 1990.
- **GWPs.** These are used to aggregate different greenhouse gases together into a common metric, showing their equivalence to carbon dioxide. At COP24 in December 2018 the international community decided to standardise reporting under the Paris Agreement transparency framework using the GWP_{100} metric. The values to be used are those from the IPCC 5th Assessment Report (AR5). There are two methodologies, and it is not yet clear which will be used. Both are different from the AR4 values used in the current emissions inventory. The decision requires national inventories to use updated GWP values by the end of 2024. The impact of this change will be to increase UK emissions (excluding peatland) by around 10-50 $MtCO_2e$ in 1990 and 5-20 Mt for 2017, largely from sectors which have significant methane emissions (i.e. agriculture and land use).

In this report we reflect both forthcoming changes in our analysis. We include the higher peatland estimates for both 1990 and 2050. We use the AR4 GWP values but illustrate sensitivities to the range of higher values from AR5. The range for the total impact of the peatland and GWP changes is around an additional 25-70 $MtCO_2e$ in 1990 and 10-35 Mt in 2017 compared to the current inventory.

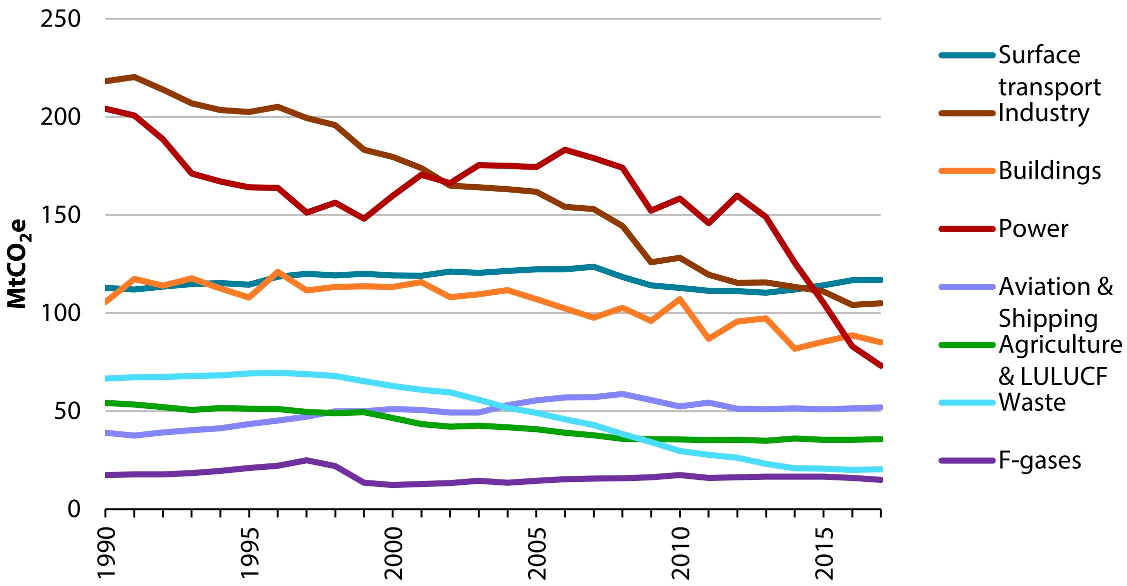
As we set out in our annual Progress Report to Parliament in 2018, reductions in GHG emissions seen so far have largely been in the power, waste, and industry sectors. Emissions in other sectors (e.g. transport) have not shown significant reductions or have increased (Figure 5.2):

[145] Evans et al. (2019) *Implementation of an Emissions Inventory for UK Peatlands.*

- **Power.** Emissions from electricity generation have fallen by 50% since 2013 and 64% since 1990. The very large recent reduction reflects a decrease in coal use for electricity generation, as electricity demand has fallen and the supply from renewables has increased.
- **Waste.** Emissions from waste have fallen by 69% since 1990, due to the UK's landfill tax, which has reduced the amount of biodegradable waste going to landfill, and due to an increase in methane captured at landfill sites.
- **Buildings.** Emissions from buildings have fallen by 13% since 2013 and are around 20% below 1990 levels. There has been low uptake of energy efficiency measures, and limited deployment of low-carbon heating options (e.g. heat pumps).
- **Transport.** Emissions from transport have increased by 6% since 2013 and are now 4% higher than in 1990. Although vehicles have become more fuel efficient, this has been offset by increasing travel demand.

We will include a wider assessment of the change in emissions in 2018 in our next annual Progress Report to Parliament, in July 2019.

Figure 5.2. Progress reducing UK emissions (1990-2017)



Source: BEIS (2019) *2017 Greenhouse Gas Emissions, Final Figures*.
Notes: 2017 is the latest year for which final data is available. Figure based on the current emissions inventory and does not reflect forthcoming revisions to peatland emissions or global warming potentials (see Box 5.1).

2. Options for deep decarbonisation in the UK

There is a range of technologies and behaviour changes that can help reduce emissions. In this section we summarise the options to reduce emissions from current levels. We split these into 'Core', 'Further Ambition', and 'Speculative' options:

- **Core options** are those low-cost low-regret options that make sense under most strategies to meet the current 80% 2050 target. They also broadly reflect the Government's current level of ambition (but not necessarily policy commitment or action).
- **Further Ambition options** are more challenging and on current estimates are generally more expensive than the Core options.
- **Speculative options** currently have very low levels of technology readiness, very high costs, or significant barriers to public acceptability. It is very unlikely they would all become available. Some of these options would be required alongside the Core and Further Ambition options to reach net-zero GHG emissions by 2050.

These sets of options are discussed in sections (b)-(d), following an explanation of our approach.

(a) Approach to identifying options to reduce emissions

In identifying options for reducing emissions we have considered:

- **Feasibility.** This includes the barriers to deploying different options (including non-financial barriers such as public acceptability), and also the timings over which changes can be made (e.g. how long assets last, how quickly they can therefore be replaced, and whether it is possible to build up supply chains sufficiently to deliver the options).
- **Costs.** Our scenarios take into account the relative cost-effectiveness of different ways to reduce emissions. Higher overall levels of ambition require more expensive and harder to implement options. We cover the costs and benefits of our scenarios in detail in Chapter 7.
- **The wider criteria in the Climate Change Act.** These include impacts on affordability for consumers, energy security and competitiveness, as well as wider economic benefits. We cover these for the scenarios in aggregate alongside the costs and benefits in Chapter 7.
- **Existing policies.** Our scenarios are consistent with actions and policies to which the Government is already committed to. Additional new policies will be required to meet an 80% or net-zero 2050 target.
- **Advice from our expert advisory group.** We appointed an expert group of academics and practitioners to advise us on our approach to constructing scenarios and the judgements involved. Their advice is summarised in Chapter 6, on delivery of a net-zero target.

Further detail on the options to reduce emissions are set out in the accompanying report *Net Zero - Technical report*.

(b) Core options that are likely to be required under any climate strategy

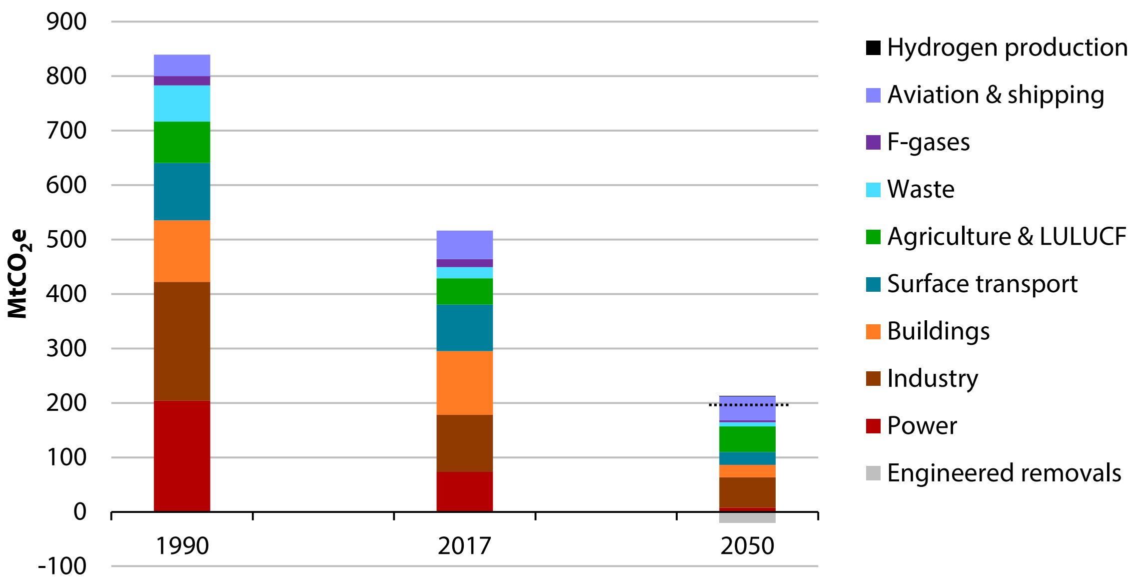
The Core options include lower-cost energy efficiency and extensive decarbonisation of the power and transport sectors.

- **Buildings.** The Core scenario reflects an improvement in energy efficiency and an increasing uptake of low-carbon heating. Current Government aspirations and commitments (e.g. to make as many homes as possible EPC band C by 2035, and to stop the installation of gas heating in new homes from 2025), whilst in need of strengthening and extending, target the decarbonisation of homes across the actions in the Core scenario.

- **Industry.** The Core scenario broadly reflects a range of Government policies to decarbonise industry through improved energy efficiency and low-carbon technologies. These include the Industrial Clusters Mission (which aims to establish the world's first net-zero carbon industrial cluster by 2040), the ambition to improve business energy efficiency by at least 20% by 2030, and the CCUS Action Plan.
- **Power.** The Core scenario reflects a continuation and expansion of current commitments to contract low-carbon power and to deliver on the Government's CCUS Action Plan.
- **Transport.** The Core scenario reflects the Government's current commitment to phase-out sales of conventional petrol and diesel cars and vans by 2040.
- **Aviation and shipping.** Aviation emissions in the Core scenario are aligned with the Government's objective to keep 2050 emissions at or below 2005 levels (i.e. 37.5 $MtCO_2$). Shipping emissions are consistent with the internationally agreed target, which is to reduce global international shipping emissions by at least 50% below 2008 levels by 2050.
- **Agriculture and land use.** The Core scenario is based on the measures identified in our fifth carbon budget advice, but with lower take-up to reflect the lack of firm policy commitment in this area. It includes some emissions reduction from livestock, soils, and waste manure management. It is also aligned to current government and devolved administration ambition on afforestation, for an additional 27,000 hectares per year from 2025.
- **Waste.** Many of the Core opportunities are already included in government and devolved administration plans. The Core scenario includes stopping sending five key biodegradable waste streams to landfill by 2030 or earlier. It also reflects an increase in recycling rates in line with current ambition in England and the devolved administrations (e.g. from around 45% in England, Scotland and Northern Ireland and over 60% in Wales today, to 65% in England by 2035 and 70% in Scotland and Wales by 2025).
- **F-gases.** The Core scenario reflects the current policy agreed by EU member states to reduce F-gas emissions by two-thirds by 2030 compared to 2014 levels.
- **Greenhouse gas removals (GGRs).** The Government have committed to developing a strategic approach to GGRs. In the Core scenario, there is an increase compared to today in the use of wood as a construction material, together with inclusion of bioenergy with carbon capture and storage (BECCS) at the bottom end of the 20-65 Mt range identified in our 2018 report on *Biomass in a low-carbon economy*.

The Core options we have identified would cut emissions by over 300 $MtCO_2e$ from 2017 levels, to 193 $MtCO_2e$ in 2050 (Figure 5.3). This is 77% below 1990 levels. Remaining emissions would largely be from industry, agriculture, aviation, heavy transport and heating of buildings. Around 70% of the remaining emissions would be from CO_2 sources.

Figure 5.3. 2050 GHG emissions in the Core scenario compared to 1990 and 2017



Source: BEIS (2019) *2017 Greenhouse Gas Emissions, Final Figures*; CCC analysis.
Notes: Dotted line shows net emissions in 2050, taking into account negative emissions. Figure includes high estimate of additional peatland emissions and is based on the current inventory GWPs (see Box 5.1).

(c) Further Ambition options that will be needed to go beyond an 80% reduction

Given the higher levels of ambition considered in this report, we have undertaken new research on the areas where it is most challenging to reduce emissions. These, along with other recent evidence and the Committee's 2018 reports on hydrogen, biomass and land use inform the options we consider for Further Ambition.

We have identified new potential for deep emissions reductions and opportunities to go further including on electricity generation, GGRs, industry, buildings, agriculture, transport, and aviation (Box 5.2).

We first set out our findings for those sectors able to reduce emissions close to zero, then for harder-to-treat sectors, followed by options for removing CO_2 from the atmosphere and finally a summary of the effect of deploying all the options together.

Box 5.2. New CCC research on opportunities for very deep emissions reductions (and removals)

- **Electricity generation.** We commissioned a project to examine the potential for accelerating the rate of electrification, in line with earlier uptake of electric vehicles and heat pumps. The project involved detailed modelling of the network implications and system functionality. It also reviewed evidence on the long-term deployment limits for low-carbon technologies like offshore wind.
- **Greenhouse gas removals (GGR).** We have used new evidence on the potential for, and costs of, GGR, with greater consideration than previously of direct air capture of CO_2 with CCS (DACCS), enhanced weathering, and biochar. These are in addition to BECCS and wood in construction considered in the Committee's 2018 report *Biomass in a low-carbon economy*. We have worked with the UK Energy Research Centre on their review of the evidence on costs and potential of BECCS and DACCS, as well as reviewing the literature and state of knowledge on the potential for enhanced weathering, biochar and deploying DACCS at scale in the UK.
- **Industry.** We have extended our analysis to look at potential for reducing emissions in a wider range of industry sub-sectors compared to our previous scenarios. We have also undertaken new analysis on the potential for emission savings from resource efficiency. We have commissioned new work on reducing emissions from fossil fuel production (e.g. offshore oil and gas), and through industrial fuel switching.
- **Buildings.** We commissioned new analysis to understand the challenges of reducing emissions in homes which are expected to be among the hardest to decarbonise (e.g. heritage buildings).
- **Agriculture.** We commissioned new research to identify additional non-CO_2 emissions reduction in agriculture, focusing on a range of measures to reduce non-CO_2 emissions from livestock.
- **Transport.** We commissioned research to develop cost estimates for the refuelling infrastructure likely to be required by zero-emission heavy goods vehicles (HGVs) for three potential technology options: hydrogen HGVs; electric HGVs accompanied by on-road catenaries to recharge the vehicles as they drive; and electric HGVs accompanied by extremely fast high-powered charging infrastructure.
- **Aviation.** Jointly with the Department for Transport, we commissioned a project assessing potential to reduce aviation emissions through new engine and aircraft designs, changes to airlines' operations, and improvements to air traffic management.
- **Societal change.** We have worked with an expert on social and behavioural change to review the evidence for shifts in consumption patterns and use of technologies, and the potential implications for how these can be unlocked through policy interventions.

(i) Reducing emissions from electricity, heating, surface transport, industry, waste, F-gases, and shipping to very low levels

Reinforcing our previous analysis, we have identified potential to reduce emissions from electricity generation, heating in buildings, surface transport, industry, waste, F-gases, and shipping to very low levels by 2050:

- **Electricity generation.** The Further Ambition options we consider for electricity generation result in emissions of 3 $MtCO_2e$ in 2050, which are residual emissions from CCS facilities operating as part of a fully decarbonised electricity supply. Fully decarbonising electricity supply can be achieved through increasing the share of renewables and firm low-carbon power from around 50% today to around 95% in 2050, whilst meeting additional demand for electricity from electric vehicles and heat pumps. Decarbonised gas – via CCS and hydrogen

– will be required for the remaining 5%. Renewable generation could be four times today's levels, requiring a sustained and increased build out between now and 2050, complemented by firm low-carbon power options such as nuclear power and CCS (applied to biomass or gas-fired plants). Overall, these changes could be made at an average abatement cost of around £20/tCO_2e in 2050.

- **Heating in buildings.** Deploying the Further Ambition options for heating buildings would result in emissions of 4 MtCO_2e in 2050. This requires roll-out of technologies such as heat pumps, hybrid heat pumps and district heating in conjunction with hydrogen, and new smart storage heating, combined with high levels of energy efficiency. New homes should not be connected to the gas grid from 2025. By 2035 almost all replacement heating systems for existing homes must be low-carbon or ready for hydrogen, such that the share of low-carbon heating increases from 4.5% today to 90% in 2050. These changes could be made at an average cost of around £140/tCO_2e. Remaining emissions in 2050 largely come from a small proportion of homes which could be very expensive to treat (e.g. due to space constraints and the costs of the heating systems they require).
- **Surface transport.** The Further Ambition options we have identified for reducing emissions in surface transport lead to emissions of 2 MtCO_2e in 2050. This will need all cars and vans to be electric by 2050, and for the vast majority of HGVs to be either electric or hydrogen powered. These changes are likely to be cost saving overall. Remaining emissions in 2050 are largely from a small level of conventionally powered HGVs and rail freight.
  - Getting all cars and vans to be electric by 2050 will require all sales to be pure battery electric by 2035 at the latest. These are likely to be significantly cost-saving compared to conventional vehicles. It would require 3,500 rapid and ultra-rapid chargers near motorways to enable long journeys and 210,000 public chargers in towns and cities. Today in total there are 21,000 public chargers of all speeds.
  - HGVs are harder to decarbonise. Our new research suggests that it is possible to get to very-low emissions by 2050 by switching most of these vehicles to hydrogen power or electrification. A hydrogen-based switchover would require 800 refuelling stations to be built by 2050 and electrification would need 90,000 depot-based chargers for overnight charging.
- **Industry.** We have undertaken a fuller analysis of emissions reduction potential in the industry sector (Box 5.3). We previously classed this as a 'hard-to-treat' sector, but have identified potential to reduce emissions to low levels. The Further Ambition options for industry would lead to emissions of 10 MtCO_2e in 2050, at an average abatement cost of around £120/tCO_2e. This is achievable through a combination of wider deployment of CCS, hydrogen, and electrification. There is also potential for additional savings through resource efficiency. The remaining emissions in the Further Ambition scenario mostly come from smaller non-combustion processes and uncaptured emissions where CCS is deployed.
- **Waste.** We have identified some limited opportunities to go beyond the Core options in the waste sector. The Further Ambition options involve additional emissions reduction from treatment of waste water, and by 2025 stopping sending biodegradable waste to landfill and increasing recycling rates to 70% across the UK. These result in waste emissions of 7 MtCO_2e in 2050. Some remaining emissions in 2050 are likely to be unavoidable from continuing waste degradation at legacy landfill sites.

- **F-gases.** The Further Ambition options include additional emissions reduction from a transition to lower-emission medical inhalers and tighter standards in the refrigeration, air conditioning and heat pump sector (e.g. through a switch to low-GWP refrigerants and measures to reduce leakage). These changes could be marginally cost saving but are of small size. Overall, this leads to F-gas emissions of around 2 $MtCO_2e$ in 2050.
- **Shipping.** The Further Ambition options in shipping are the same as the Core scenario (i.e. improved energy efficiency and ship operations, and use of alternative fuels). However, they are deployed significantly further and faster. This leads to shipping emissions of less than 1 $MtCO_2e$ in 2050. It could be achieved at a cost of around £200/tCO_2e, although it would require a globally coordinated transition to support a new fuelling infrastructure.

Our Further Ambition measures would not reduce emissions completely to zero in any of these areas. However, if they were applied none of these sectors would remain as a significant source of emissions. Across these sectors emissions would be reduced from 430 $MtCO_2e$ today (having been around 745 $MtCO_2e$ in 1990) to 29 $MtCO_2e$ in 2050.

Box 5.3. New evidence on potential to reduce emissions from industry

The Further Ambition scenario for industry would lead to remaining emissions of 10 $MtCO_2e$ in 2050. This compares to remaining industry emissions of 45 $MtCO_2e$ in 2050 in the most ambitious scenario we considered in our fifth carbon budget advice, which was aligned to the UK's current target for at least an 80% reduction in GHG emissions by 2050 relative to 1990. This reflects the increased ambition of the potential target and an updated evidence base.

The improved evidence base has drawn on work including:

- The Committee's 2018 Hydrogen and Biomass reviews.
- A 2018 study on fuel switching by Element Energy and Jacobs for BEIS.
- Reviews of the evidence on the abatement potential of resource efficiency, along with the potential to reduce emissions from off-road mobile machinery and smaller non-combustion process emissions sources.
- New work we commissioned from Element Energy and the Sustainable Gas Institute in two parts.
  - New research on the costs and abatement potential for measures to cut emissions from fossil fuel production and fugitive emissions.
  - An extension to the 2018 Element Energy and Jacobs fuel-switching study to consider the potential of low-carbon fuels to abate some industrial combustion emissions that the previous study had not considered.

In combination, these studies have improved the coverage of our evidence base. In particular, by increasing our understanding of the opportunities for abatement from smaller industrial sectors, fossil fuel production and fugitive emissions, and of the use of hydrogen.

Based on this improved evidence, our Further Ambition scenario for 2050 includes abatement from:

- CCS in sectors with non-combustion process emissions (cement, lime, ammonia and glass) and sectors which use 'internal' fuels produced by their feedstock (the iron, petrochemicals, refining and oil and gas production sectors). This represents around 24 $MtCO_2e$ of abatement in 2050.
- Widespread deployment of hydrogen, electrification or bioenergy for stationary industrial heat/combustion in those manufacturing sectors not treated with CCS as identified above and for off-road mobile machinery. This represents around 27 $MtCO_2e$ of abatement in 2050.

Box 5.3. New evidence on potential to reduce emissions from industry

- Improvements in resource and energy efficiency, along with material substitution, representing 14 $MtCO_2e$ of abatement in 2050. If these measures were not delivered the emissions could largely be reduced by other means, but at considerably higher cost.
- Reduced methane venting and leakage through gas recovery, reduced emissions completions, continuous monitoring, flaring where needed and conversion/closure of parts of the gas grid. This represents around 4 $MtCO_2e$ of abatement in 2050.

We estimate that the annual cost for cutting industrial emissions to 10 $MtCO_2e$ using the measures above would be £8 billion in 2050, compared to a theoretical scenario with no climate change policy action at all. This is a challenging scenario that requires a fast pace of deployment of low-carbon technology in comparison to the natural turnover rate of industrial assets. However, it is supported by recent work by the Energy Transitions Commission which found it is technically and economically feasible to achieve net-zero emissions in heavy industry by mid-century.

Sources: Element Energy and Jacobs (2018) *Industrial fuel switching market engagement study*; Element Energy (2019) *Assessment of options to reduce emissions from fossil fuel production and fugitive emissions*; Element Energy (2019) *Extension to fuel switching engagement study*.

(ii) Reducing emissions from hard-to-treat sectors – agriculture and aviation

Agriculture and aviation stand out in our analysis as sectors where there are limited options currently available to reduce emissions. For agriculture that reflects some of the fundamental biological processes involved. For aviation it reflects the high energy-density required for aviation fuel.

We have identified some potential to reduce emissions from agriculture and aviation further beyond the Core scenario, but these sectors are likely still to be significant emitters in 2050.

- **Agriculture, land use, and forestry.** Deploying the Further Ambition options for agriculture, land use and forestry would lead to emissions of 24 $MtCO_2e$ in 2050. Of these 26 Mt are from agriculture, while land use and forestry is a sink of 2 $MtCO_2e$.
  - **Agriculture.** We have identified potential for more ambitious uptake of the measures included in the Core scenario. We have also included additional potential from on-farm measures targeting livestock emissions (e.g. improved breeding and diets). It is difficult to reduce agriculture emissions to near-zero given the inherent biological processes and chemical reactions arising from crops, soils and livestock. Most remaining emissions are non-CO_2, particularly methane.
  - **Land use and forestry.** Our Further Ambition options for land use and forestry are based on our land use report published in 2018,[146] aligning to the multi-functional land use scenario. This includes a 20% reduction in consumption of beef, lamb, and dairy which is replaced by an increase in consumption of pork, poultry, and plant-based products. In combination with an improvement in arable yields and grazing intensity this would release land for increased afforestation (e.g. of 30,000 hectares per year), peatland restoration (e.g. to 55% of land area restored compared to 25% today), and the growing of energy crops (e.g. to 700,000 hectares by 2050 from very low levels today). Emissions

[146] CCC (2018) *Land use: Reducing emissions and preparing for climate change.*

from land use also include those from the cultivation of biomass used for GHG removal (see below).

- **Aviation.** We have identified technical potential for additional emissions reduction beyond the Core scenario, including through more ambitious uptake of the Core options plus some use of hybrid-electric aircraft from the 2040s, and from reductions in design speeds of aircraft. However, the Further Ambition options for aviation would still result in emissions of 31 $MtCO_2e$ in 2050. This is because a fully zero-carbon plane is not anticipated to be available by 2050, particularly for long-haul flights which account for the majority of emissions.

In total these harder-to-treat sectors would still have emissions of 55 $MtCO_2e$ in 2050 in this scenario, down from around 75 Mt in both 1990 and 2017.

(iii) Removal of CO_2 from the atmosphere

Greenhouse gas removal (GGR) is a term that covers a range of options to remove greenhouse gases – primarily CO_2 – from the atmosphere. Our advice in this area draws on our updated assessment of the role of sustainable biomass published in our 2018 report *Biomass in a low-carbon economy* (Box 5.4). Our Further Ambition scenario includes established natural ways of removing CO_2 and less-established options:

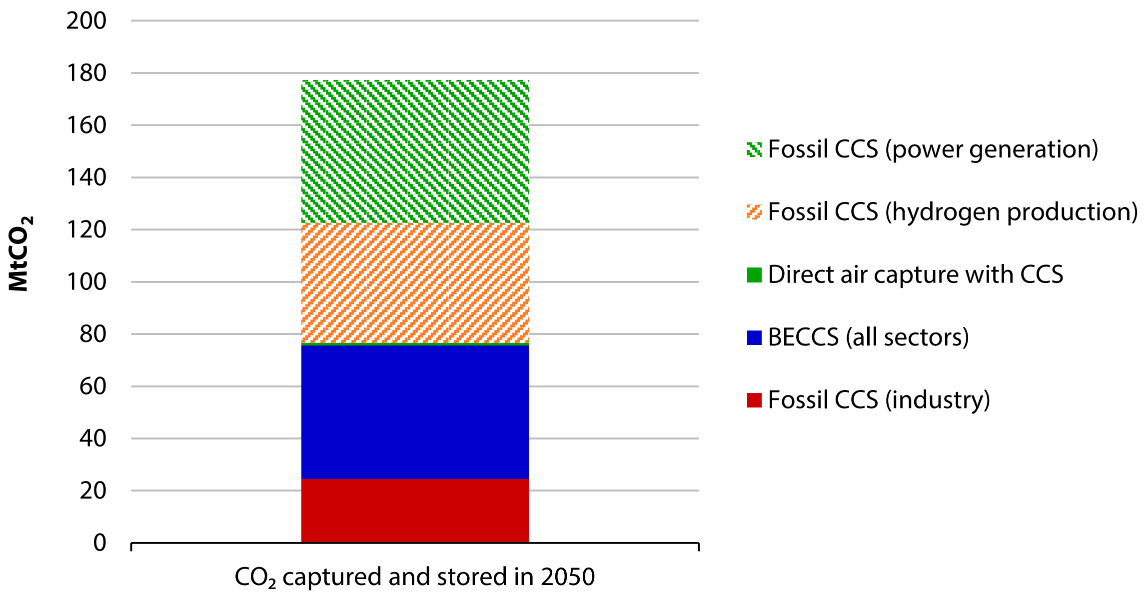
- **Established 'land-based' removals.** Afforestation and other land-management practices (e.g. peatland restoration) are well-established ways of using land in a way that achieves an overall absorption of CO_2 from the atmosphere which then remains in the land over the long-term. Afforestation of around 30,000 hectares per year (increasing woodland cover from the current 13% of UK land area to 17%), combined with an increase in active woodland management, increases the net forestry sink to 22 $MtCO_2e$ per year by 2050. We account for these removals in the Land Use sector (i.e. without them land use would be a significant emissions source rather than a small sink).
- **Wood in construction.** Wood-based products and timber frame construction has an established history in the UK. It provides a store of carbon on the timescale of decades to centuries in the built environment. Its potential emissions saving is relatively small at 1 $MtCO_2$ of removals in 2050, as it is limited by the rate at which buildings are constructed. The Further Ambition option assumes that 40% of houses and flats are built with a timber frame (up from under 30% today). The costs of using wood as a construction material are essentially negligible as approximate cost-parity exists with alternative construction methods.
- **BECCS.** The level to which sustainable low-carbon biomass production can be increased is finite, given land constraints and competition from other uses (e.g. food production). It is therefore important to pursue ways of using this finite resource that maximise its contribution to emissions reduction. This means combining bioenergy with CCS, whether for power generation, hydrogen production or production of biofuels for areas that cannot move away from hydrocarbon fuels (e.g. aviation). Bioenergy is already used in the energy system, while CCS has been proven in a number of other countries. However, to date they have not been combined at scale.
  - We have assumed overall bio resource available to the UK of around 200 TWh (of which only 17% is imported and the rest is produced in the UK). This is equivalent to around 10% of UK primary energy consumption in 2050.

- Of this, 173 TWh goes into BECCS in 2050, providing 51 $MtCO_2$ of removals. The energy generated provides 6% of power generation, as well as 21 TWh of biofuels for aviation and buildings off the gas grid, saving a further 5 $MtCO_2e$ in those end-use sectors. Our estimate of BECCS costs is based on it being used in the power sector at a cost of £158/tCO_2e, based on a mix of domestically-grown and imported feedstocks.
- A small amount of biogas (14 TWh) is assumed to be available after reductions in food waste, of which half is assumed to be used in gas-fired CCS power generation and the other half is used to displace natural gas in industry (79%) and buildings (21%).

- **DACCS.** CO_2 can also be removed from the atmosphere by stripping it from the air and sequestering it using CCS. Capturing CO_2 from the air is challenging, requiring significant energy input given the low atmospheric concentration of CO_2.
  - Our analysis assumes costs based on DACCS being co-located with BECCS plants, which provides access to the necessary heat, power and CO_2 infrastructure. Different approaches are being pursued, and the technology is generally at the pilot scale.
  - In the Further Ambition scenario we assume some, but very limited, deployment of DACCS at a scale sufficient to drive learning-by-doing. Current DAC designs are modular and the technology is inherently scalable (e.g. it is not constrained by the need to access land to plant trees). If breakthroughs can be made it could make the overall net-zero challenge materially easier.
  - This small-scale deployment removes 1 $MtCO_2$ from the atmosphere at an assumed cost of £300/tCO_2.

CCS plays a vital role in many GGR approaches. Although the UK has not yet made progress in deploying CCS at scale, it is well placed to do so and this should be a policy priority (see Chapter 6). Many other countries do not have access to the CO_2 storage potential that the UK does, so although resources (e.g. biomass, energy input to DAC) may have lower costs elsewhere the UK could still be a relatively good place to deploy these solutions. The Further Ambition scenario has up to 175 Mt total CO_2 captured and stored in 2050 (Figure 5.4).

Figure 5.4. Total CO_2 captured and stored in the Further Ambition scenario in 2050



Source: CCC analysis.

Notes: 1. The volumes shown here for CO_2 captured and stored for fossil CCS are based on the production of 148 TWh of electricity from gas CCS plants and 225 TWh of hydrogen from advanced gas reforming plants (see Chapter 2 of the accompanying Technical Report). However, as stated in that chapter, it is not possible to foresee the exact generation/production mix in 2050. Hence we denote these blocks in the chart with shading.

2. 'BECCS (all sectors)' covers the burning of biomass (including agricultural and forestry residues), waste wood, biomethane/biogas and the biogenic part of municipal and commercial and industrial waste (MSW/C&IW) in industry and for power generation, plus CO_2 captured and stored from the production of biofuels for aviation and burning in homes (bioLPG in off-gas hybrid heat pumps).

3. Fossil CCS for power generation and industry covers burning of fossil fuels, plus the non-biogenic part (46% of the total) of MSW/C&IW.

Box 5.4. The role of sustainable biomass

In 2018, the Committee updated its advice on the role of sustainable biomass in decarbonising the UK economy to 2050. It drew on the latest evidence on the circumstances in which biomass can be both low-carbon and sustainable. It set out scenarios and requirements for the future supply of sustainable biomass, together with an assessment of how this limited resource can be prioritised for the most valuable end-uses to maximise GHG abatement across the economy.

Approach

We take into account the full lifecycle emissions of biomass, including changes in land carbon stocks. The analysis was conducted in parallel to our report on UK land use, which forms the basis of the UK biomass supply scenarios. We define sustainability in broad terms to include biodiversity, ecosystem impacts (including flood mitigation, water and soil quality) and social issues such as impacts on food production and land tenure. The analysis to determine the most effective use of biomass throughout the economy draws on energy system modelling undertaken jointly with our 2018 report on Hydrogen, along with new research on non-energy uses of biomass - particularly wood in construction.

Findings

The work confirmed the view that harvesting and using biomass can play an important role in reducing emissions - provided that it is done as part of a system of sustainable land use. As a minimum this requires managing the carbon stocks in plants and soils so that they increase over time, including a concerted effort to reverse declines in forest cover where these are occurring and to build up stocks on managed land where they have been degraded by human activity.

There is scope to increase terrestrial carbon stocks and levels of sustainable harvested biomass both globally and in the UK. But stronger governance is needed to ensure this happens in practice:

- By applying good practice and minimising competition with food production, sustainable biomass can be produced for use in construction, energy production and other bio-based products.
- For wood in construction, there is the potential to increase volumes of sustainable sawn log so that annual carbon sequestration in new UK buildings rises for housing and non-residential buildings.
- At the same time, there is potential to increase production of UK sustainable low-grade biomass to meet between 5% and 10% of UK energy demands in 2050. At the lower end, this implies fully utilising the UK's biogenic waste sources, including maintaining today's levels of agricultural and forestry residues. At the upper end it requires increasing tree planting rates and planting over 1 million hectares of land with energy crops (around 7% of the UK's current agricultural land).
- Supplementing this with sustainable imports could increase biomass use to up to 15% of UK primary energy consumption by 2050, based on a UK 'fair share' of global sustainable resource.
- Using this in conjunction with CCS - either to produce hydrogen, in industry, for aviation biofuels or power - could sequester 20-65 $MtCO_2e$ in the UK by 2050.

Significant increases in biomass supply will only be possible with strong global sustainability governance. In the Biomass review we recommended:

- BEIS and DfT should update the sustainability criteria to reflect the growing evidence base in this area (e.g. Forest Research criteria). As a general rule, high-risk feedstocks (e.g. those from primary, high-carbon, highly biodiverse or slow-growing forests) should be regulated out and best practice encouraged (e.g. use of genuine agricultural and forestry residues, certain perennial crops grown on marginal land). They should also assess ways to incentivise a 'race-to-the-top' by rewarding performance over and above established thresholds.
- Ensuring that changes in terrestrial carbon stocks are fully accounted for in sustainability criteria. This means closing the loophole around stocks in managed forests by requiring that long-term

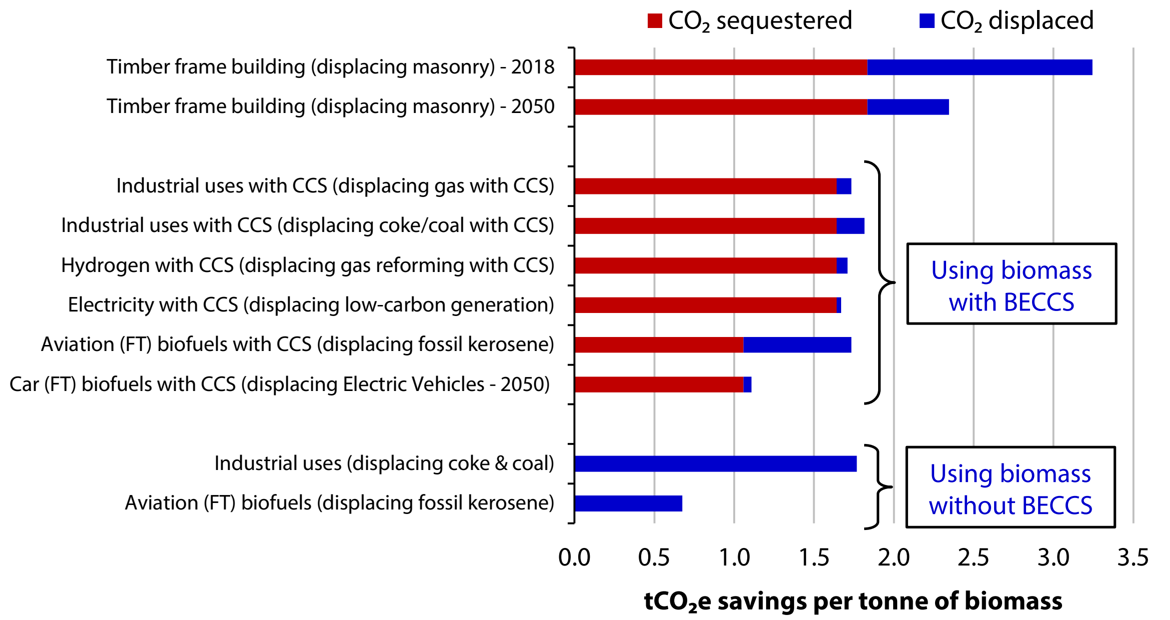
Box 5.4. The role of sustainable biomass

changes in forest carbon stock at landscape scale are captured in the calculation of climate impacts. The general principle is to avoid sourcing from areas where carbon stocks are falling. BEIS and DfT should also explicitly rule out harvest of whole forest carbon tracts exclusively for energy use, in line with best practice.

- Enhancing monitoring and reporting, including by making use of satellite mapping, geographically-specific datasets, track and trace initiatives and enhanced levels of soil carbon monitoring. The UK should lead this shift, including through high-quality independent monitoring and reporting of UK stocks and supply chains (and linking this to other data such as international forest inventories).
- Adopting a wider approach to managing risks, beyond the current approach of placing conditions on subsidy schemes. Sustainability criteria should be embedded in procurement and financing rules; broader strategic coordination of trade and development policy would be beneficial.

Ensuring that biomass is used in the most effective way is essential. This means that current uses will need to change so as to prioritise uses which sequester atmospheric carbon whilst also providing a useful energy service or product, for example wood in construction and BECCS (Figure B5.4). Government must design policies and support mechanisms consistent with this long-term best use, and avoid lock-in to sub-optimal uses in surface transport, buildings and single-use bioplastics.

Figure B5.4. Estimated GHG abatement across different biomass applications



Source: CCC (2018) *Biomass in a low-carbon economy*.
Notes: Shows estimates of GHG abatement provided by an oven dried tonne of biomass used in various sectors, considering an appropriate counterfactual (i.e. what we would expect it to be displacing, long-term).

Source: CCC (2018) *Biomass in a low-carbon economy*.

(iv) Summary of Further Ambition options

Table 5.1 summarises the extensive roll-out of abatement measures across the economy in the Further Ambition scenario. Figure 5.5 illustrates what this means for remaining emissions, by sector and by gas.

- Together the combination of Core and Further Ambition options would cut emissions by 96% from 1990 levels, to 35 $MtCO_2e$ in 2050. This is 93% below 2017 levels. Remaining emissions would largely be from agriculture and aviation. CO_2 emissions would be slightly below net-zero in this scenario, whilst emissions of all long-lived gases would be slightly above net-zero.
- These estimates reflect the updated evidence for emissions from peatland (at the high end), but, in line with current emissions estimates across the economy, use the GWP weightings from the IPCC's Fourth Assessment report (see Box 5.1). If the GWP weightings from the Fifth Assessment are used instead then the estimate for the remaining emissions would be 37-45 $MtCO_2e$. This reflects the high share of methane remaining in the scenarios, for which the weighting changes in AR5. The range reflects the two proposals that the IPCC has made (and between which the international community have not yet expressed a preference).

Around 10% of the emissions reduction in the Further Ambition scenario involves a significant change in societal and consumer behaviours, for example an acceleration in the shift towards healthier diets with reduced consumption of beef, lamb, and dairy products (Figure 5.6). However, over half of the emissions reduction requires some change from consumers, for example to purchase an electric car or install a heat pump.

Considerations on how the Further Ambition scenario can be delivered, including the infrastructure and policy challenge, is set out in Chapter 6.

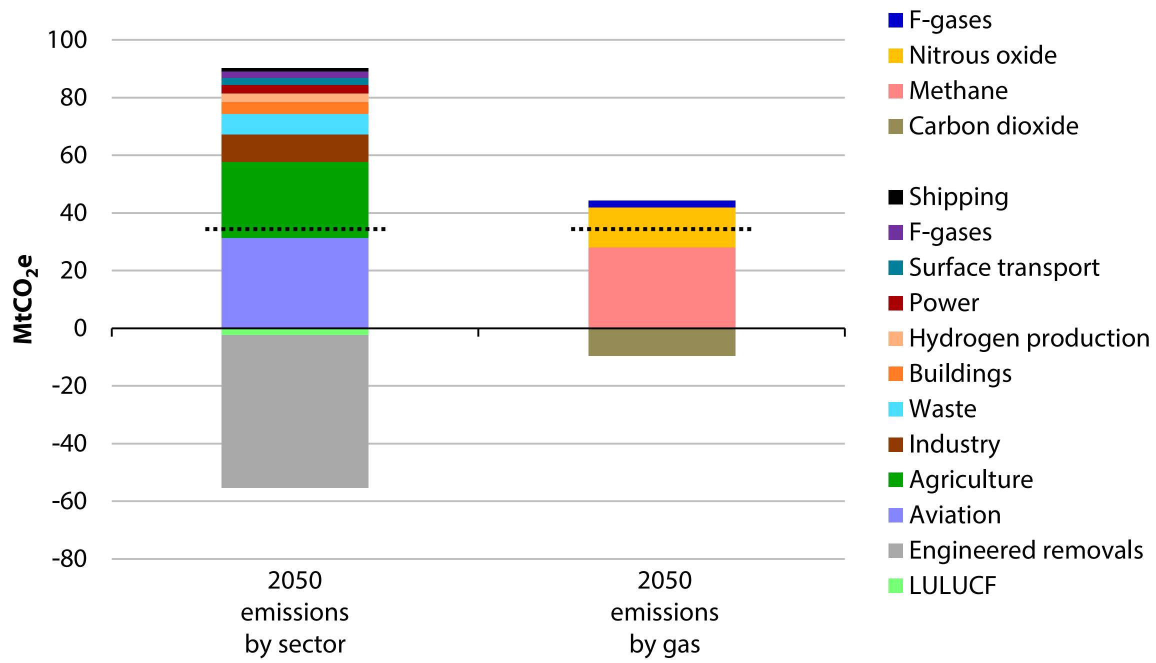
Costs of delivering the Further Ambition scenario are higher compared to the Core scenario, given that it removes nearly all GHG emissions from the economy. We set out our analysis of costs and benefits in Chapter 7.

Table 5.1. Measures required under the Core and Further Ambition scenarios in 2050

Sector	Measure	2017	2050 scenario	
			Core	Further Ambition
Power	Share of low-carbon generation	50%	97%	100%
	Low-carbon generation (TWh)	155	540	645
Buildings (Share of low-carbon heat*)	Low-carbon heat in existing homes	4.5%	80%	90%
	Low-carbon heat in non-residential buildings		100%	100%
Industry	CCS**	0%	50%	100%
	Low-carbon heat***	<5%	10%	85%
Surface transport (Share of fleet)	Battery electric cars and vans	0.2%	80%	100%
	Electric and hydrogen HGVs	0%	13%	91%
Aviation	gCO_2 per passenger-km	110	70	55
	Sustainable biofuel uptake	0%	5%	10%
Shipping	Ammonia uptake	0%	75%	~100%
Land use and forestry	Afforestation (% of UK land area)	13%	15%	17%
	Peatland restoration (% area in good condition)	25%	n/a	55%
Engineered removals ($MtCO_2$)	BECCS	0	20	51
	Direct air capture	0	n/a	1

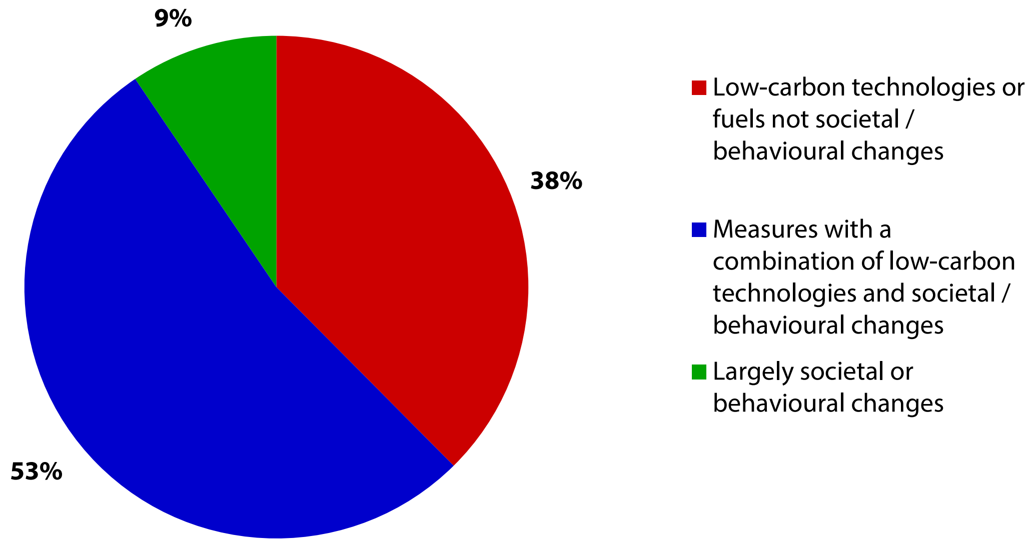
Source: CCC analysis.
Notes: *2017 represents share of heat from low-carbon sources, 2050 represents the number of existing homes with low-carbon heat. **In manufacturing sectors with process emissions or internal fuel use (fuels produced using the industries' feedstock). ***Excluding in sectors with process emissions or internal fuel use (2017 and 2050 Core scenario exclude existing electricity use).

Figure 5.5. Remaining emissions in the Further Ambition scenario by sector and gas (2050)



Source: CCC analysis.
Notes: Dotted line shows net emissions in 2050, taking into account negative emissions. Figure includes high estimate of additional peatland emissions and is based on the current inventory GWPs (see Box 5.1).

Figure 5.6. Role of societal and behavioural changes in the Further Ambition scenario



Source: CCC analysis.

(d) Speculative options that could cut emissions further but are highly uncertain

We have identified a range of options that are more speculative than those in the Further Ambition scenario. These Speculative options currently have very low levels of technology readiness, very high costs, and/or significant barriers to public acceptability. It is very unlikely they would all become available by 2050 but some contribution from Speculative options is likely and will be required in order to reach net-zero GHG emissions domestically.

Speculative options that we consider include:

- **Further societal and behavioural changes.** There is potential for larger changes in consumer choice, particularly in sectors where there are significant remaining emissions in 2050 (i.e. agriculture and aviation).
  - **Agriculture.** There is potential for further changes in diets beyond the Further Ambition scenario, by further reducing meat consumption. The Speculative option reflects reductions in livestock farming in line with a 50% reduction in beef, lamb, and dairy consumption compared to current levels. This would be closer to, but still not meet, the Government's current healthy eating guidelines. If consumption levels remain higher, this scenario could still be met with a role for alternative sources of protein grown off-farm (e.g. synthetic meat). This could save an additional 11 $MtCO_2e$ in 2050 beyond the Further Ambition scenario.
  - **Aviation.** The Further Ambition scenario allows a 60% increase in passenger demand above 2005 levels by 2050 (demand is currently around 30% higher). An additional reduction in emissions could be possible if demand were to be lower than this level (e.g. as an illustration, 20-40% above 2005 levels would imply a further saving in emissions of 4-8 $MtCO_2e$). This could, for example, reflect a future change in consumer preferences and social norms, or more ambitious policy to limit growth in demand.
- **More extensive changes to land.** The diet changes under the Further Ambition scenario release land which can be used to increase afforestation rates. It may therefore be possible to achieve higher rates of afforestation than we assume in the Further Ambition scenario. Additional peatland restoration may also be possible.
  - Increasing the tree planting rate from 30,000 hectares per year in the Further Ambition scenario to 50,000 hectares per year with the Speculative option would save an additional 11 $MtCO_2e$ in 2050. By 2050 UK forest cover would be increased to 19%.
  - Land released from diet change could also be used for more peatland restoration and the growing of more energy crops and short-rotation forestry, delivering a further 3.5 $MtCO_2e$ and 4 $MtCO_2e$ of abatement respectively by 2050.
  - Additional emissions reduction from peatland that does not require land to be released out of agricultural production is possible beyond the Further Ambition scenario, through better use of lowland agricultural peatland (e.g. seasonal management of the water table). This could save an additional 1.5 $MtCO_2e$ in 2050.
- **Removals.** Our Further Ambition scenario has removals from wood in construction, BECCS and a small deployment of DACCS, but more ambitious uptake of these may be possible as well as more speculative options including enhanced weathering and biochar.
  - **BECCS.** More ambitious deployment of BECCS may be possible, if available biomass resource turns out to be higher than our assumed level of around 200 TWh. The Committee's 2018 report on Biomass presented scenarios for the UK share of global

biomass resources of around 100-300 TWh, depending on land availability and governance arrangements internationally. If the biomass resource were at the upper end of this range and all of this extra resource were to be used for BECCS, this would provide an extra 32 $MtCO_2$ of removals.

  - **DACCS** does not have a particular limit that constrains its potential scale of deployment. The scale of its deployment therefore depends on its costs relative to alternatives and the pace at which the industry can scale up. The 2018 Royal Society and Royal Academy of Engineering report on greenhouse gas removal[147] included 25 $MtCO_2$ of DACCS in the UK. That would require energy input of around 50 TWh (equivalent to the output of up to 10 GW of offshore wind), an increase of around 14% in use of CCS compared to our Further Ambition scenario and an extra annual investment of around £4 billion per year through the 2040s to pay for DAC facilities with a land footprint of the order of 50 km^2.
  - **Enhanced weathering** is a process that entails finely crushing up rocks and spreading them on land so that the fragments of rock react with CO_2 in the air, removing it from the atmosphere. This option has not yet reached a stage that provides confidence that it can be done effectively without significant adverse impacts, but further research should be pursued to determine whether it can be. We do not include it even as a Speculative option in this report.
  - **Biochar** entails treating biomass in a way that enables it to store bio-carbon in a stable form that is resistant to decomposition when mixed with soil. While this option is more developed than enhanced weathering, it is not yet mature and also competes for finite sustainable biomass resources with other options (e.g. BECCS) that are expected to be more effective in permanently sequestering the carbon in biomass. We therefore do not include a specific estimate of biochar potential as a Speculative option.

- **Synthetic fuels.** These may be technically possible but will be thermodynamically and economically challenging, and therefore currently appear likely to be significantly more expensive than other Speculative options. If these challenges could be resolved and scaled-up globally then synthetic fuels could potentially have a large role.
  - Synthetic fuels are produced by combining a CO_2 input source (e.g. from DAC) with a large amount of zero-carbon energy (e.g. in the form of stored hydrogen), in order to produce a significantly smaller amount of hydrocarbon energy. The CO_2 is then released to the atmosphere on combustion of the fuel. These multiple steps make it both a thermodynamically and economically inefficient process.
  - For example, to produce 115 TWh of synthetic jet fuel, which is the requirement after our Further Ambition options in aviation have been applied, would require around 200 TWh of zero-carbon electricity. This is equivalent to a further 33% of the total UK electricity generation requirements under Further Ambition.[148]
  - Furthermore, once CO_2 has been captured the extra costs of sequestering it are relatively low, suggesting that is likely to be a cheaper route to achieving the same emissions reduction than converting it into a hydrocarbon and using it to displace remaining fossil fuels like kerosene.

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[147] The Royal Society and the Royal Academy of Engineering (2018) *Greenhouse gas removal.*

[148] Analysis provided by the Royal Society. Underlying assumptions are listed in the assumptions log which accompanies this report.

– Therefore, although there is a large technical potential for synthetic fuels and the prospect of synthetic fuels is attractive to businesses looking to reduce their own emissions rather than offset them through removals, the challenges of overcoming the very difficult production and economic barriers make this a Speculative option.

– We illustrate potential for emissions reductions of up to around 45 $MtCO_2e$ should these barriers prove surmountable, based on the remaining emissions in our scenarios from combusting fossil fuels without CCS.

- **Higher CCS capture rates.** The Further Ambition scenario assumes that 95% of CO_2 is captured when CCS is applied in electricity generation, industry, and for hydrogen production. The Speculative option assumes a higher capture rate (99%), which would save an additional 7 $MtCO_2e$. Though uncertain, higher capture rates are potentially possible without increasing costs significantly.[149]
- **Wider hydrogen roll-out.** Hydrogen is rolled out extensively in the Further Ambition scenario. It could be rolled out further, and faster, across industry, to replace residual gas use in buildings, and for use in trains. These currently appear relatively challenging so we only include them as a Speculative option. Together they could save a further 7.5 $MtCO_2e$ in 2050.

It is possible that other currently unknown opportunities could arise even beyond these Speculative options. However, given timeframes required to commercialise and deploy options, it is unlikely they would be able to make a major contribution to reducing emissions by 2050.

3. Getting to net-zero UK GHG emissions

Reducing UK GHG emissions to net-zero by 2050 will require all of the Core and Further Ambition options and some of the Speculative options. In this section we set out three illustrative mixes to achieve that and then compare these to what is needed by the UK's current 2050 target for an 80% reduction in emissions relative to 1990.

(a) Getting to net-zero GHG emissions in 2050

Together all the Core and Further Ambition options lead to a 96% reduction, meaning that 33 to 45 $MtCO_2e$ of additional emission savings would be needed from the Speculative options (with the range reflecting the uncertainties in the emissions accounting set out in Box 5.1).

The gap to net-zero GHGs could be closed through deeper roll-out of Further Ambition options, through further deployment of greenhouse gas removals, or through use of synthetic fuels (Figure 5.7):

- **Deeper roll-out of Further Ambition options.** This includes further changes in demand (e.g. in aviation and in diets), land use (e.g. afforestation and peatland management), higher CO_2 capture rates for CCS (i.e. across electricity generation, industry, and hydrogen production), and wider, and faster, deployment of hydrogen across buildings, industry, and transport. Together these could save up to a further 56.5 $MtCO_2e$ in 2050 which would be sufficient to get to net-zero GHG emissions overall.
- **Engineered removals.** Our Further Ambition scenario has a level of BECCS in line with a fair UK share of sustainable global biomass resource, and limited deployment of DACCS (i.e. 1 $MtCO_2e$ in 2050). There could be potential to deploy both these options to a greater extent,

[149] IEAGHG (2019) *Towards zero emissions CCS.*

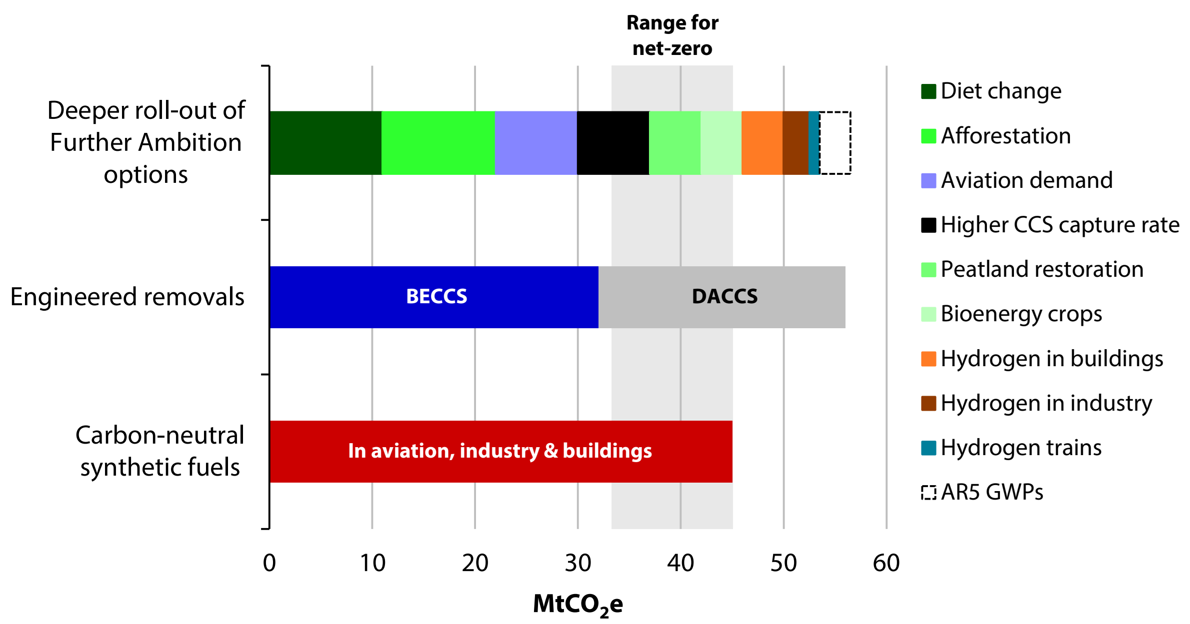
such that up to around 56 $MtCO_2e$ further emissions savings could be available. A combination of these additional options could therefore fill the gap to reaching net-zero GHG emissions.

- **Synthetic fuels.** These may be technically possible but will be thermodynamically and economically challenging, requiring considerable energy inputs, and therefore likely to be significantly more expensive than other Speculative options. One pathway to a net-zero scenario in the UK would involve these challenges being overcome, with synthetic fuels being scaled-up globally to reduce emissions from the remaining fossil fuel combusting sectors to zero.

These scenarios highlight the challenge of delivering across all areas, including currently Speculative options, in order to reach net-zero GHG emissions by 2050. Developing a sufficient range of the Speculative options will also be important to provide a backup in case some other options fail to deliver fully and as a contingency given uncertainty in projections of future emissions (Box 5.5).

Alternative ways of getting to net-zero emissions have been suggested (Box 5.6). Specifically, some scenarios rely on widespread use of synthetic fuels to decarbonise some sectors (e.g. aviation). Such a strategy may be feasible but is likely to make it harder and more costly to get to net-zero GHG emissions overall, given the additional inefficiencies and costs.

Figure 5.7. Additional abatement potential from Speculative options in 2050



Source: CCC analysis.
Notes: Shaded area reflects range for additional emissions reductions required beyond the Further Ambition scenario to get to net-zero emissions in 2050 (i.e. 33-45 $MtCO_2e$). AR5 GWPs area reflects that emissions and emission savings would be higher with higher GWPs, consistent with the upper end of the shaded area.

Box 5.5. Uncertainty in emission scenarios

Key uncertainties for future emissions include economic factors, changes in society and behaviours, the rates at which technologies become available, and their costs and emissions reduction potential:

- **Economic factors.** These include the rate of economic growth and the level of future fossil fuel prices, as well as demographic factors such as population. Our assumptions for future economic growth are based on the Office for Budget Responsibility's central projection, and we use the UK government’s fossil fuel price projections. To the extent that economic growth or population turn out higher than expected, or fossil fuel prices lower, this would potentially lead to higher emissions and therefore more take-up of low-carbon technologies and behaviours would be required.
- **Social and behavioural factors.** Uncertainty over these relates to the level of demand for goods and services, and how consumers react to new technologies and options for reducing emissions. Both of these can be influenced by changes in preferences and tastes, at the individual and societal level. These preferences can change relatively quickly but are difficult to predict.
- **Technology development, costs, and emissions reduction potential.** Our scenarios take into account the range of known options for reducing emissions, and allow for future innovation to improve performance and reduce costs of these options. However, there is uncertainty about exactly which options will become fully commercialised, and about exactly how far their performance will be improved and their costs will reduce.

Our scenarios take a conservative approach to these uncertainties and to the potential for emissions reduction. They do not assume unspecified technological breakthroughs or radical changes in consumer behaviour. They take into account known changes to the emissions inventory, and reflect conservative limits on deployment of new resources (e.g. biomass).

- **Changes to the emissions inventory.** In the coming years these include addition of emissions from peatland and changes to the Global Warming Potentials used to calculate emissions. These are expected to increase estimates of emissions, for the present day and back to 1990 (Box 5.1). We take these into account in our analysis, so that we do not underestimate the reductions needed.
- **Technology.** Our scenarios are based on currently known technologies and options to reduce emissions. We do not assume innovation produces unspecified breakthroughs to reduce emissions, or that technologies will be developed, commercialised and deployed on unrealistic timescales.
- **Resource deployment.** Our scenarios include wider use of biomass. Where this resource is deployed we assume overall demand is consistent with a sustainable level of supply. This means within the limit for a UK share of potential global sustainable resource, as identified in our 2018 report on *Biomass in a low-carbon economy*.

These uncertainties suggest that flexibility will be needed to respond if there are developments that make emissions reduction more difficult. There is also potential for some areas to develop more positively than expected (e.g. costs may fall faster, particularly with sustained widespread deployment backed by clear, stable, well-designed policies as has occurred, for example, in offshore wind). These would make targets easier to meet.

Box 5.6. Wider evidence on the opportunities for very deep emissions reductions

Many studies have been published since the Paris Agreement to explore ways that countries could pursue the deep decarbonisation required. We have reviewed these approaches in developing our own scenarios.

Our focus is on scenarios with specific actions that go beyond those in our previous publications and that are relevant to a developed country like the UK. Organisations who have published such studies include the Energy Transitions Commission (ETC) and the European Commission (EC).

- The ETC focused on ways to reach net-zero CO_2 emissions by mid-century in harder-to-abate sectors such as industry, freight transport and aviation. They identified a three-pronged approach: demand reduction for high-carbon goods such as steel; improved levels of energy efficiency; deployment of low-carbon options (CCS, hydrogen, and electrification).
- The EC presented two scenarios that achieve net-zero GHG emissions by 2050 using different approaches: a strong reliance on low-carbon technologies (including CCS and BECCS) or an envisaged change in consumer choices towards low-carbon options.

Both of these studies have many options in common with our scenarios:

- Large reductions in energy use due to the deployment of energy efficiency and resource efficiency measures, such as recycling and re-use of goods, improved design of vehicles and buildings and increased sharing of goods and buildings.
- Extensive switch to low-carbon fuels across most sectors, with major roles for both electricity and low-carbon hydrogen. The EC envisage electricity accounting for half of final energy consumption in 2050 and hydrogen accounting for 10%, compared to around 45% and 20% respectively in our scenarios.
- Lifestyle changes such as less growth in air travel[150] and a shift in diets[151] are incorporated into one of the EC scenarios.

However there are some fundamental divergences from our approach:

- Both the ETC and EC envisage a substantial role[152] for synthetic fuels in industry, transport and buildings. We class these as a Speculative option due to the additional energy required in their production (see Section 2 regarding synthetic jet fuel) and the lower efficiency of use compared to, for example, an electric motor. The EC also noted that this is a potential barrier.
- CCS has a key role in industry in both studies. However, the role for CCS in power generation is lower than the level we currently envisage, where BECCS and gas CCS plants potentially provide around a third of generation (see Chapter 2 of the Technical Report).
- Bioenergy: our approach is to preferentially use bioenergy in combination with CCS in order to maximise the level of negative emissions. However, both the ETC and EC have substantial volumes of bioenergy used without CCS: for example over half used for aviation fuel (ETC). Our analysis suggests that this is not the most effective use given the relatively low level of emissions reduction it achieves compared to use with CCS.

Sources: Energy Transitions Commission (2018) *Mission Possible*; European Commission (2018) *A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*.

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[150] A 70% growth in long-haul air transport activity (2015-2050) as opposed to 104% growth in current projections.
[151] Approximately 25% fewer calories from animal products, per capita, in 2050 compared to a baseline scenario without the proposed dietary changes.
[152] The EC scenarios envisage approximately 15% of final energy consumption from synthetic fuels.

(b) Scenarios for net-zero emissions compared to those for the existing 2050 target

We have set out scenarios for reaching a 100% reduction in GHG emissions compared to 1990 levels by 2050. These go beyond the currently legislated target for at least an 80% reduction.

Given the potential to meet the 80% target in different ways it is difficult to say exactly what is needed additionally to meet a net-zero GHG target. In one sense, the key difference is that an 80% target has the flexibility not to pursue some abatement options, whereas a net-zero target requires that all opportunities to reduce emissions are taken. There is still some flexibility in means (e.g. whether low-carbon power is from offshore wind or nuclear; whether buildings are heated by heat pumps or hydrogen), but not in ends – where low-carbon options are available, one of them must be used.

However, since our Core scenario is close to the 80% target, the additional Further Ambition measures give a good indication of the extra effort required for a net-zero GHG target, supplemented by some of the Speculative options. Key features are:

- **Heat for buildings should be decarbonised across the building stock,** including peak heat for buildings on the gas grid. Peak power generation must also be decarbonised.
- **Low-carbon hydrogen becomes a key option,** for industry, peak power, shipping and potentially for peak heat in buildings and for HGVs.
- **CCS, low-carbon hydrogen and electrification must be fully deployed in industry alongside efficiency.** These measures are no more expensive than similar applications in the power sector or in heating and can be deployed on a similar timescale, but policy design is more challenging, particularly given competitiveness concerns and the need to align changes with broader refurbishments (see Chapter 6).
- **HGVs should be decarbonised.** The best solution is not yet clear – hydrogen or electrification or a combination of the two. Technological progress is likely to be driven globally and some coordination will be required with connected markets in Ireland and mainland Europe.
- **Choices should shift towards healthier lower-carbon diets**, allowing a fifth of UK agricultural land to shift to tree planting, energy crops and peatland restoration that will also improve climate resilience and improve ecosystem services.
- **BECCS.** Sustainable biomass can make an important contribution, but in aiming for net-zero emissions it must be used in the most carbon-efficient ways (i.e. use of wood in construction and use of bioenergy with CCS).
- **Some further abatement will be needed** from either a material societal shift away from carbon-intensive goods and services, more radical changes in land use, extensive deployment of emerging technologies to directly remove CO_2 from the atmosphere, or some combination of these.

The changes required to reduce UK GHG emissions to net-zero would also support reductions in emissions outside the UK, by reducing the UK's imports of high-carbon goods and services (Box 5.7). It will be important to monitor estimates of UK consumption emissions closely and ensure that, as a minimum, the gap between consumption and territorial emissions does not widen. Should it do so this may require further UK action to reduce emissions.

Box 5.7. Consumption-based emissions

Emissions associated with the activities of UK residents can be measured in two main ways: on a territorial basis, which includes emissions produced solely within the UK's borders, or on a consumption basis which aims to cover emissions associated with UK activity and expenditure wherever it occurs in the world (and does not include the emissions from producing the UK's exports).

Consumption-based emissions were estimated to be around 70% higher than territorial-based emissions in 2016 (see Box 3.3 in Chapter 3). Consumption-based emissions have a higher uncertainty than territorial estimates given the need to estimate emissions across international supply chains.

The UK should ensure that action to reduce emissions within its own borders does not result in an increase in the imported part of its consumption emissions. Such an increase could occur due to either an increase in total UK consumption, or a transfer of activity to overseas (known as 'offshoring').

The Committee will continue to monitor emissions on a consumption basis as part of our regular progress monitoring. The Government should consider the cost-effectiveness of measures to cut emissions based on their effect on all emissions, not just those included in the UK territorial account.

Our Further Ambition options include a number of demand reduction measures, such as resource efficiency and dietary change, which target goods and services whose production may be more difficult to decarbonise. These include: fossil fuels, industrial products (steel, cement, and lime) and foods such as red meat and dairy products. This approach is taken primarily because these measures are a relatively low-cost way for the UK to achieve net-zero territorial emissions. However, the substantial import dependency of these goods and services means that these actions are also likely to reduce total UK consumption-based emissions. The UK's progress towards net-zero emissions on a territorial basis will contribute additionally towards reducing global emissions, since the carbon content of the UK's exported goods and services will be lower. Furthermore, the lower UK territorial emissions will reduce the consumption emission footprints of countries that import from the UK.

Figure B5.7 shows the estimated reduction due to our Further Ambition options, from 2016 to 2050, in the imported part of the UK's consumption-based emissions for the goods and services listed above. The total reduction is 18 $MtCO_2e$, or a 27% reduction compared to the level (64 $MtCO_2e$) in 2016. The drivers of this reduction are:[153]

- A 30% reduction in the tonnage of iron and steel, and a 26% reduction in cement, lime and plaster, consumed in the UK between 2016 and 2050. See Chapter 4 of the Technical Report for details.
- A 20% reduction in the amount of beef, lamb and dairy produce consumed in the UK between 2016 and 2050. Beef and lamb consumption are assumed to be replaced by pork and poultry products; dairy products by legumes and pulses. See Chapter 7 of the Technical Report for details.
- Lower consumption of fossil fuels[154] and imported bioenergy as a result of all Further Ambition options in aggregate. These reduce emissions from extraction and production of these fuels.
- We do not include additional emissions reductions from reduced growth in UK aviation. Only the departing flights are included in the UK's territorial emissions, but clearly fewer departing flights will also be associated with fewer arriving flights. These will be counted in the territorial emissions of the countries from which they depart and will help to reduce global emissions but may not count in the UK's consumption emissions.

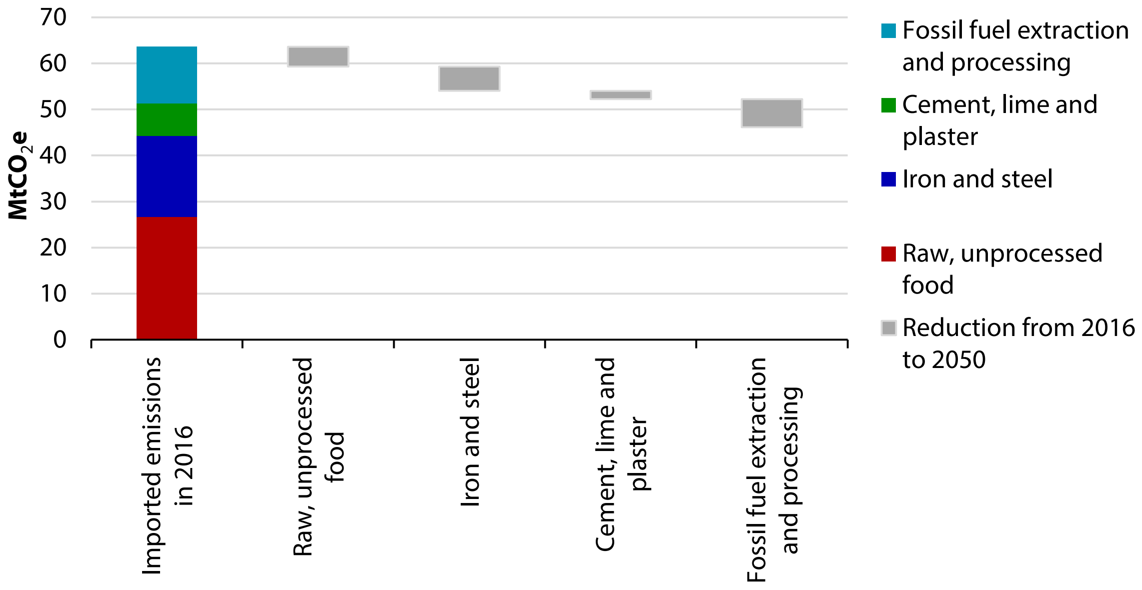
[153] There will be other drivers of change such as the UK's total consumption of such goods and services, and the proportion that are imported. However, it is beyond the scope of this analysis to estimate such changes.
[154] A 34% reduction in gas, 85% reduction in oil and 89% reduction in solid fossil fuels between 2016 and 2050.

Box 5.7. Consumption-based emissions

- We have not attempted to estimate the impact on consumption emissions of the increased investment in low-carbon technologies in our scenarios.
  - We note that the total change in UK investment is relatively small (an extra 1% of GDP, while total capital spend has ranged from 15% to 24% since 1990). Furthermore, the decarbonisation of UK industry implied by our scenarios demonstrates the potential to meet increased investment needs without large increases in emissions.
  - In our 2013 report *Reducing the UK's carbon footprint*, we carried out an assessment of emissions associated with the lifecycle[155] of low-carbon technologies included in our scenarios for power generation, surface transport and heating. We found that there were substantial savings in lifecycle emissions compared to fossil-fuel technologies. For example, we estimated that a battery electric car would have lifecycle emissions of less than 20 gCO_2e/km in 2050, compared to 125 gCO_2e/km for a petrol car in the same year.

Overall, it is likely that the reduction in UK territorial emissions in our scenarios would result in a larger reduction in global emissions, particularly if policy is developed with life-cycle emissions in mind.

Figure B5.7. Change in imported emissions for certain goods in the Further Ambition scenario



Source: 2016 statistics from University of Leeds analysis for Defra (2019) *UK's carbon footprint 1997-2016*; estimated changes 2016-2050 from CCC analysis.
Notes: Emissions shown are only those associated with the imports of: raw unprocessed food, iron and steel, cement/lime/plaster and fossil fuels. Hence the total in 2016 is less than that of total imported emissions. Aggregation of greenhouse gases uses GWPs from the IPCC 5th Assessment Report.

[155] Lifecycle emissions of a product are those caused directly and indirectly at each stage of its life, from the extraction of raw materials and manufacturing right through to its use and final re-use, recycling or disposal.

4. Feasible timing for the net-zero transition

Our analysis has focused on feasible reductions by 2050, but has also considered whether different sources of emissions could get to the same levels earlier, specifically by 2045.

- There are some areas in which it would be difficult to achieve as much decarbonisation by 2045 as by 2050, notably in buildings, industry and heavy transport, while afforestation will deliver less by 2045 than by 2050.
  - **Buildings and industry.** The need for strategic decisions, repurposing/upgrading of infrastructure and the turnover of the capital stock mean that it is difficult to see how these sectors could contribute as much emissions reduction towards an earlier date than 2050 for net-zero emissions.
  - **Heavy-duty transport.** For larger vehicles (e.g. lorries, coaches, and ships), there are challenges around developing zero-emissions vehicles, development of fuelling infrastructure and stock turnover that would mean that we would expect emissions to be significantly higher in any date prior to 2050.
  - **Afforestation.** The land-based carbon sequestration from afforestation increases over time as more new trees are planted. Our Further Ambition scenario removes 3 $MtCO_2e$ less in 2045 than in 2050.
- While in other areas (e.g. such as cars and vans, power generation, non-residential buildings, BECCS[156] and F-gases) the level of decarbonisation by 2045 could match that in our Further Ambition scenario by 2050, an earlier date for net-zero would increase risks of non-delivery across the range of areas.
- The scope for Speculative options to compensate for shortfalls in these sectors would also be impacted by an earlier net-zero date. As these options are currently not established, any deployment of them is likely to be towards the end of the period between now and 2050. Any reduction in the amount of time to roll them out could therefore reduce significantly the potential for their deployment in contributing to reaching net-zero emissions.

The Further Ambition scenario already falls slightly short of reaching net-zero GHG emissions by 2050, but the gap could be closed by Speculative options. Achieving net-zero significantly earlier than 2050 would be considerably more difficult due to higher emissions in still-decarbonising sectors, risks around the compressed timeframe, and reduced scope to deploy Speculative options.

Our assessment is that achieving net-zero GHG emissions domestically prior to 2050 is not credible for the UK as a whole.

[156] The main constraint on deploying BECCS by 2050 is the available sustainable biomass resource rather than roll-out rates.

5. Implications for Scotland, Wales, and Northern Ireland

(a) The challenge of reaching net-zero emissions in the devolved administrations

The devolved administrations have an important role to play in delivering the long-term decarbonisation scenarios for the UK. The possible range of technological and behavioural options discussed in this chapter are broadly similar across the whole of the UK. However, each devolved administration has unique characteristics that make certain options more or less effective, and bring different opportunities and challenges in achieving net-zero GHG emissions.

The options identified in our Further Ambition scenario above should be applied in each of the devolved administrations:

- Reduce emissions from electricity, heating, surface transport, waste, F-gases, and shipping to very low levels.
- Reduce emissions from hard-to-treat sectors – agriculture, industry, aviation.
- Remove CO_2 from the atmosphere through afforestation and other land-based sinks.

The key factors affecting the ability of devolved administrations to reach net-zero GHG emissions can be split into: different proportions of economic activity in hard-to-treat sectors; existing infrastructure that will impact decarbonisation in the long-term; the way land is used; opportunities for engineered removals (e.g. BECCS); and potential to deliver Speculative options.

Emissions in hard-to-treat sectors

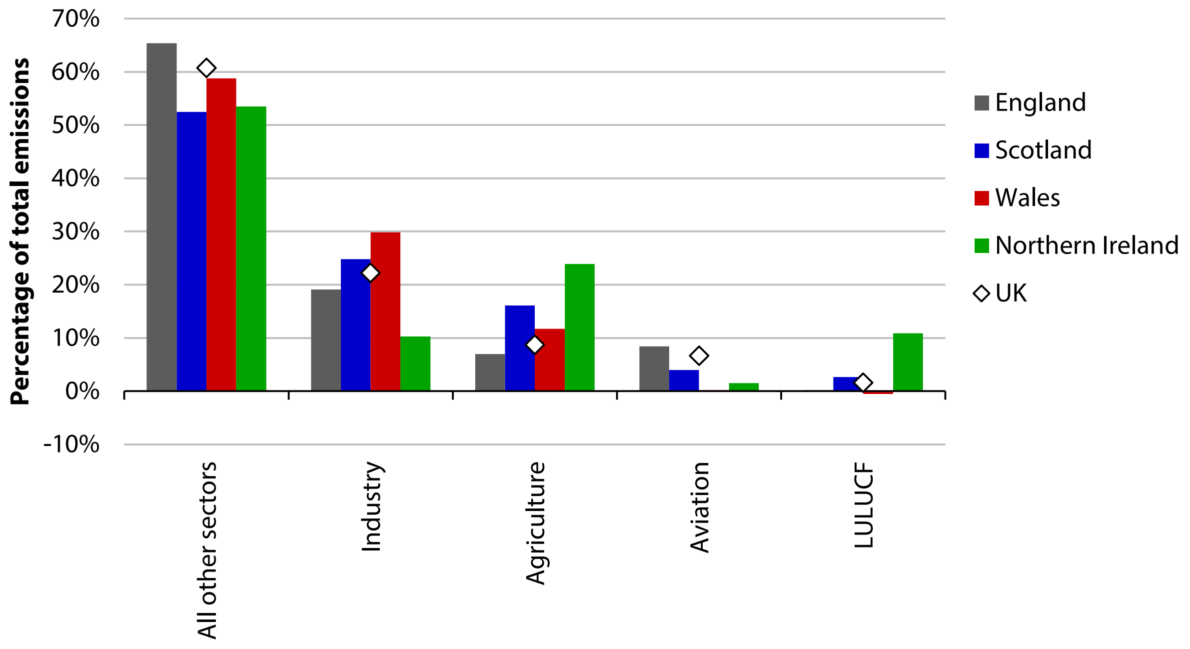
Current emissions from hard-to-treat sectors are different in each devolved administration (Figure 5.8). Higher or lower shares of current emissions in these hard-to-treat sectors will likely result in higher or lower residual emissions after all mitigation measures have been carried out.

- **Agriculture.** All three devolved administrations have a higher proportion of total emissions from agriculture compared to England.
- **Aviation.** Emissions from aviation make up a much lower share of total emissions in all three devolved administrations compared to the UK. The vast majority (around 90%) of all UK air passengers travel through airports in England,[157] with English airports acting as a hub for long-haul flights for passengers from all areas of the UK.
- **Industry.** Wales has a much higher share of total emissions (30%) from industry compared to the UK as a whole (22%), driven by the cluster of heavy industry in South Wales. Scotland also has a higher level of emissions from industry while Northern Ireland has a much lower share. However, our new analysis suggests emissions can be reduced to low levels in industry in the long-term, so these shares are less important than agriculture and aviation.

Land use emissions, especially from peatland, are also important, and discussed below.

[157] CAA (2018) *Size of reporting airports 2018.*

Figure 5.8. Sectoral share of emissions in England, Scotland, Wales, and Northern Ireland (2016)



Source: NAEI (2018) *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2016*.
Notes: Includes emissions from peatland and international aviation and shipping.

Differences in infrastructure

Some differences in infrastructure will continue as far as 2050. This is particularly important for the gas and electricity networks, existing housing stock, and clusters of heavy industry:

- The gas network is much less developed in Northern Ireland, with only 24% of households connected to the gas grid in 2017 (although this is increasing), compared to 87% for the UK as a whole. Scotland and Wales also have a higher proportion of homes off the gas grid than the UK average. Heat decarbonisation options that rely on the gas network will not be possible in these particular properties, and will require a greater use of other options such as heat pumps and smart storage heating.
- The cluster of heavy industry in South Wales could be a large point source of residual emissions, unless effective measures to reduce emissions such as CCS are put in place.

Differences in land use

Emissions from land use, land-use change and forestry are inherently location-specific. New research for the Committee's 2018 Land Use report[158] used spatial modelling to generate future emissions scenarios for each devolved administration and for regions of England. This new evidence provided further insight into potential for afforestation, growth of biomass as timber and for energy, as well as an assessment of emissions from degraded peatland:

- **England.** England has a much larger proportion of land used for crops than the rest of the UK, comprising around one-third of land area in 2016, compared with one-fifth for the UK as a whole. Cropland will continue to be the dominant land use in England in our Further

[158] CCC (2018) *Land use: Reducing emissions and preparing for climate change.*

Ambition scenario, but a 40% fall in grassland area will allow increases in land used for forestry, restored peatland, and agro-forestry.

- **Scotland.** Around 20% of land in Scotland is currently forested, the highest proportion in the UK, which could rise to almost 30% under deep emissions reduction scenarios. Emissions from degraded peatland compared to total emissions are much higher in Scotland than the rest of the UK. They are expected to add up to 9.7 $MtCO_2e$ to estimates of Scottish emissions in 1990 once they are included in the inventory. However, there is potential to more than double the area of restored peatland from 0.6 million hectares today to over 1.4 million hectares by 2050, which would reduce these emissions to around 7 $MtCO_2e$. Scotland is capable of producing 33% of the UK's solid biomass by 2050 - the majority of which is from forest management and new planting - and 50% of timber.
- **Wales.** Livestock is an important agricultural activity in Wales, making grassland the dominant use of land in 2016 (74%). The amount of grassland could reduce by around 25% by 2050, with land for forestry increasing by around 70%. Wales has a very small amount of peatland, which is expected to add less than 0.5 $MtCO_2e$ to estimates of emissions once it is included in the inventory. Wales is expected to produce less than 10% of the UK's solid biomass and timber in 2050.
- **Northern Ireland.** The livestock sector dominates agriculture in Northern Ireland (over 90% of agriculture GVA in 2016), and in particular beef and dairy. This is reflected in the high proportion of grassland in Northern Ireland, which comprised 75% of land area in 2016. Crops are only 4% of land, and forest coverage is also lower than the rest of the UK at 6%. Grassland offers the biggest opportunity to move to lower-carbon land uses such as forestry, agro-forestry and biomass, which could increase by up to 11% of land by 2050. Peatland is expected to add 2.3 $MtCO_2e$ to the estimate of emissions in Northern Ireland in 1990, although this could fall to around 1.8 $MtCO_2e$ in 2050 with peatland restoration.

Opportunities for engineered CO_2 removal and storage

The Further Ambition scenario for the UK involves a substantial amount of CO_2 removal from the atmosphere, largely through use of BECCS. Under current accounting rules the emissions credit for that removal is allocated where the CO_2 storage occurs, rather than where the biomass is grown. Access to CO_2 storage, and the most suitable sites for BECCS plants are therefore the key criteria in sharing this abatement within the UK.

- Wales and Northern Ireland have limited access to CO_2 storage sites and so do not appear to be the best places to locate BECCS plants.
- Scotland has excellent CO_2 storage sites in the North Sea, including disused oil and gas fields. It also has excellent potential to grow and supply around 33% of all UK biomass. Together these imply Scotland is a good place for BECCS plants to locate, although where these produce electricity or hydrogen, transmission constraints will also need to be considered.

These differences in agriculture, aviation, land use and access to CO_2 storage are the key factors affecting our Core and Further Ambition scenarios for Scotland, Wales, and Northern Ireland. In addition, there is potential to deliver Speculative options to further reduce emissions.

Potential for Speculative options that could cut emissions further

Achieving net-zero GHG emissions for the UK will rely on a range of Speculative options that currently have very low levels of technology readiness, very high costs, and/or significant barriers to public acceptability.

It is very unlikely they would all become available by 2050 but some contribution from Speculative options will be required to close the gap to a net-zero target. This could be achieved by deeper roll-out of the measures included in the Further Ambition scenario, further deployment of engineered removals, and/or through the use of synthetic fuels. The opportunities to deliver these Speculative options vary across the UK, which affect the ability of Scotland and Wales to deliver net-zero emissions (Table 5.2):

- **Deeper roll-out of Further Ambition options.** These options focus on aviation demand, changes to agriculture and land use, CO_2 capture rates for CCS, and hydrogen. They enable both Scotland and Wales to go beyond the Further Ambition scenario, although in each case the potential to deliver abatement through changes in aviation demand is lower than for the UK as a whole, and would be more reliant on changes to CCS capture rates, agriculture and land use.
- **Engineered removals.** These removals will rely on a wider roll-out of BECCS and DACCS, which combined could deliver up to 52 $MtCO_2e$ under the Further Ambition scenario. Scotland is well placed to produce biomass and store CO_2. If DACCS were deployed more widely in the UK, there would be good reason to co-locate it with the BECCS in Scotland deployed in our Further Ambition scenario. Conversely, Wales has more limited access to CO_2 storage and the deployment of further engineered removals in Wales is less credible.
- **Synthetic fuels.** Use of synthetic fuels across industry, aviation and buildings could deliver additional abatement of up to around 45 $MtCO_2e$ for the UK, around half of which is due to their use in aviation. Removing emissions from aviation using synthetic fuels could deliver a further 1.4 $MtCO_2e$ of abatement in Scotland, whereas Wales has less than 0.1 $MtCO_2e$ of emissions from aviation under our Further Ambition scenario (Figure 5.8).

Given the uncertainty associated with all of these Speculative options, we only consider it credible to set a target that requires a significant contribution from them if there are multiple options for how to achieve the necessary emissions reduction. As only one of the identified routes for the UK is potentially feasible for Wales, it would not be prudent to set a target for Wales that relies on these Speculative measures being delivered (Table 5.2).

Table 5.2. Summary of potential to deliver Speculative options in Scotland and Wales		
Speculative measure	**Scotland**	**Wales**
Deeper roll-out of Further Ambition options	🟢	🟢
Engineered removals	🟢	🔴
Synthetic fuels	🟡	🔴
Overall	🟢	🔴
Source: CCC analysis.		

(b) Scenarios for the devolved administrations in 2050

Whilst the economic and geographical characteristics of each devolved administration imply different extents and timings for overall emissions reduction, the set of possible technological and societal measures that will be required to reduce emissions are essentially the same across the whole of the UK.

It is important to recognise that the different levels of emissions in 2050 in our scenarios reflect different opportunities to reduce emissions rather than any difference in political ambition to pursue decarbonisation. Our assessment of the potential for decarbonisation in the devolved administrations requires applying the same sets of mitigation measures as in our UK-wide Core, Further Ambition, and Speculative scenarios. The abatement that each measure produces then depends on their effectiveness in each devolved administration.

The residual emissions under the Further Ambition scenario are presented in Figure 5.9. The key differences in residual emissions for each devolved administration compared to the UK are:

- **Aviation.** The devolved administrations each have a much smaller share of residual emissions in aviation compared to the UK.
- **Industry.** As a proportion of positive residual emissions (i.e. net emissions excluding LULUCF and engineered removals), emissions from industry are much higher in Wales (22%) compared to Scotland (11%), Northern Ireland (4%), and the UK as a whole (12%).
- **Agriculture.** Scotland, Wales, and Northern Ireland each have a higher share of residual emissions from agriculture (47%, 58%, 49% respectively) compared to the UK (29%).
- **Land use and forestry.** Compared to the positive residual emissions, the LULUCF sector is a much larger sink in both Scotland (33%) and Wales (47%) than the UK as a whole (3%). This reflects the good opportunities for afforestation and minimal peatland emissions in Wales, and the significant opportunity for large increases in forest area in Scotland that offsets larger emissions from degraded peatland. Unlike the rest of the UK, LULUCF is a net source of emissions in Northern Ireland due to low forest coverage and high levels of peatland emissions, and accounts for 26% of residual emissions.

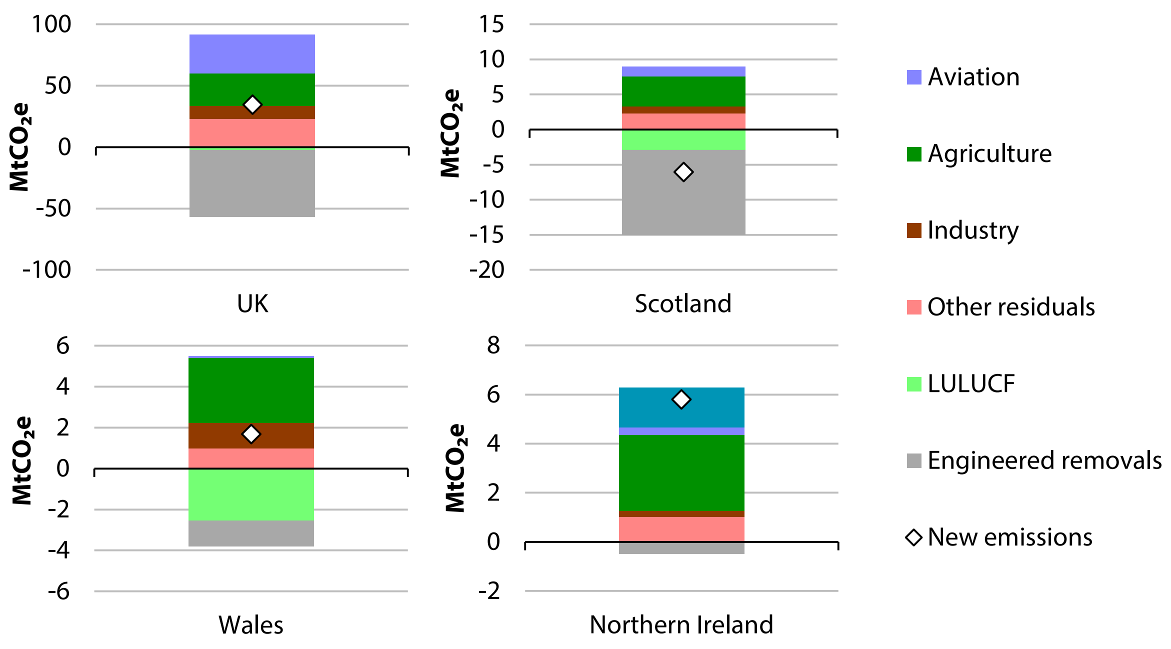
- **Engineered greenhouse gas removals.** There is limited opportunity for CO_2 removal through use of BECCS in Wales and Northern Ireland. New evidence for our Land Use report suggests Scotland could provide around 33% of the UK's solid bioenergy by 2050, and 50% of timber. In our Further Ambition scenario, we have assumed that Scotland has the opportunity to deliver 22% of total UK engineered removals, given access to this domestic bio-resource and Scotland being well placed for CCS (see Box A.1 of the Technical Report).

Taken together these scenarios imply that delivering the Further Ambition scenario across the UK would result in net-negative emissions in Scotland, and net-positive emissions in Wales and Northern Ireland.

Whether and when net-zero GHG emissions can be achieved requires consideration both of the emissions level under the Further Ambition scenario and potential to go further with Speculative options (Table 5.3):

- For **Scotland**, the reduction of 104-110% by 2050 under Further Ambition already provides confidence that net-zero GHG emissions can be achieved in or before 2050. Potential to go beyond Further Ambition with Speculative options in Scotland indicates that deeper emissions reductions could be achieved if necessary. The gap to net-zero emissions in 2045 for Scotland would require 0-4 $MtCO_2e$ of abatement delivered through Speculative options.
- For **Wales**, the reduction of 95-97% under the Further Ambition scenario is at the limit of our current assessment of feasibility, given that setting a target that relies on Speculative options would entail too great a risk. Given that methodological decisions have not yet been taken, we therefore consider that the lower end of the range for emissions reduction (95%) is the maximum extent of credible reductions in Wales by 2050.

Figure 5.9. Residual emissions in the Further Ambition scenario for the UK, Scotland, Wales, and Northern Ireland (2050)



Source: CCC analysis.

Our assessment for the level of feasible emissions reduction by 2050 has changed significantly more for Wales and for Scotland than for the UK as a whole:

- For **Wales**, this reflects a large change in our assessment of potential decarbonisation of industry across the UK, based on new evidence of opportunities for decarbonisation (e.g. on the potential for use of hydrogen in industry), which affects Wales disproportionately given its high share of current industry emissions.
- For **Scotland**, this reflects significant changes in our assessment of the opportunities presented by the land sector in terms of carbon sequestration, and our greater ability to disaggregate these opportunities across the UK.

Table 5.3. Core and Further Ambition scenarios for the UK, Scotland, Wales, and Northern Ireland (2050)

Scenario in 2050		UK	Scotland	Wales	Northern Ireland
Core	Emissions in 2050 ($MtCO_2e$)	193	12	13	10
	Reduction on 1990 levels	77%	85%	76%	63%
Further Ambition	Emissions in 2050 ($MtCO_2e$)	33 to 45	-8 to -4	2 to 3	5 to 6
	Reduction on 1990 levels	95% – 96%	104% – 110%	95% – 97%	78% – 80%
Ability of Speculative options to go beyond the Further Ambition scenario					
Earliest credible year for net-zero GHG emissions		2050	2045	Post-2050	Post-2050

Source: CCC analysis.
Notes: Range presented for Further Ambition includes uncertainty around methodologies selected for global warming potentials and the inclusion of peatland emissions (Box 5.1).

This reflects the Committee's recent work that has focused on challenging sectors that could have a large impact on the UK's ability to reach net-zero emissions, including our 2018 reports on land use, hydrogen, and biomass.[159] The accompanying Technical Report sets out in more detail how our assessments have changed for Scotland, Wales, and for the UK as a whole.

[159] CCC (2018) *Land use: Reducing emissions and preparing for climate change*; CCC (2018) *Hydrogen in a low-carbon economy*; CCC (2018) *Biomass in a low-carbon economy*.

Chapter 6: Delivering a net-zero emissions target for the UK

Introduction and key messages

Chapter 5 set out the technical ways in which greenhouse gas emissions can be reduced to net-zero by 2050. In this chapter we focus on the actions required to deliver these reductions.

Reaching net-zero GHG emissions requires extensive changes across the economy, with complete switchovers of several parts of the UK capital stock to low-carbon technologies and development of new industries for carbon capture and storage and low-carbon hydrogen production. Major infrastructure decisions need to be made in the near future and quickly implemented. The public will need to be engaged in making the required changes.

The key messages in this chapter are:

- **The foundations are in place.** Policy development has begun for many of the components needed to reach net-zero GHG emissions: low-carbon electricity (which must quadruple by 2050), efficient buildings and low-carbon heating (needed throughout the building stock), electric vehicles (EVs), carbon capture and storage (CCS), diversion of biodegradable waste from landfill, phase-out of fluorinated gases, increased afforestation and measures to reduce emissions on farms. These policies must be strengthened and they must deliver action.
- **Delivery must progress with far greater urgency.** Many current plans are insufficiently ambitious; others are proceeding too slowly, even for the current 80% target:
  - 2040 is too late for the phase-out of petrol and diesel cars and vans, and current plans for delivering this are too vague.
  - Over ten years after the Climate Change Act was passed, there is still no serious plan for decarbonising UK heating systems and no large-scale trials have begun for either heat pumps or hydrogen.
  - Carbon capture (usage) and storage (CCUS), which is crucial to the delivery of net-zero GHG emissions and strategically important to the UK economy, is yet to get started. While global progress has also been slow, there are now 43 large-scale projects operating or under development around the world, but none in the UK.
  - Afforestation targets for 20,000 hectares/year across the UK nations (due to increase to 27,000 by 2025), are not being delivered, with less than 10,000 hectares planted on average over the last five years. The voluntary approach that has been pursued so far for agriculture is not delivering reductions in emissions.
- **Challenges that have not yet been confronted must now be addressed** by government. Industry must be largely decarbonised, heavy goods vehicles must also switch to low-carbon fuels, emissions from international aviation and shipping cannot be ignored, and a fifth of our agricultural land must shift to alternative uses that support emissions reduction: afforestation, biomass production and peatland restoration. Where there are remaining emissions these must be fully offset by removing CO_2 from the atmosphere and permanently sequestering it, for example by using sustainable bioenergy in combination with CCS.
- **Clear leadership is needed, right across Government, with delivery in partnership with businesses and communities.** Emissions reduction cannot be left to BEIS and Defra or to the Treasury. It must be vital to the whole of government and to every level of government in the UK. Policies must be fully funded and implemented coherently across all sectors of the economy to drive the necessary innovation, market development and consumer take-up of low-carbon technologies, and to positively influence societal change.

This chapter is set out in five sections:

1. The transition to a net-zero emissions economy
2. What is needed to underpin delivery of net-zero emissions in the UK
3. High-level policy implications for delivering net-zero emissions
4. Policy pre-conditions of a net-zero target
5. Implications for policy made in Scotland, Wales and Northern Ireland

1. The transition to a net-zero emissions economy

Chapter 5 presents a quantitative picture of how net-zero emissions could be achieved in the UK. Delivering this will require concerted policy action over the next three decades across every emitting sector of the economy. It is essential that this includes stronger actions in the near term to put the UK on track towards net-zero emissions by 2050.

This section considers the constraints on how quickly the transition could happen and what this means for near-term actions.

(a) Limiting factors on the rate of decarbonisation

There are various constraints on how quickly a transition to net-zero emissions can occur without major disruption. The time needed for development of markets, supply chains and infrastructure, as well as innovation and turnover of the capital stock limit the rate of decarbonisation that can be achieved as a smooth transition and without the need to write off substantial parts of the capital stock (e.g. vehicles, heating systems, industrial plants):

- **Development of markets and skilled supply chains.** Society cannot immediately switch universally from buying current technologies to new ones. There are constraints relating to people's awareness of the newer technologies and the capacity of supply chains to supply and/or install them. It takes time to develop a market for electric cars until the point is reached when all new vehicles are electric. It is not feasible to ramp up installation rates of heat pumps straight away to the current level of gas boiler sales (over a million per year) from the current level of 20,000 per year, not only due to the lack of market development but also because there are not enough qualified heat pump installers.

- **Infrastructure development.** Some low-carbon technologies require supporting infrastructure - new networks (e.g. hydrogen or CO_2 networks) or expansion of the capacity of existing grids (e.g. strengthening electricity distribution grids to support electric vehicles and heat pumps). The lead-times for planning and delivering this infrastructure - particularly for new infrastructure - constrains the deployment rate of technologies that rely on it.

- **Innovation.** The costs of mass deployment of low-carbon technologies can depend heavily on whether efforts have been made to reduce the technology costs for roll-out at very large scale. Implementing policies prior to very widespread roll-out that aim to bring down costs, including 'learning-by-doing' via deployment, can reduce the costs of later deployment significantly.

- **Stock turnover.** Even once the market moves to selling only low-carbon technologies (e.g. vehicles or heating appliances) it still takes time to turn over the capital stock so that these technologies are taken up by all users. Typical turnover rates can be around 15 years for vehicles and boilers, with shorter times for heavier vehicles and longer elsewhere (e.g. industrial sites, aircraft). It is possible to reduce the time for capital stock turnover through extensive early write-off of assets (i.e. 'scrappage') but this comes with additional costs particularly for capital-intensive technologies (e.g. higher costs for cars than for boilers, as cars have substantially higher capital costs). It may also cause a more disruptive transition as supply chains must scale up beyond the normal turnover rate and then scale back down again.

- **Natural systems.** Outside the energy system, the date for net-zero emissions also affects the contribution that different options can make to achieving it. For example, while we can move quickly to higher rates of tree planting (e.g. 30,000 hectares per year, compared to less than 10,000 recently), the impact of these on carbon sequestration builds up over time as the cumulative amount of planting grows and as younger trees mature (e.g. at 30,000 hectares per year, sequestration would increase by around 5 $MtCO_2$ in a decade).

The scenarios we set out in Chapter 5 are constructed with these constraints on the potential speed of decarbonisation in mind. They reflect the need to develop markets and supply chains, and build up deployment so as to benefit from learning in the early phase. They do not assume a significant role for scrappage.

If the scenarios are to be delivered by 2050, consistent with reaching net-zero greenhouse gases (GHGs) by that date, there must be timely near-term action, including provision of supporting infrastructure and development of policies to deliver action.

(b) Key near-term actions to put the UK on track to net-zero GHG emissions by 2050

Without strong near-term action (Figure 6.1), it would quickly become infeasible to decarbonise sufficiently to reach net-zero GHG emissions by 2050 without resorting to major scrappage schemes and/or much greater disruption to lifestyles, which may not be deliverable.

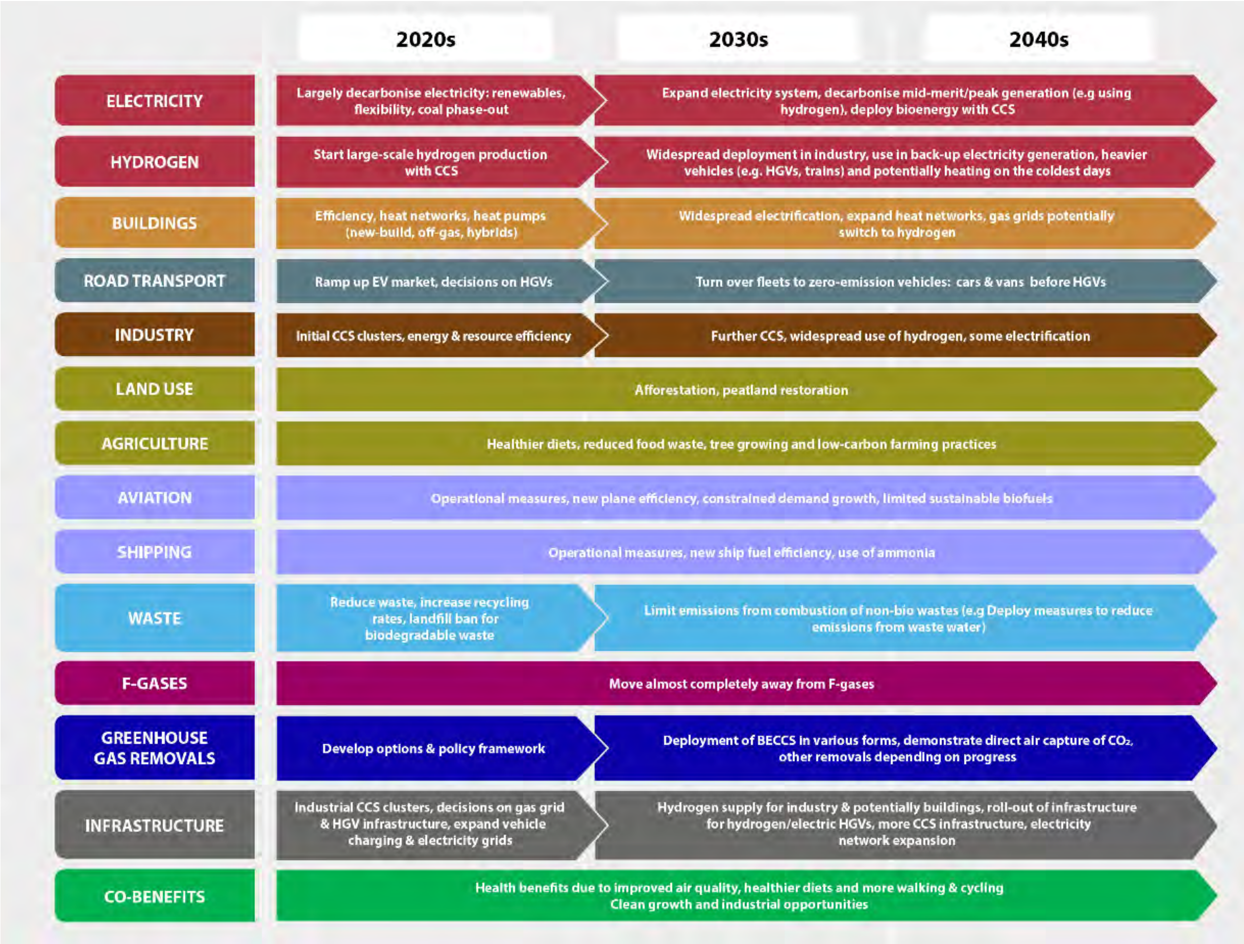
Based on the Further Ambition scenario presented in Chapter 5, there is a set of required near-term actions that are on the 'critical path' towards achieving net-zero emissions by 2050:

- **Afforestation.** Reaching the necessary level of CO_2 removal through afforestation by 2050 requires an early and sustained increase in tree-planting rates. These must increase from current rates below 10,000 hectares per year to at least 30,000 hectares per year.
- **Buildings.** Major improvements are required to the energy efficiency of buildings, in order to improve comfort levels, lower energy bills and prepare the building stock for a switch to low-carbon heating. Retrofit of hybrid heat pumps, enabling continued use of existing boilers and radiators, could sensibly be done alongside energy efficiency improvements in many cases.
- **Public engagement.**
  - **Healthy lifestyle choices.** People can take action immediately to improve their diet and increase the amount of walking and cycling they do. The Government must engage with people over why and how they can make these improvements, and take supporting actions (e.g. ensuring that road infrastructure encourages people to view cycling as a safe option).
  - **Future of heating.** Currently the general public has a low awareness of the need to move away from natural gas heating and what the alternatives might be. There is a limited window to engage with people over future heating choices, to understand their preferences and to factor these into strategic decisions on energy infrastructure. This is especially important if solutions to heat decarbonisation could differ in different parts of the UK.

- **Market development.** Accelerated take-up of technologies is needed in the 2020s, for example rapid electrification of transport and heating accompanied by the growth of charging infrastructure for electric vehicles and strengthening of electricity networks:
  - **Electric vehicles.** The need to switch the entire fleet of light-duty vehicles to ultra-low-emission vehicles (ULEVs) by 2050 means that by 2035, at the very latest, all sales of new cars and vans will need to be ULEVs. If possible, an earlier end to sales of petrol and diesel vehicles would be preferable (e.g. by 2030 if feasible), as this will have lower financial costs, lower cumulative CO_2 emissions and lead to better air quality. This means a rapid ramping up of the market share of EVs, from around 2% today, during the 2020s.
  - **Heat pumps** are an established solution in many other countries, but not yet in the UK. Establishing them as a mass-market solution will take some time, with strong progress required during the 2020s. There are particular opportunities in new-build properties, homes off the gas grid, non-residential buildings and hybrid heat pump systems retrofitted around existing gas boilers.
- **Power sector decarbonisation.** More rapid electrification must be accompanied with greater build rates of low-carbon generation capacity, accompanied by measures to enhance the flexibility of the electricity system to accommodate high proportions of inflexible generation (e.g. wind). The Energy White Paper planned for 2019 should aim to support a quadrupling of low-carbon power generation by 2050. While key options like offshore wind look increasingly like they can be deployed without subsidy, this does not mean they will reach the necessary scale without continued Government intervention (e.g. continued auctioning of long-term contracts with subsidy-free reserve prices).
- **Hydrogen and CCS.** In order to develop the hydrogen option, which is vital in our scenarios, significant volumes of low-carbon hydrogen must be produced at one or more CCS clusters by 2030, for use in industry and in applications that would not require initially major infrastructure changes (e.g. power generation, injection into the gas network and depot-based transport). More broadly, plans for early deployment of CCS must be delivered with urgency - CCS is a necessity not an option for reaching net-zero GHG emissions.
- **Infrastructure.** Development of new infrastructure will be important in opening up new avenues for decarbonisation, for example CCS and hydrogen. Expansion of electric vehicle charging networks and electricity grid capacity will be important in facilitating strong growth in electric vehicles. Decisions will be required on the future pathways for heating buildings and decarbonisation of heavy goods vehicles during the 2020s, with important implications for infrastructure roll-out.
- **Bioenergy with CCS.** Deployment of sustainable bioenergy with CCS (BECCS) will need to start sufficiently early (e.g. by 2030) to build up to a potentially large contribution from BECCS in the longer term.

We discuss what is required to deliver each of these over the remainder of this chapter.

Figure 6.1. The transition implied in our Further Ambition scenario over the period to 2050



2. What is needed to underpin delivery of net-zero emissions in the UK

Achieving net-zero emissions in the UK has important implications for required investment and finance, decisions over infrastructure, innovation and the role of societal change. We set out those implications in this section.

(a) Investment and financing

Delivering net-zero emissions will involve increased investments, generally offset by reduced fuel costs. For example, wind and solar farms are costly to build, but avoid the need to pay for gas and coal; energy efficiency involves an upfront cost followed by reduced energy use. CCS and hydrogen are clear exceptions, requiring both increased upfront spend and higher fuel costs.

Precise investment needs are difficult to predict in advance - they will depend on the mix of technologies deployed to achieve a net-zero target and on their future costs (see sections on innovation in this chapter, 2(c), and in Chapter 7).

Capital cost increases in our scenarios are highest for the power and buildings sectors. Power sector annual investment rises to around £20 billion. Investment in buildings is around £15-20 billion higher in 2050 than it would have been without decarbonisation (the precise figure will depend on the mix of technologies deployed). By comparison, investment in the power sector averaged around £10 billion over 2013-2017. In total there is an extra investment requirement across the economy of around 1% of GDP in 2050.

The additional investment requirements for decarbonisation would either result in reallocating some of the UK's capital investment into low-carbon assets or increasing capital investment. Annual capital investment in the UK has fluctuated between 15-24% of GDP over the last 30 years, highlighting that changes in annual investment of a few percentage points of GDP is something the economy has adjusted to in the past.

Some of this investment will come from Government funds, but the volume of additional investment required means that the private sector will need to contribute a significant proportion. Investable propositions (i.e. with suitable risk-return criteria to appeal to the private sector) will be needed to bring in the required volume of capital at a relatively low cost.

Beyond providing direct funding, Government has a role in facilitating private sector investment:

- Some mechanisms for this already exist - Government's success in encouraging private sector investment in offshore wind through the Contracts for Difference scheme is an example where good policy design, with appropriate risk allocation, has helped reduce costs of capital - but more action will be needed to further increase investment in low-carbon technologies.
- Government has already recognised the need to develop the UK's green finance capabilities in its Clean Growth Strategy and through the creation of the Green Finance Task Force. It will be important to carry out proposals recommended by the Task Force[160] (e.g. developing green mortgage products that value energy-efficient properties, developing new green lending products, creating an investment fund to support early-stage low-carbon technologies).
- Government has a role in reducing the policy risk element of financial risk. Setting out clear and stable long-term goals and signalling Government commitment to a net-zero target, as well as a commitment to policies and projects to achieve it, can reduce policy risk and consequently reduce risk premiums and the costs of financing low-carbon investment.
- Policy should also encourage a smooth transition of investment from high-carbon to low-carbon assets to minimise financial risks (see Chapter 7 for more on financial risks of climate change) and wider policies that encourage investors to prioritise low-carbon investments could be helpful (e.g. mandatory disclosure of exposure to climate risks).
- To limit the required scale of investment, market mechanisms should reward options that use energy relatively efficiently, in order to limit costs and build requirements for low-carbon capacity (see section 4(e)).

Government success in providing clear and stable mechanisms that attract sufficient volumes of low-cost capital will be key to the overall success in reaching a net-zero GHG target, given the importance of capital-intensive options. It will also be key to minimising costs for consumers and taxpayers and to making the most of the business opportunities that the transition can bring.

[160] Green Finance Task Force (2018) *Accelerating Green Finance*.

(b) Infrastructure development and decision points

Achieving net-zero emissions will require new infrastructure. In many areas, electricity networks will need to be strengthened. Just how much infrastructure will need to be developed in each sector will depend on decisions on the pathway to achieving net-zero emissions. However, given an understanding of lead-times for technology uptake and infrastructure development we can set out a timeline of when decisions will be required and when the infrastructures will need to be in place:

- **Carbon capture and storage (CCS).** It is clear that reaching net-zero GHG emissions will require important contributions from CCS in industry, for hydrogen production, combined with bioenergy (e.g. for power generation) and in flexible fossil-fired power generation. This could require 75-175 MtCO_2 stored annually by 2050.
  - Given the large amount of CCS required by 2050, long lead-times for CO_2 infrastructure (especially CO_2 storage) and infrequent refurbishment rates in industry, developing regional 'cluster'-based infrastructure is on the critical path for achieving net-zero emissions. As well as enabling industrial CCS, it will also provide the opportunity for low-carbon hydrogen for industry, which we expect to be most cost-effectively produced with CCS.
  - CO_2 infrastructure development should start as early as possible, and will need clusters in all areas with large industrial emissions (see section 4(a)). At least one CCS cluster should be operational by 2026 and the others following soon after (e.g. by 2030). Delayed availability of CO_2 transport and storage infrastructure may mean higher industry emissions in 2050 and/or a greater role for scrappage, increasing costs.
  - It will be important for BEIS[161] (working with industry) to identify when those industrial sites that require CCS by 2050 would need to fit CCS in order to align to their refurbishment cycles, and what that implies for the dates by which CO_2 transport and storage infrastructure needs to be available for different clusters.
- **The gas distribution grid and use of hydrogen.** Hydrogen has the potential to replace fossil fuels in areas where electrification may reach limits of feasibility and cost-effectiveness: industrial heat, heat for buildings on colder winter days (e.g. as part of a hybrid heating system), back-up power generation and heavy-duty vehicles. Moving beyond an 80% target changes hydrogen from being an option to an integral part of the strategy. Gas distribution networks will not be able to continue to provide natural gas on a widespread basis by 2050 - they will either need to be decommissioned or, if feasible, repurposed to hydrogen. Decisions will be required from the mid-2020s on the balance between electrification and hydrogen in decarbonising heating, and the implications for gas networks (Figure 6.2).
- **Infrastructure for zero-emission vehicles.**
  - **Cars and vans.** Electric cars and vans will reach parity with petrol and diesel vehicles on a social basis[162] during the 2020s (see section 4(b)) - charging infrastructure should be developed in a way that enables a rapid transition to EVs. By 2030, at least 1,200 rapid chargers near major roads and 27,000 chargers around local towns and regions are likely to be required to meet current service levels. Although this would provide good

[161] The Department for Business, Energy and Industrial Strategy.

[162] The analysis on a social basis is without taxes, so ignores the further consumer benefit that EVs do not pay fuel duty.

coverage, further installations will be required after 2030, to keep pace with the increasing size of the electric vehicle fleet as the stock turns over.

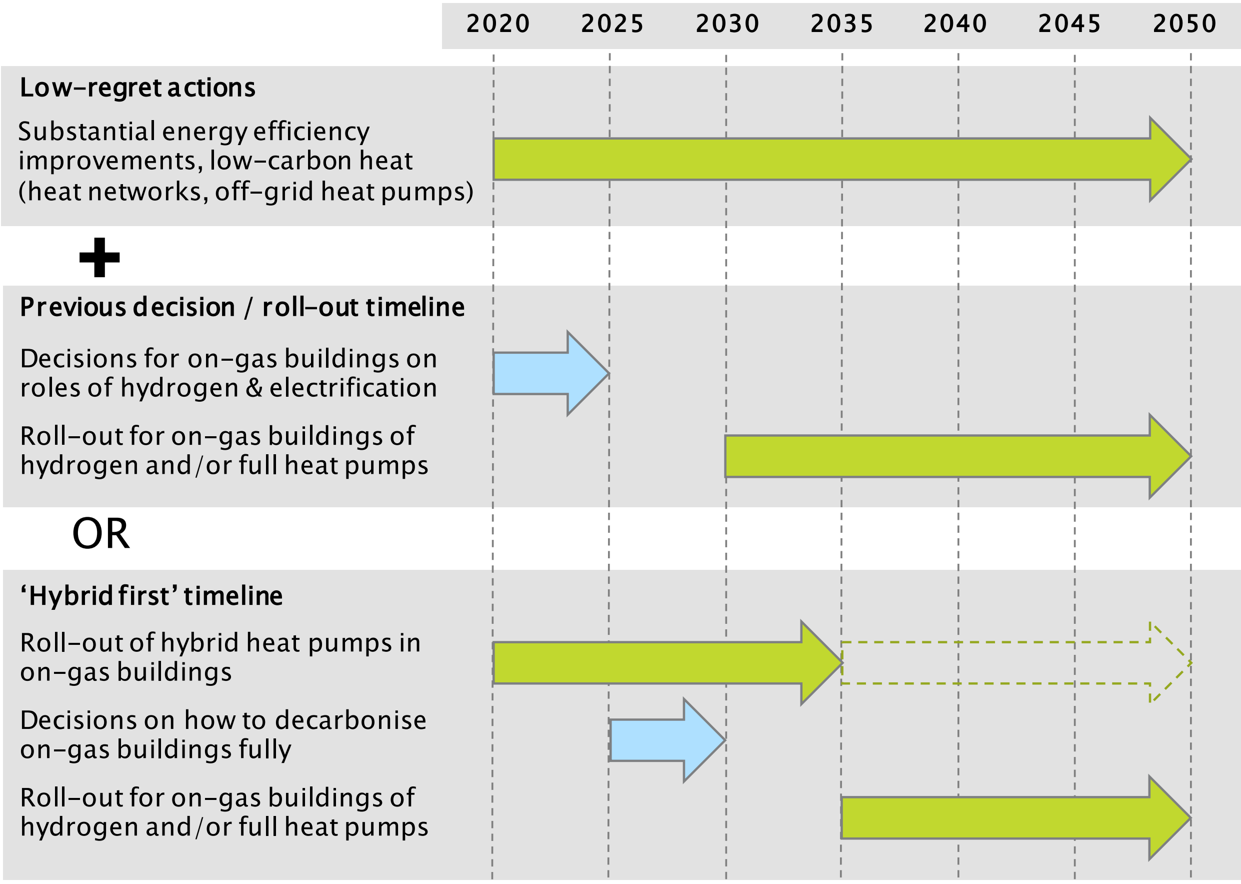
  - **Heavy goods vehicles (HGVs).** To reach net-zero emissions by 2050 it will be necessary for HGVs to move away from combustion of fossil fuels and biofuels to a zero-emissions solution (e.g. hydrogen, battery vehicles). Given the current evidence on lead-times for infrastructure and the time taken to turn over vehicle stocks, the government will need to make decisions how HGVs will be decarbonised in the second half of the 2020s. This will necessitate small-scale trial deployments of hydrogen HGVs in a variety of fleets prior to this, in the UK or elsewhere. As HGVs need to travel internationally, the eventual choice is likely to need to be consistent with equivalent decisions made elsewhere in Europe.

- **Electricity networks.** Given important roles for electrification in both transport and heat, electricity demand will rise in most areas. Solutions that enhance system flexibility (e.g. smart charging of vehicles and hybrid heat pumps), will be important in ensuring that demand peaks are manageable and enabling maximum use of renewable generation. Many networks will need to be upgraded in a timely manner and future-proofed to limit costs and enable rapid uptake of electric vehicles and heat pumps:
  - The cost of upgrading distribution network capacity is relatively insensitive to the size of the capacity increase, as most of the cost is in the civil works rather than the equipment (e.g. larger cables).[163]
    - It is essential, therefore, that when grid capacity is increased, this is to a sufficient level to avoid having to upgrade the capacity again prior to 2050.
    - A relatively large expansion in capacity is likely to have low regrets, 'future-proofing' the network to enable greater electrification if necessary and/or enabling demand to respond more readily to variations in low-carbon electricity supply.
  - As electric vehicles are likely to be cost-saving by 2030 (see section 4(b)), it is important that grid capacity constraints do not impede their growth in the 2020s. It will therefore be important either to make anticipatory investments to upgrade electricity networks and/or to re-open the allowed investment partway through the 2023-2028 regulation period (i.e. RIIO ED2) to ensure timely upgrades.
  - Transmission network capacity will need to keep pace with developments on generation (e.g. large-scale offshore wind) and interconnections, and with the need to ensure that peak demand can be met reliably in all areas on still days as well as on windy days.

These infrastructure developments will not occur without government leadership. The Government, in partnership with the National Infrastructure Commission, should give urgent consideration to how the required infrastructure can best be identified, financed and delivered. Regional coordination will be required, including for transport where powers are devolved.

[163] Vivid Economics and Imperial College (2019) *Accelerated electrification and the GB electricity system*.

Figure 6.2. Timing of key decisions and changes to deliver the net-zero scenarios for buildings



Source: CCC (2018) *Hydrogen in a low-carbon economy*.
Notes: 'Low-regret' actions are those that the Committee has recommended should be pursued immediately, with subsequent decisions to be made by the mid-2020s on the respective roles of hydrogen and electrification in on-gas buildings. The 'hybrid first' timeline proposed in the Hydrogen report would entail pursuing widespread deployment of hybrid heat pumps in on-gas properties in parallel to the low-regret actions, with decisions how to achieve full decarbonisation potentially to come slightly later.

(c) The importance of innovation

Innovations in the decade since the Climate Change Act was passed already mean that the Committee's estimates of the cost of reducing emissions by 80% on 1990 levels are now estimated to be less than 1% of GDP by 2050, compared to 1-2% of GDP estimated in 2008. This reflects rapid falls in the costs of renewable power generation technologies and batteries, as well as a better understanding of the wide range of ways in which deep decarbonisation can be achieved (see Chapter 7).

Innovation is not limited to technologies, it also cover institutions, business models, policy designs and behaviours.

The dramatic reductions in offshore wind costs during this decade, due to deployment led by the UK, highlight the value of 'learning by doing' in achieving cost reductions via deployment, including the importance of good policy design, rather than relying only on research and development. As well as reducing future costs of UK decarbonisation, UK deployment of less-mature technologies also reduces the costs for other countries, making global action to tackle climate change more tractable.

Moving to a net-zero GHG target for 2050 makes deployment of known solutions all the more important, including an important role for less-mature technologies. In addition to supporting research and development (R&D) on innovative solutions, policy will need to drive innovation via deployment to reduce technology costs and costs of capital, and to ensure that policy mechanisms and infrastructure provide opportunities for deployment of novel solutions:

- **Learning-by-doing.** In many cases, the biggest driver of cost reduction will be deployment at scale, both through reduced technology costs and reduced cost of capital - both of these effects have been apparent in the last decade for offshore wind. Policy frameworks will need to drive deployment of some less-mature solutions, even if these have higher costs than other low-carbon technologies in the near term.
- **Policy design.** Market frameworks and regulation each have a role in driving innovation, for example the Contracts for Difference auctions for power generation and in flue-gas desulphurisation driven by air quality regulations. There is considerable value in policy designs that provide certainty over the emissions goal but allow for new solutions, including through new business models (e.g. heating as a service). Policy should also encourage 'system-level' innovation (i.e. for interactions between different parts of the energy system, land use and industrial processes).
- **Supporting infrastructure development.** Many potential innovations will need to interact with the wider system, including supporting infrastructure. In some cases the infrastructure already exists (e.g. the electricity grid), but in other cases, such as hydrogen and CCS, infrastructure is not yet available to provide this support. CCS infrastructure will be important for innovative removals solutions technologies such as direct air capture of CO_2, in addition to deployment of CCS in industry, and on fossil and bioenergy generation (see section 4(a)).

The limited amount of time available to develop new technologies means that not all potential innovations will be able to make a significant difference by 2050, given the multi-decadal timescale for commercialisation of new technologies.[164] However, the example of offshore wind development shows that these timeframes can be compressed in some cases, which does provide scope for well-designed policy to pull through known but undeveloped solutions in the time available.

In areas in which near-full decarbonisation could be achieved with the set of technologies that is already established (e.g. power generation, buildings, light-duty vehicles) the focus should be on establishing policy frameworks that drive deployment at scale, allowing markets to deliver with low cost of capital, while having the flexibility to enable innovative solutions to contribute as they become available.

In some of these areas, although the technologies exist to reduce emissions to very low levels, estimated costs of doing so are relatively high (e.g. for heating buildings). Policy frameworks will therefore need to be designed in a way that not only drive the necessary decarbonisation, but also in a way that gives the best chance of realising and benefiting from cost reductions.

[164] See Vivid Economics and UKERC (2019) *Accelerating innovation towards net-zero emissions*.

There is also a range of areas in which solutions have been proposed, but innovation will be required to go beyond the reach of established technologies or methods, such as in hydrogen, heavy goods vehicles, and carbon capture and storage. These also require a policy framework that enables their value to be realised (recognising that initially some solutions will not be cost-competitive), provides supporting infrastructure and drives learning-by-doing.

Costs of some technologies will be driven down via global deployment. For other technologies, specific UK policy support could be important, either because the UK needs a particular solution that others do not or because the UK is best-placed to develop particular solutions:

- **UK challenges.** In many areas of the economy, the UK has similar challenges to other countries in decarbonising (e.g. switching the car fleet to electric vehicles). However, in others, such as heat decarbonisation, the UK's situation is significantly different. The UK has a much more developed gas grid than most other countries, and therefore the nature of the challenge and the solutions (e.g. potentially switching grids to hydrogen) may be different. In such areas, the UK is likely to need to drive the development of solutions.
- **UK opportunities.** Some of the potential for cost reduction in early-stage technology deployment comes from deploying infrastructure in the UK in a coordinated and cost-efficient manner. For example, around half of the cost reductions for CCS come from developing CO_2 infrastructure at the right scale and with lower risk than for individual projects[165] (see section 4(a)) - this cost reduction for UK deployment is directly linked to UK action on infrastructure rather than a global effort.

In addition to the technologies that are important in delivering the Further Ambition scenario, there is a range of more Speculative options we have identified as potentially contributing to achieving net-zero emissions in the UK. Although some of these require further R&D, they will also require deployment support if they are to make a significant contribution by 2050.

We consider impacts of innovation on estimated costs of decarbonisation by 2050 in Chapter 7.

(d) Social change

The scenarios set out in Chapter 5 contain important contributions from social changes, with people choosing to behave in different ways. In our 2050 scenarios, the degree of social change is not dramatic, but over 60% of the abatement requires some level of change (see Figure 5.4). They also imply co-benefits in terms of cleaner air and healthier lifestyles (see Chapter 7).

There is potential for larger changes than we have assumed, and there may be a need for these, depending on delivery of other measures. Changes are important both in choices around activities and taking up new technologies:

- **Changes in activities.** There are many ways in which choices made by individuals or groups can reduce greenhouse gas emissions, some of which have significant co-benefits (see Chapter 7):
  - **Healthier lifestyles.** Our Further Ambition scenario involves a 20% shift away from beef, lamb and dairy towards healthier diets. This is less than the scale of change supported by the government 'EatWell Guide' on achieving a healthier and more balanced diet. However, it would require a faster shift than is currently underway. Achieving such a change will improve people's health, reduce emissions from UK agriculture and free up land that can be used to sequester carbon and/or grow biomass. We also assume a

[165] CCS Cost Reduction Taskforce (2013) *The potential for reducing the costs of CCS in the UK.*

significant role for shifting from shorter car journeys to walking and cycling, which also provide substantial health co-benefits.

  – **Constrained aviation demand.** Plausible options for how aviation could become zero-carbon, even by mid-century, are lacking. Given a population that is anticipated to grow and rising incomes, some growth in demand is expected. However, this cannot be unfettered. We have maintained our previous assumption that demand grows by 60% relative to 2005 levels (25% relative to today) by 2050, but latest evidence on the opportunities to reduce the carbon-intensity of flying suggest that these should more than offset demand growth, leading to an overall fall in emissions of around 20%.

- **Uptake of new technologies.** Successfully adopting and using new technologies is an essential part of reaching net-zero emissions. Decarbonisation of home heating and cars both require adoption of new technologies, whether electric (i.e. heat pumps and electric vehicles) or potentially hydrogen (e.g. hydrogen boilers). Smart controls systems (e.g. for timing of vehicle charging or operation of hybrid heat pumps) will be needed to provide people with the services they need in a way that fits the requirements of the wider system.

It will also be important for business to embrace the transition to net-zero emissions, supported by policy, by taking up low-carbon technologies, driving innovation and developing new business models.

These contributions in a transition towards net-zero emissions depend on Government strategy and policy being designed in a way that engages properly with people in a range of ways (see section 3(c)).

The Energy Systems Catapult (ESC) has explored the role of households in a net-zero emissions society to accompany this report (Box 6.1), looking at opportunities and challenges for households to reduce emissions from today's levels and to support the stretch from an 80% emissions reduction to a net-zero GHG target.

As well as describing a net-zero emissions world for households of different types, the ESC looked at average household emissions under different decarbonisation scenarios and the options households can take to contribute to the decarbonisation effort. Figure B6.1 shows how much UK household emissions have already fallen since 1990, and how much further they need to fall to achieve our decarbonisation ambitions.

Box 6.1. The role of households in a net-zero emissions society

Average household emissions fell by more than 40% between 1990 and 2017, from 14.8 to 8.8 tCO_2e. The current 80% target in the Climate Change Act would already require household emissions to come down another 60% to 3.5 tCO_2e in 2050. Achieving net-zero emissions requires almost full decarbonisation across most sectors. Households' emissions could range between 1.2-1.7 tCO_2e depending on household choices. Active engagement from households to reduce their carbon footprint will be vital to achieve this goal:

- **Heating.** Almost all household heating will need to be low-carbon, reducing average heating emissions to below 0.1 tCO_2e in 2050. This will involve changes to the way we heat our homes:
  - **Low-carbon heating systems** will replace the natural gas boilers used in most homes today. Heat pumps, heat networks and hydrogen boilers could be used. Solutions will depend on factors including location (e.g. in urban and therefore heat-dense areas district heating could be a good solution) and home type (e.g. in homes with space constraints solutions such as smart electric heating, which takes up less space than heat pumps, may be preferable).
  - **Improvements to the fabric of our homes** (e.g. insulation, draught proofing, new windows) can reduce the rate of heat loss from the building, thereby reducing the amount of energy required to maintain a comfortable temperature. Improvements could be combined with other home improvements, and energy savings can outweigh costs.
- **Transport.** Household transport emissions need to be close to zero in 2050:
  - **Switching to electric vehicles** will be essential. Electric vehicles are rapidly falling in price and are expected to be cheaper than conventional cars by the mid-2020s (when fuel savings are taken into account). Electric cars currently offer an average range of around 150 miles, which is more than sufficient for most car journeys (average trip distances are currently 8-12 miles) but could be a limitation for longer trips. The range of new electric vehicles will continue to increase as battery costs fall, ensuring more households can find a solution that suits their needs.
  - **Shifting to more sustainable modes of transport** could be a cost-effective alternative to private car ownership, depending on location. This could mean more walking and cycling (which would also provide health benefits by increasing the amount of physical activity people do) or low-carbon public transport (electric buses and trains) for longer journeys.
- **Electricity.** Household electricity emissions will also need to be very low in 2050, less than 0.03 tCO_2e. Many of the changes to continue reducing electricity emissions will occur on the supply side (e.g. more deployment of offshore wind) but households can take action by installing renewable technologies (e.g. solar PV). It will also be important to ensure that electric cars and/or heat pumps consume electricity smartly, in response to the needs of the grid - with smart systems in the home and across the grid, this can be automated based on price signals driven by supply and demand.
- **Diet and agriculture.** Agriculture is one of the largest remaining sources of emissions in our net-zero scenarios. Mapping of UK agriculture emissions against consumer diets is challenging (as not all food products produced in the UK are consumed here and much of what we consume is imported from abroad). However, taking UK agricultural emissions on a per household basis suggests average household emissions in our net-zero scenarios of between 0.4-0.7 tCO_2e in 2050, down from 1.6 tCO_2e today. While increases in the productivity of agriculture will bring down some emissions from food production, a big part of this reduction relies on household effort:
  - **Shifts towards healthier diets** relying less on carbon-intensive animal products (like lamb, beef and dairy) would bring down emissions from agriculture in the UK. Transitioning from a high-meat diet to a low-meat diet can enable a person to reduce their dietary emissions

Box 6.1. The role of households in a net-zero emissions society

by 35%. Even if reductions in our meat consumption do not translate into proportionate UK emissions reduction they would lead to real emissions reduction elsewhere in the world.

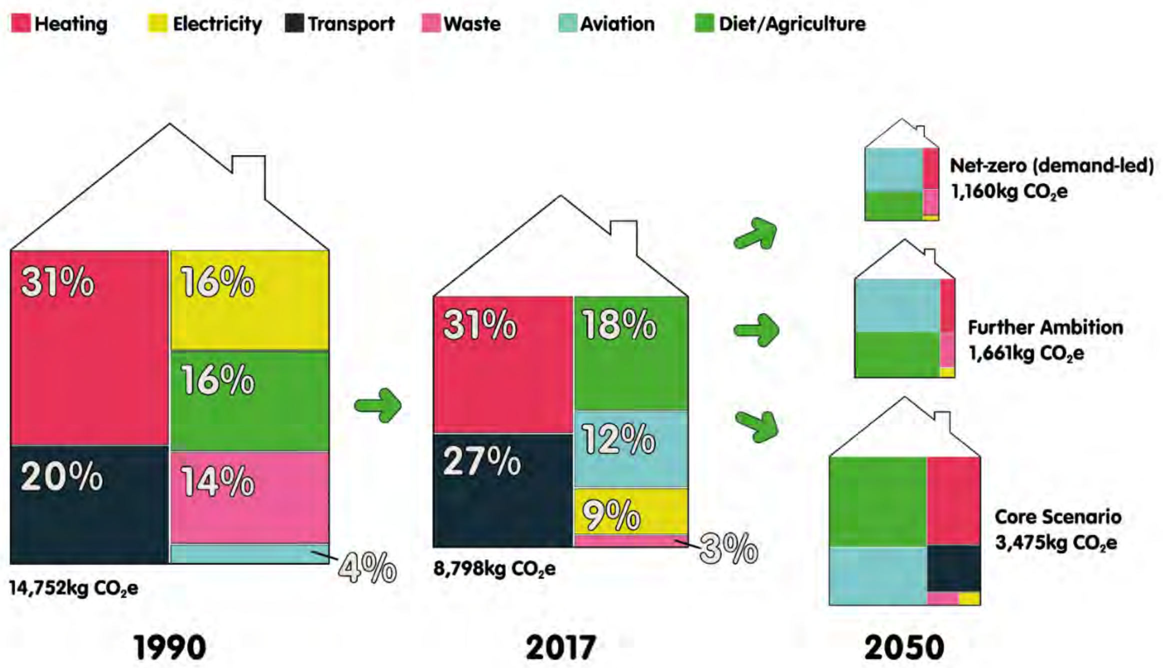
– **Reducing food waste** is a key step that individuals can take to reduce emissions. Currently, a significant share of agricultural land is devoted to the production of food that ends up being thrown away, often still in an edible state. Around 10 million tonnes of food that leaves the farm is wasted each year, with 70% of this being binned within households. This equates to consumers spending 14% of their weekly shop on food that goes in the bin.

- **Aviation** is the other big contributor to household emissions in our net-zero scenarios. Average household emissions range from 0.5-0.7 tCO_2e (for context, a return flight from London to New York is currently around 1 tCO_2e, half of which will be accounted for in the UK). Although technology is expected to help reduce emissions to some extent (e.g. aircraft fuel-efficiency improvements), achieving emissions reduction will require action from households:

  – **Choosing to fly less.** Not everyone in the UK flies - Government surveys suggest that half of those surveyed had not flown at all in the preceding year. Those who do could replace short-haul flights with train journeys and choose to go on fewer long-haul flights.

  – **Offsetting emissions.** In the long term, households that choose to continue to fly will still be able to, but their emissions will need to be offset by removing CO_2 from the atmosphere (see section 4(h)). This could be done directly by the airline, with the cost of offsets added to the ticket price.

Figure B6.1. Household emissions in 1990, 2017 and for different decarbonisation scenarios in 2050



Source: Energy Systems Catapult (2019) *Living Carbon-Free - Exploring what a net-zero target means for households.*

Source: Adapted by CCC from Energy Systems Catapult (2019) *Living Carbon-Free - Exploring what a net-zero target means for households*, available at theccc.org.uk

3. High-level policy implications for delivering net-zero emissions

The Committee's work since the Paris Agreement has increasingly been looking beyond what is needed to achieve an 80% emissions reduction, to achieving deeper decarbonisation. We have identified a range of approaches to reducing emissions to very low levels, which close the gap towards net-zero emissions. For many, but not all of these, policy development is underway. These policies must be strengthened and they must deliver action.

In moving from the present 2050 target to a net-zero target, the areas that were important as options (in case other sectors or technologies underperformed) become areas in which full delivery is now required.

Our expert advisory group on reaching net-zero emissions in the UK highlighted the major changes required in the way that policy approaches the low-carbon transition and the need for near-term action (Box 6.2).

The rest of this section is set out in five parts:

(a) The Clean Growth Strategy provides the right framework for action, but more is needed

(b) Policy must be stable and attractive to business

(c) People must be engaged in strategies for decarbonisation

(d) Skills gaps must be closed

(e) A true cross-Government effort is required

Box 6.2. The Expert Advisory Group on Reaching Net-zero Emissions in the UK

The Advisory Group (AG) was appointed to support and critically evaluate independently the Committee's analysis of scenarios and policy requirements for achieving net-zero emissions within the UK.

The group's members were drawn primarily from the academic community and also included representatives from business and industry. The group's chair, Professor Jim Watson of UCL, provided a summary report setting out the group's key conclusions, which are as follows:

1. A transition to a net-zero UK economy is technically achievable. *The advisory group's main concern is about whether this can be delivered – particularly the ability of government to implement the fundamental and wide ranging policy reforms necessary to achieve this goal by 2050.*

2. There is a need for a fundamental change in the UK policy approach to the low-carbon transition *– from the current piecemeal approach that focuses on specific actions in some sectors to an explicitly economy-wide approach. This should build on the world-leading Climate Change Act and include:*

- *Policy leadership at the heart of government. Whilst BEIS have played an important role so far, for example in leading the Clean Growth Strategy, action to reduce emissions cannot be left to one government department. HM Treasury needs to take a leading role, so net-zero becomes an explicit goal of economic policy (alongside other goals such as productivity improvement). Leadership should also mean a much more active role in delivery for all departments and agencies.*
- *The promotion of GHG emissions monitoring to the same status as economic monitoring, e.g. by publishing regular emissions metrics alongside GDP and productivity statistics.*

Box 6.2. The Expert Advisory Group on Reaching Net-zero Emissions in the UK

- *Ensuring that all policy decisions and sectoral strategies are informed by the requirement for them to contribute to the delivery of net-zero by 2050, e.g. through reforms to the 'Green Book'. In a net-zero world there is no room for any sectors to remain 'untouched', including agriculture and aviation.*
- *A flexible and responsive approach to policy that allows quick action and adaptation to take place if there is insufficient progress towards net-zero.*

3. The 2050 target should be implemented as a 100% reduction in GHGs from the UK on a production basis. *This can include a significant contribution from greenhouse gas removal (GGR) options.*

- *The use of offsets to achieve a small percentage of required emissions reductions is a possibility, and would provide government with some flexibility. Any offsets should support the international transition to net-zero.*
- *When monitoring progress towards net-zero, production and consumption emissions should be reported at the same time.*

4. All options that can help to meet a net-zero target domestically should be explored fully. *Single transition pathways, which rely on all technologies and measures succeeding are too risky and inflexible. They do not take into account the inherent uncertainties that lie ahead. The CCC analysis includes conservative assumptions about demand reduction. Therefore an important source of flexibility could be greater ambition on the demand side.*

5. Net-zero should not simply mean a shift in long-term aspirations*, with implementation left to future governments and generations. It also requires government and other actors to do things differently in the next five years. For example:*

- *The fundamental policy reforms discussed in recommendation 2 need to start now alongside more detailed policies. Whilst prices (including for carbon) matter, the evidence suggests regulations can play an important role in driving rapid change. This means implementing ambitious, economically-efficient regulatory targets to provide long-term visibility to citizens, firms and other decision-makers.*
- *There is an early opportunity to maximise the use of readily available GGR options including afforestation, agroforestry and land management.*
- *There is also an urgent need to trial, demonstrate and evaluate key technical and social innovations for net-zero. Public funding should be prioritised for innovations that can make significant contributions to achieving net-zero, and where there is potential for UK global leadership and wider economic benefits. Priorities should include large-scale trials of hydrogen; development of CCS transport and storage infrastructure; deployment of BECCS at scale; scaled up demonstrations of direct air capture; and trials of innovations to reduce emissions from aviation.*

6. The costs and benefits of a transition to net-zero, including distributional impacts, require much more attention. *This includes maximising the economic opportunities to the UK (e.g. by building leading positions in key industries of the future) and the global leadership benefits of being an early adopter of a net-zero target (e.g. via climate diplomacy and expertise on the policy and regulatory reforms required). However it is also essential to ensure the UK implements a 'just transition' to net-zero so that costs and benefits are fairly shared between income groups, industries and regions – as well as between current and future generations.*

Source: Adapted by CCC from Advisory Group report on Reaching Net-zero Emissions in the UK, available at theccc.org.uk
Notes: The advisory group was chaired by Prof Jim Watson (UCL) and included Dr Naomi Vaughan (University of East Anglia), Prof Peter Taylor (University of Leeds), Michelle Hubert (independent) and George Day (Energy Systems Catapult).

(a) The Clean Growth Strategy provides the right framework for action, but more is needed

The fourth and fifth carbon budgets (for 2023-27 and 2028-32) are on the cost-effective path to meeting the existing 80% target for 2050. The Government's Clean Growth Strategy (CGS) sets out ambitions in a number of important areas, and while policy is not yet on track to meeting those budgets, it remains possible to do so.

In the CGS and subsequently, policy development has begun for many of the components needed to reach net-zero GHG emissions:

- **Low-carbon power generation.** The Contracts for Difference signed to date for low-carbon generation, plus the aim in the Offshore Wind Sector Deal to deploy 30 GW of offshore wind by 2030, are important steps in power sector decarbonisation. Consistently strong deployment of low-carbon generation will be needed in order to quadruple low-carbon supply by 2050 (e.g. including at least 75 GW of offshore wind).
- **Buildings.** The recent announcement in the Spring Statement that new homes from 2025 will be highly efficient and will have low-carbon heating from the outset is welcome and must be delivered in full. The CGS stated ambitions for all existing homes to reach EPC band C by 2035 - important in order to reduce energy bills, reduce fuel poverty and increase suitability for low-carbon heating - and to phase out the installation of fossil fuel heating systems in properties off the gas grid. The CGS also acknowledged the need to make decisions in the first half of the 2020s about low-carbon heating for on-gas properties.
- **Electric vehicles.** The Government's Road to Zero strategy states an intention to end the sale of new conventional petrol and diesel cars and vans by 2040, with an expectation that the majority of new cars and vans sold in the UK will be zero emission by 2040 and that all new cars and vans will then have significant (but unspecified) zero-emission capability.
- **Carbon capture usage and storage (CCUS).** The CGS committed to deploying CCUS at scale in 2030s, subject to cost reductions. BEIS published its CCUS Deployment Pathway in 2018, designed to enable the development of the first CCUS facility in the UK, commissioning from the mid-2020s. Further publications are planned in 2019, on delivery and investment frameworks; shared industrial CO_2 infrastructure; and barriers to CCUS deployment.
- **F-gases.** The CGS committed the UK to ensuring that F-gases reduce by at least as much as required under the EU F-Gas Regulation, delivering a reduction of 68% in F-gas emissions between 2015 and 2030. Further reductions will be required in order to reduce F-gas emissions to near zero by 2050.
- **Afforestation.** Existing tree-planting targets across the UK already amount to 27,000 hectares per year. However, current levels are only around one-third of the targets. A sharp, sustained increase in afforestation is essential in order to deliver natural greenhouse gas removals at the necessary levels by 2050.
- **Agriculture.** The Agriculture Bill currently being considered by the UK Parliament aims to reward farmers for provision of public goods as it replaces the subsidy schemes currently in place under the EU Common Agricultural Policy. This could be used to promote the uptake of low-carbon farming practices and to encourage transformational land use change in line with our Further Ambition scenario.

The Clean Growth Strategy therefore provides a good foundation for the further action needed for a net-zero GHG target. However, there was little policy detail in the CGS on how ambitions are to be delivered. The policies must be strengthened and they must deliver action. We set out key elements of what is required in section 4.

(b) Policy must be stable and attractive to business

Reaching net-zero emissions in the UK will require high levels of investment in zero-carbon technologies, considerable development and expansion of infrastructure, and innovation to reduce costs and improve the performance of low-carbon technologies. Its delivery relies on businesses being able to invest, which in turn requires that they have confidence that they can earn a reasonable return.

However, a long-term target - even one in legislation - is not sufficient to provide this confidence. It is essential to have clear, strong, effective policies. We have heard a strong message from business stakeholders, both in discussions and through responses to our Call for Evidence,[166] about the value of policy stability and long-term clarity on the regulatory landscape in enabling them to invest at acceptably low levels of risk.

Moving from an 80% target to one for net-zero GHG emissions would provide Government with an opportunity to improve clarity over the extent of decarbonisation required in each part of the economy, without removing flexibility in how those emissions reductions are achieved:

- **Clarity on objectives.** Given the more stretching nature of a net-zero target, there are considerably fewer degrees of freedom in how to meet it. While this has some downsides, it should enable government to set out more clearly the role of each sector in achieving overall net-zero emissions. For example, while the Clean Growth Strategy identified three pathways to the current 2050 target based around electrification, hydrogen or greenhouse gas removals, all of these will be needed for a net-zero GHG target.
- **Maintaining flexibility on delivery.** Being clear on the level of emissions in each sector does not require the government to impose specific technological (or other) solutions, which could stifle innovation and lead to suboptimal solutions. Policies can be structured to be prescriptive about outcomes (e.g. specific levels of emissions reductions) without pre-determining the means with which these outcomes are achieved.

Greater ambition by 2050 means that the pace of action becomes even more important. This implies an important role for regulation in providing clear investment signals, which need to be provided in advance to allow businesses to prepare, and in ensuring that the required emissions reductions occur at the necessary rate. It also means that Government will need to take on some risk where necessary (e.g. on infrastructure development), to unlock opportunities for private-sector investment.

(c) People must be engaged in strategies for decarbonisation

To date, much of the success in reducing UK emissions has been invisible to the public. The halving of power sector emissions between 2012 and 2017 was delivered through the deployment of renewables, reducing coal-fired generation through carbon pricing and reduced demand through product standards. It did not require significant changes to how people use electricity. Mandating more efficient condensing boilers since 2005 has reduced buildings emissions alongside reducing energy bills, without changing how people heat their homes.

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[166] See www.theccc.org.uk/publication/building-a-zero-carbon-economy-call-for-evidence/ for all responses to the Call for Evidence.

However, while such policy approaches have been successful in some cases, they have allowed emissions reduction to proceed in a way that has not required mass engagement. Reaching net-zero emissions will require more involvement from people:

- Over 60% of the abatement in our net-zero scenarios to 2050 involve some degree of change from consumers (e.g. driving an electric car, or installing a heat pump instead of a gas boiler).
- 10% of the abatement is driven by consumer choices - shifting more quickly towards healthier diets, reducing growth in aviation demand and choosing products that last longer and therefore improve resource efficiency.

It will not be possible to get close to meeting a net-zero target without engaging with people or by pursuing an approach that focuses only on supply-side changes:

- At the moment, while the public are generally supportive of action to tackle climate change (Box 6.3), people who wish to reduce their impact on emissions are not provided sufficient support to make decisions that achieve this. People will need help to make low-carbon choices, both in terms of avoiding high-carbon activities and in adopting low-carbon technologies (see section 2(d)). This will require making low-carbon choices more available, provision of information, trials to see what works and policy that learns by doing (Box 6.4).
- Some of the difficult decisions that will be required, (e.g. on the balance of electrification and hydrogen that replaces natural gas heating), will only be possible if people are engaged in a societal effort to reach net-zero emissions and understand the choices and constraints.
- The transition will necessitate a shift in employment, away from some inherently high-emitting activities (e.g. fossil fuel supply) to highly-skilled jobs to deliver the emissions reductions required. A strategy will be needed to ensure a just transition across society, with vulnerable workers and consumers protected (see Chapter 7).

There is currently no government strategy to engage the public in the transition to a low-carbon economy. This will need to change. People should understand why and what changes are needed, see a benefit from making low-carbon choices and have access to the information and resources required to make the change happen. The engagement strategy should recognise the importance of co-benefits, for example the Department for Health has an important role in promoting healthier choices on diet and replacing short car journeys with walking and cycling, which improve people's health and reduce emissions.

Box 6.3. Public support for a net-zero emissions target in the UK

There is growing public concern about climate change, alongside increasing support for more ambitious climate action:

- According to a 2018 poll by Opinium and Bright Blue, 75% of people are either fairly or very concerned about climate change. 64% of UK adults agree the UK should aim to cut its emissions to zero over the next few decades, while 63% agree that the UK should be a global leader in tackling climate change.
- A large majority of UK households (90%) believe the UK should cut its emissions at least as quickly as other countries. In an earlier poll by Bright Blue, climate change was found to be the top issue that 18-28 year olds want to hear senior politicians address.
- According to a 2018 Public Attitudes Tracker poll by Government, support for onshore wind is at an all-time high of 76%, with people 15 times more likely to strongly support it than strongly oppose it. Solar has also hit an all-time high, with 87% of people supporting it. 65% of the public would be happy to live within five miles of a wind project, especially if projects are community-owned.

However, the polling by Bright Blue showed a disconnect between public concern about climate change and an understanding of what is required to reduce emissions across the UK economy. In order for the UK public to transition fully to a net-zero society, meaningful engagement and clear guidance from Government is likely to be required.

Source: BEIS (2018) *Energy and Climate Change Public Attitude Tracker*; Opinium and Bright Blue (2018) *Poll on Public attitudes to UK climate leadership – Ten years since the Climate Change Act*.
Notes: The sample size for the 2018 Bright Blue poll was 4,007 UK adults. Polling was undertaken by Opinium through online interviews and conducted between 28th February and 5th March, 2018.

Box 6.4. How policy can help people make low-carbon choices

The Committee appointed Dr. Richard Carmichael from Imperial College London to work with us on understanding the potential for people to make choices that can contribute to reducing emissions, and what this means for policy. His report on *Behaviour Change, Public Engagement and Net-zero* is published alongside this report, and identifies a number of policy implications:

- If the public are to become engaged with the climate challenge and contribute to achieving net-zero emissions then the wider policy context will also need to be more supportive. New, compelling narratives will be needed to inspire and mobilise mainstream participation in solutions, adoption of technologies and change in behaviours.
- Government must create a wider context which nurtures public engagement with action on climate change and must also enable consumers to take specific concrete actions that deliver large emissions reductions.
- These changes need not be expensive and can deliver large co-benefits, to health and beyond, but they are unlikely to happen rapidly unless policy first removes obstacles to change in markets and different consumer choices.
- Predicting the levels of change that will be delivered by these interventions is very difficult. Policy to deliver rapid societal change and technology adoption is uncharted territory and inherently subject to uncertainty. Government will need to take a pragmatic approach and learn by doing.
- Policies will need to work together and in sequence to deliver change in behaviours and markets, avoid negative outcomes and build public acceptance. Access to attractive and affordable

Box 6.4. How policy can help people make low-carbon choices

products and services, and support for informed choices and for new industry practices, should be in place wherever possible before interventions which raise prices for essential goods

- Data and information and communications technology (ICT) have emerged as important assets and tools for enabling consumers to make informed decisions about technology adoption (e.g. electric cars and hybrid heat pumps). There is potential across both energy and food for providing consumers with product information and feedback on purchasing habits (e.g. on diet) and for delivering change at the system level.

The report, published alongside this advice, sets out a range of policy interventions that could encourage changes across surface transport, aviation, heating and diet change.

Source: Carmichael (2019) *Behaviour Change, Public Engagement and Net-zero*, available at www.theccc.org.uk

(d) Skills gaps must be closed

The Government has recognised the importance of developing skills in its Industrial Strategy and sector deals. These, and the other levers available to the Government, should be used to tackle any skills gaps that would otherwise hinder progress.

Our previous work has particularly identified a skills gap in building design, construction and in the installation of new measures:

- Our scenarios include substantial deployment of measures such as heat pumps and wall insulation. However, in both of these critical areas deployment has stalled.
- Alongside increasing uptake, the low-carbon skills gap must be tackled if we are to deliver homes which maintain comfort levels for occupants, and do so affordably, whilst reducing emissions. Whilst skills will need to be developed across the new build and retrofit sectors, particular challenges exist for some segments of the stock, such as heritage buildings where different approaches may be needed.
- Support to train designers, builders and installers is urgently needed for low-carbon heating (especially heat pumps), energy and water efficiency, ventilation and thermal comfort, and property-level flood resilience.

We have not undertaken a comprehensive review of the skills required to meet our new net-zero scenarios. However, it is clear that there will be a sizeable challenge given the rapid changes involved. Some areas have overlaps with existing industries that would decline as emissions are reduced (e.g. CCS and the oil and gas sector).

The Industrial Strategy and the sector deals provide one opportunity to address the skills challenge. The ongoing overhaul of technical and vocational training presents another opportunity. Regional skills assessments will also be critical (e.g. through the Skills Advisory Panels).

(e) A true cross-Government effort is required

Emissions reduction must be embedded meaningfully in the objectives of the key Ministerial departments - and at each level of government in the UK, so policy decisions can have the greatest impact. It must also be integrated with businesses and society at large.

Since many of the solutions cut across systems, fully integrated policy, regulatory design and implementation is crucial. That may require new frameworks, for example to ensure that departments, other than BEIS alone, sufficiently prioritise net-zero GHG emissions. Policy teams across departments must be sufficiently resourced to develop and implement the changes required.

Reaching net-zero emissions will require action across the economy, and across responsibilities of a wide range of government actors, at different levels and with different responsibilities. They will all need to embrace the challenge:

- **HM Treasury.** The strategic question of how to pay for the remaining economy-wide decarbonisation must now be confronted. Treasury has previously sanctioned the large annual spend that has driven deployment and cost reduction for renewables in the power sector. Those costs will decline to 2050, but others (e.g. for heating and industry) will rise. We therefore recommend that Treasury conducts a review of how the costs of achieving net-zero emissions are distributed and the benefits returned across the various integrated sectoral challenges. This will require consideration of how costs fall on consumers, the fiscal impacts, risks of competitiveness effects and the impacts of decarbonisation across the whole economy. We set out our evidence on these in Chapter 7. The review should make an integrated assessment of the full range of policy levers, including carbon pricing, taxes, financial incentives, public spending, regulation and information provision.
- **UK government departments.** Most obviously, action at UK government level will be required by those departments with lead responsibility for one or more of the emitting sectors (i.e. **BEIS** on energy and industry, **MHCLG** on buildings, **DfT** on transport and **Defra** on waste, agriculture and land use).[167] However, other departments will be important to deliver the full range of changes that will be necessary. For example **the Department for Health** has an important role in raising awareness and increasing public engagement on action to reduce emissions and **the Department for Education** has a key role on skills.
- **The Governments of Scotland, Wales and Northern Ireland** must make full use of the policy levers available to them and work with the UK government closely to ensure delivery in those areas that are not devolved. This means making particular use of devolved policy levers on the demand side even where supply-side policies are reserved to the UK government (e.g. encouraging walking and cycling), providing 'soft' support (e.g. advice on buildings retrofits) to support UK government policies, and use of planning and procurement powers to drive decarbonisation (see section 5).
- **Cities and local authorities** are well placed to understand the needs and opportunities in their local area, although there are questions over well they have sufficient resources to contribute strongly to reducing emissions. They have important roles on transport planning, including providing high-quality infrastructure for walking and cycling, provision of charging infrastructure for electric vehicles, and ensuring that new housing developments are designed for access to public transport. They can improve health outcomes for people who live and work in the area by implementing clean-air zones that discourage use of polluting vehicles and other technologies.

[167] The Department for Business, Energy and Industrial Strategy (BEIS), the Ministry of Housing, Communities and Local Government (MHCLG), the Department for Transport and the Department for the Environment, Food and Rural Affairs.

- **Regulators** will also need to help drive the transition to net-zero emissions in a number of areas.
  - These most obviously include Ofgem, especially on energy network infrastructure (see section 2(b). Regulatory frameworks may need to evolve as new vectors emerge and with an increasing integration between systems (e.g. hydrogen, which will need to be produced using CCS and could supply power generation, heating, transport and industry).
  - There could also be a role for financial and pension regulators, for example in requiring and monitoring disclosure of exposure to climate risks and compatibility of investments with a net-zero target.

The shift from aiming for an 80% reduction to net-zero emissions reduces the flexibility to leave significant residual emissions in any sector: each sector must get very close to the Further Ambition scenario presented in Chapter 5. This raises the question of whether sectoral targets may be a useful tool to provide greater focus on what is required in each sector.

4. Policy pre-conditions of a net-zero target

Parliament should understand that setting a net-zero target is a commitment to a concerted increase in policy effort in the near term. This will need to address the key areas for 2050 that are not already on track, as well as those that become more important for a net-zero GHG target.

This section sets out what is required across the key options included in our Further Ambition scenario.

Many of the messages in this section are not new: the Committee has been recommending many of these approaches for some time. In setting a net-zero target, each of these areas must be addressed without delay.

(a) Carbon capture and storage (CCS)

The Committee has consistently stressed the importance of CCS in achieving the current 2050 target for an 80% reduction at lowest cost and as an enabler of deeper emissions reductions beyond that. The Clean Growth Strategy stated an ambition to deploy carbon capture usage and storage (CCUS) at scale during the 2030s, subject to costs coming down sufficiently. Given its strategic importance in achieving deep decarbonisation, CCS is a necessity for a net-zero target.

By 2050, CCS has a large potential role to play in multiple applications. Our Further Ambition scenario requires annual CO_2 capture volumes of up to 175 $MtCO_2$ by 2050, across industry, greenhouse gas removals (GGR), hydrogen production and power generation. While the amount of CCS for energy generation from fossil fuels could be significantly lower than we have assumed, we stress that all currently credible pathways through which the UK could reach net-zero emissions domestically all involve a significant role for CCS, especially for industry and GGR.

The evidence base[168] is clear that UK deployment of CCS is required to unlock the greatest opportunities for cost reduction:

- The UK has some of the most advantageous CO_2 storage potential of any country in the world, and will need a large contribution from CCS by 2050. The CO_2 transport and storage

[168] For example Pöyry and Element Energy (2015) *Potential CCS Cost Reduction Mechanisms*; CCSA (2016) *Lowest cost decarbonisation for the UK: The critical role of CCS.*

infrastructure required for CCS is capital intensive and is also subject to large economies of scale – costs can be reduced significantly compared to one-off projects through sharing of large-scale infrastructure between projects. The earlier CO_2 infrastructure is deployed at such scale in the UK, the earlier CCS can be deployed cost-effectively.

- Reductions in cost of capital can be achieved by proving the technology and business model in the UK. It is clear that a significant part of the reductions in the strike prices for offshore wind following deployment at scale in the UK has resulted from reductions in the cost of capital, as the technology becomes more established, and supply chains and business models develop. While technology costs can be reduced via global deployment, reductions in the cost of capital for CCS in the UK will require UK deployment.

Our assessment is that delivery of CCS requires action on CO_2 infrastructure, development of the hydrogen option and policy frameworks across energy generation, industry and greenhouse gas removals:

- **CO_2 infrastructure.** An approach to CO_2 infrastructure development and funding is needed that is separate from that for individual projects. CO_2 infrastructure roll-out and initial projects should lead to multiple CCS clusters being operational by the mid-2020s, and all major clusters having CO_2 infrastructure by around 2030.
- **Development of the hydrogen option.** Given the importance of hydrogen in our net-zero scenarios, especially in industry, and the importance of CCS to its production at large scale, hydrogen production should start at scale by 2030 at each of the industrial CCS clusters.
- **Policy frameworks.** Delivery of CCS projects across the range of applications requires a policy framework that covers energy generation, industry and greenhouse gas removals. In addition to supporting infrastructure development, a framework to support decarbonisation of heavy industry should be developed and implemented by the end of 2022. Initial industry projects could require a support mechanism prior to this. Given the scale of BECCS that might be required by 2050, the Government should aim to have an initial BECCS project at scale early on (e.g. by around 2030).

Given the lack of progress to date on CCS and its greater role as ambition goes beyond an 80% reduction by 2050, progress in deploying CCS in the 2020s is a crucial enabler to putting the UK on track to meeting a net-zero target.

(b) Bringing forward the electric vehicle switchover

Due to sharp reductions in battery costs, we anticipate that the lifetime costs of electric cars and vans will reach parity with internal combustion engine (ICE) vehicles, without subsidy, by the mid-2020s from a social perspective (i.e. before considering that electric vehicles do not pay fuel duty). The absence of fuel duty for electric vehicles means that they will reach parity even earlier from a consumer perspective.

Bringing forward the switchover to electric vehicles earlier than 2040 will lead to lower greenhouse gas emissions in 2050 and on the pathway to this, improve air quality, and be financially beneficial to the UK (Figure 6.3).

Given these advantages in cost, greenhouse gas emissions and air quality, the aim should be for electric vehicles to have as high a share as possible of the new-vehicle market by 2030. Ideally, ultra-low emission vehicles would reach 100% of sales of cars, vans and motorbikes by 2030 or soon after, but must certainly do so by 2035.

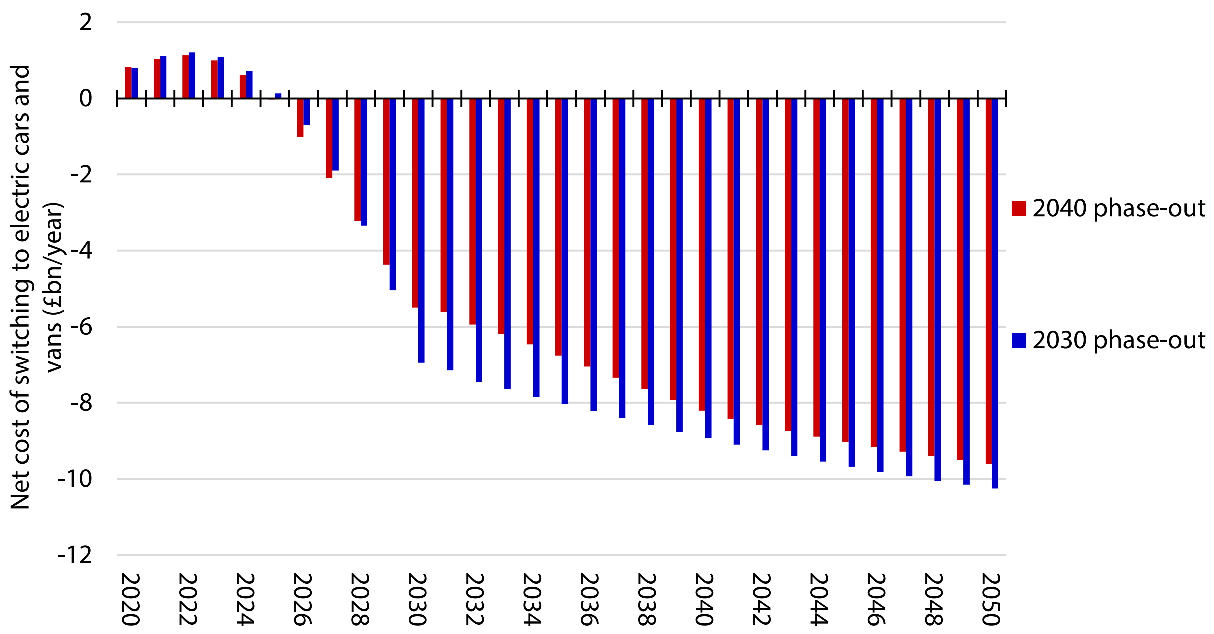
Scaling up from the current 2.5% share of car sales will require timely investments in charging infrastructure and policy to encourage uptake and provision of models by the industry:

- The government must bring forward the end of sales of new conventional cars and vans to 2035 at the latest, ideally earlier, and extend this to cover any car or van with petrol or diesel combustion engines. This will ensure that by 2050 very few petrol and diesel vehicles will remain, which can then be addressed through regulation if necessary. The scope should also be extended to cover motorbikes.
- Financial incentives will be required in the near term to support the still early market of electric cars, vans, small HGVs and motorbikes, until cost parity is reached with conventional vehicles from the view of a private consumer, likely in first half of the 2020s. Electric car and van charging infrastructure roll-out must be monitored to ensure that sufficient deployment occurs in readiness for the growing proportions of the fleet being fully electric.

We also identify several other priorities for the transport sector:

- Trials of zero-emission HGVs and associated refuelling infrastructure should be planned from now until the early 2020s to develop an evidence base to enable decisions to be made on the most cost-effective and practical zero emission option. The Government must prepare to make this decision in the mid-2020s, with international coordination, to enable infrastructure to be developed ready for the deployment of zero emission HGVs in the late 2020s and throughout the 2030s. Vehicle and fuel taxation from the 2020s onwards should be designed to incentivise commercial operators to purchase and operate zero emission HGVs.
- The Government must encourage walking, cycling and the use of public transport in preference to car usage wherever possible, including through provision of infrastructure for safe and practical cycling, to exploit opportunities for emissions reductions in the nearer term, as well as achieving health co-benefits from active travel and improved air quality.
- Opportunities to improve the logistical efficiency of HGVs should be explored, including increased roll-out of urban consolidation centres to minimise journeys into busy urban centres and adjusting delivery times to ensure HGVs can avoid congestion.
- Rail electrification should be planned on a rolling basis to keep costs low, and trials of hydrogen trains on UK rail should be supported where necessary.

Figure 6.3. A 2030 switchover to electric vehicles would save more money than a 2040 switchover



Source: CCC analysis.
Notes: Costs are compared to continued use of petrol and diesel cars, and are the subsidy free total lifetime (14 years) costs relating to all new vehicles bought in that year. Includes upfront vehicle cost, refuelling cost (discounted at 3.5%), and costs of charging infrastructure, electricity generation and network expansion. To better represent vehicles available in the future we assume the costs and efficiencies of petrol and diesel cars also develop over time. As a result, these figures are not directly comparable to others in this advice. Until 2028 costs are slightly higher for a 2030 phase-out date, which is largely due to electric vehicles being more expensive until this point and greater charging infrastructure requirements. Costs for a 2035 switchover date are not shown, but are slightly higher than for a 2030 switchover.

(c) Making sure UK heating systems are fully low-carbon by 2050

Energy efficiency retrofit of the 29 million existing homes across the UK should now be a national infrastructure priority. A fully-fledged strategy for decarbonised heat must be developed in 2020. The Government's planned 2050 heat roadmap must establish an approach that will lead to full decarbonisation of buildings by 2050. It is essential that Treasury commits to working with BEIS on this and to allocating sufficient funding. The strategy must include:

- **A clear trajectory of standards** covering owner-occupied, social- and private-rented homes and non-residential buildings, announced well in advance. This includes standards for energy efficiency, detailed plans on phasing out the installation of high-carbon fossil fuel heating and improvements in the efficiency of existing heating systems. Energy efficiency is the key precursor to low-carbon heat and delivers most benefits when deployed early.
- **A regulatory and support framework for low-carbon heating** (heat pumps, biomethane, and networked low-carbon heat) to address the multi-billion pound funding gap. Decarbonising homes by 2050 implies ensuring that by 2035 at the latest, all new heating system installations are low-carbon. In order to develop supply chains, this will require signalling well in advance, alongside deployment of heat pumps at scale in the 2020s.

- **A review of the balance of tax and regulatory costs across fuels** in order to improve alignment with implicit carbon prices and reflect the progressive decarbonisation of electricity: costs are significantly larger for electricity than gas or oil heating, and the full carbon costs are not reflected in the pricing of heating fuels. These factors currently weaken the private economic case for electrification.
- **An attractive package for householders aligned to trigger points** (such as when a home is sold or renovated). Regulatory and support frameworks for energy efficiency and low-carbon heat should facilitate this. It is critical that this also includes removal of barriers which prevent occupants from bringing about the necessary action to improve the quality of the buildings they live and work in. This could require legislative reform to address issues such as the misalignment of freeholder and leaseholder incentives.
- **A nationwide training programme to upskill the existing workforce**. A properly skilled workforce is critical to enabling effective deployment of energy efficiency and low-carbon heating measures which perform as they should. The UK Government should use initiatives under the Construction Sector Deal to tackle this low-carbon skills gap. New support to train designers, builders and installers is urgently needed for low-carbon heating (especially heat pumps), energy and water efficiency, ventilation and thermal comfort, and property-level flood resilience.
- **A governance framework to drive decisions on heat infrastructure** through the 2020s. Making strategic decisions on the future of heat provision and the gas grid will be difficult for any government. It requires the acceptance of higher short-term costs and a long-term outlook, beyond the standard Parliamentary timetable. Nevertheless, as an infrastructure issue with long lead-times, it must be addressed with strategic decisions in the 2020s if we are to achieve the necessary decarbonisation by 2050.

The allocation of costs to consumers and the Exchequer will depend on policies put in place to drive the required changes. HM Treasury should undertake a review of where the costs of the transition fall and develop a strategy to ensure this is perceived as fair (see section 3(e)). In relation to buildings, it should include consideration of the use of fiscal levers and Exchequer revenue, costs from carbon trading schemes, the costs to industries, and the impact on energy bill-payers (including the fuel poor). It should cover the costs over the full period from now to 2050.

The Government must implement policies to deliver the commitments announced under the Future Homes standard - namely to ensure new build homes have low-carbon heating and world-leading levels of energy efficiency by 2025, alongside ambitious standards for new non-residential buildings. In addition to being low-carbon, these new buildings must be energy and water efficient and climate resilient.

Realising deep emissions reductions in buildings will require co-ordination and co-operation across all levels of Government, industry, businesses and householders. Policy development by central Government and Devolved Administrations must be implemented effectively at local level, with evolution in the planning system to keep pace with Government ambitions. Cooperation from industry is central, driving down costs through innovation and delivering solutions in homes and businesses. Finally, the absence of public engagement on these critical issues must be addressed, to prepare for and inform the changes to come and to enable individuals to take action now to drive down emissions associated with their homes and businesses.

(d) Reducing emissions from industry, not offshoring them

It is urgent that the Government establishes an overall framework to support long-term industrial decarbonisation, as committed to in the Clean Growth Strategy. Further delay is likely to result in higher costs overall, due to the need for early write-off of assets (i.e. scrappage).

The scenarios we set out for reducing UK emissions from industry rely on retaining the industrial base that we have and decarbonising it, rather than 'offshoring' of emissions to other countries (i.e. 'carbon leakage'). The design of the policy framework to reduce UK industry emissions must ensure it does not drive industry overseas, which would not help to reduce global emissions, nor the UK economy. As a carbon-neutral economy, reshoring industry to the UK will ultimately improve the global effort to tackle climate change.

The Government should also help to ensure that the UK realises the benefits of ambitious decarbonisation. By providing an attractive investment environment, including stable policy, the UK can become a leader in production of low-carbon goods, attract increased investment in productive new and existing industries, and develop new businesses and products (see Chapter 7).

Encouraging deep decarbonisation in industries at risk of carbon leakage will likely require new policy mechanisms, as it is unlikely that carbon prices under the EU emissions trading system (or a UK equivalent) will rise high enough with sufficient lead-time to incentivise the range of changes required. There is a range of possible ways of decarbonising industry in a way that avoids offshoring of emissions, where much of the cost of industrial decarbonisation is either passed on to consumers in higher prices or borne by taxpayers:

- **Creation of a low-carbon market.** Demand for low-carbon goods could be created through certification and regulation of end uses (e.g. buildings), creating a premium price for low-carbon goods. In this case the consumers would bear the cost. Alternatively, such a market could be driven by public procurement, in which case Government and taxpayers would bear the cost.
- **Sectoral agreements** would be a direct way of ensuring that one country's firms in a given industry sector are not at a competitive disadvantage to those in other countries. This will tend to work better in industry sectors in which there is a small number of firms (e.g. steel). Under this approach industry would pay for the emissions reductions, which could then be passed through consumers in higher prices without competitiveness impacts.
- **Border-tariff adjustments** would raise the price of high-carbon imported goods, stop the need for free allowances and thus allow all UK emissions to be subject to carbon pricing without the need to compensate for costs not faced by international competitors. This could enable the policy to support deep decarbonisation in sectors that would otherwise be at risk of carbon leakage. It would also send a signal to other manufacturing countries to decarbonise their production. Under this approach industry would pay for the emissions reductions, which could then be passed through consumers in higher prices without competitiveness impacts.
- A recent review of business models for BEIS has set out some further potential options (for supporting industrial carbon capture), which largely draws on comparable existing policies.[169] This identified a range of ways of providing funding for industrial decarbonisation

[169] Element Energy (2018) *Industrial carbon capture business models*. Report for BEIS.

potentially through taxpayer funding (e.g. a contract for difference on the CO_2 price, regulated asset base, tradeable CCS certificates).

It may be that for an interim period, industrial decarbonisation of trade-exposed sectors can be funded by taxpayers, but this is unlikely to be fiscally sustainable in the longer term given increasing decarbonisation over time. As other countries take action to meet their commitments under the Paris Agreement, there would need to be a transition away from taxpayer funding.

(e) Scaling-up of decarbonised electricity supply

Our Further Ambition scenario has a very important role for electrification as a key route to reducing emissions, across surface transport, buildings and some industrial processes. Much of this is high-efficiency electrification, keeping costs and the demand for low-carbon electricity manageable (at 600 TWh per year) by 2050, around double the size of today's system. If less efficient decarbonisation choices are made, electricity demand in 2050 could be considerably higher (Figure 6.4).

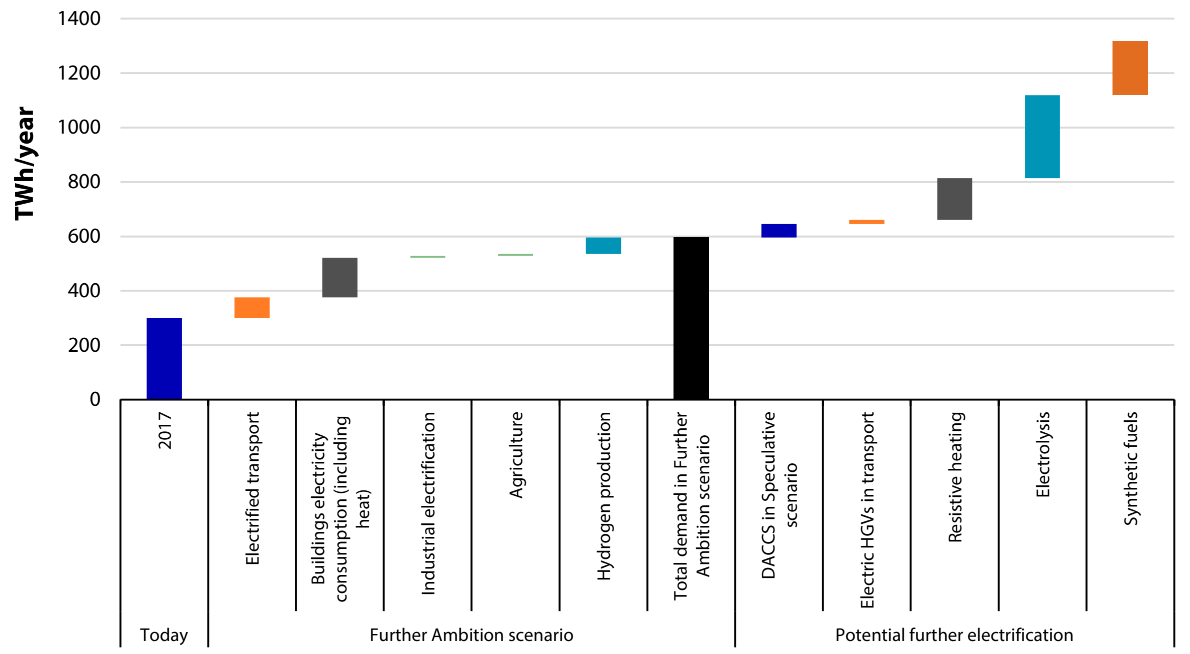
However, there is also considerable potential for electricity to extend beyond these uses at higher costs, generally when used at lower overall efficiencies. Given the Speculative options we have identified, there is potential for electricity demand to be much higher than in our Further Ambition scenario, potentially up to four times the size of today's power system (Figure 6.4). It is inherent in these more Speculative options that they would tend to be deployed towards the back end of a transition to net-zero emissions.

Keeping open the option of having a larger low-carbon electricity system than we have assumed under the Further Ambition scenario would allow for a wider range of ways to reach net-zero emissions. In order to achieve this, it will be important for build rates in the near term to be relatively high, both in order to reduce the amount that needs to be built later on and to develop supply chains. It makes sense to do so both to reduce emissions from the current system and to expand the system through electrification:

- Contracts can now be signed for renewable capacity (i.e. wind and solar) in the early 2020s that are cost-competitive with high-carbon generation. As such, strong deployment of these renewables through the 2020s will not have high costs, even when including deployment of flexibility measures to accommodate high levels of inflexible generation. As costs of low-carbon generation have reduced, it has only strengthened the case for achieving a carbon intensity of below 100 gCO_2/kWh by 2030.
- Accelerating the rate of electrification by adding flexible loads, in the form of electric vehicles and hybrid heat pumps, to the system at scale in the 2020s would increase demand and enhance the ability of the system to accommodate inflexible generation. This would enable greater additions of renewables in parallel during the 2020s, and in doing so would reduce the average cost of electricity.[170] As well as maintaining high build rates for the power sector, this would enable the transport and buildings sectors to progress more rapidly towards zero greenhouse gas emissions and also improve air quality.

[170] Vivid Economics and Imperial College (2019) *Accelerated electrification and the GB electricity system*.

Figure 6.4. The roles for electrification in Further Ambition and potential to go beyond this



Source: CCC analysis based on the capacity and generation mix in the 'Hybrid 10 Mt' scenario of Imperial College (2018) *Analysis of alternative heat decarbonisation pathways.*
Notes: The entry for HGVs in transport refers these vehicles switching to electricity rather than hydrogen.

(f) Embedding emissions reduction and removal in agriculture and land policy

There is now an opportunity to define a better land strategy that responds fully to the challenge of climate change. The Government's Agriculture Bill and proposed Environment Bill will set the future direction of policy for the use of land. This is an important moment to influence the design of a set of policies that have been largely out of scope for decades. It is essential that the key objectives of the Climate Change Act - achieving deep emissions reduction and adapting to the impact of a changing climate - are at the heart of reforms.

A future land strategy that delivers the UK's climate goals whilst balancing other pressures will require fundamental changes to how land is used:

- Implementing low-carbon practices within the current pattern of land use can offer some emissions reduction, by improved farming practices such as better soil and livestock management, but would still leave agriculture as one of the biggest emitting sectors.
- Deep emissions reductions can be achieved by releasing agricultural land for other uses, even while maintaining current per capita food production. Afforestation (increasing forest cover from 13% of all UK land today to up to 19% by 2050), restoring over half of peatlands, catchment-sensitive farming and agricultural diversification can contribute to meeting these reductions. Land use will have to change due to the impacts of climate change and it is important that future land use decisions are taken to both reduce emissions and improve resilience of land to climate impacts.
- Changes in farming practices and dietary preferences will drive the release of land, but these can build on a number of government initiatives already taking place. These include:

improving sustainable agricultural productivity; promoting healthy eating through government nutritional guidelines which could reduce consumption and production of the most carbon-intensive foods; reducing food waste along the supply chain; and increasing forest productivity. Land released through these measures can be used for afforestation, peatland restoration and biomass production, where environmental risks are managed.

Existing policy is not delivering enough - tree-planting rates are well below government targets across the UK. New land use policy should promote transformational land uses and reward landowners for public goods that deliver climate mitigation and adaptation objectives. New policies should also reflect better the value of the goods and services that land provides. The key measures that have clear, multiple benefits are: afforestation and forest management; restoration of peatlands; low-carbon farming practices; improving soil and water quality; reducing flood risks and improving the condition of semi-natural habitats. Measures should be rewarded if they go beyond a minimum standard that land-owners should already be delivering.

Support should be provided to help land managers transition to alternative land uses. This includes help with skills, training and information to implement new uses of land, and support with high upfront costs and long-term pay-backs of investing in alternative uses. It should also include action to address barriers to the take-up of innovative farming practices, which will drive productivity improvements. A structured approach to incorporating the potential impacts from a changing climate into long-term planning is essential for land managers to adapt successfully to climate change. The government should provide support and information through the National Adaptation Programme or the new Environmental Land Management System, to allow this planning to take place.

In addition to reducing emissions from parts of the land use and agriculture sector, it will also be necessary to incentivise greenhouse gas removals, both through established natural methods (i.e. afforestation and soil carbon sequestration) and other removals approaches such as sustainable production of bioenergy and use with carbon capture and storage (BECCS). We consider how removals can be incentivised in section (h)).

(g) Implications for aviation and shipping policy

A net-zero target will require more effort from all sectors, including aviation. The Committee's advice is that a net-zero target for 2050 should cover all sources of GHG emissions, including international aviation and shipping. We will set out our recommended policy approach for aviation in follow-up advice to the Government later in 2019.

Reducing emissions from aviation will require a combination of international and domestic polices, and these should be implemented in ways that avoid perverse outcomes (e.g. carbon leakage). A package of policy measures should be put in place that include carbon pricing, support for research, innovation and deployment, and measures to manage growth in demand:

- **A long-term goal for international aviation emissions.** The International Civil Aviation Organisation's current carbon policy, CORSIA, has an end date of 2035. It will need to be based on robust rules that deliver genuine emission reductions (see section (h) below). A new long-term goal for global international aviation emissions consistent with the Paris Agreement would provide a strong and early signal to incentivise the investment in new, cleaner, technologies that will be required for the sector to play its role in meeting long-term targets. This is particularly important in aviation given the long lifetimes of assets. A similar approach has been agreed for global shipping emissions in the IMO, which has set a target for greenhouse gas emissions to be at least 50% below 2008 levels by 2050.

- **Support for research, innovation, and deployment.** Our analysis, and that of industry, suggests the largest contribution to reducing aviation emissions will come from new technologies and aircraft designs. Many of these developments are likely to be cost-effective, given their potential fuel savings. The Government should build on the approach set out in the Aerospace Sector Deal and Future Flight Challenge, and set out a clear strategy to ensure these technology solutions are developed and brought to market in a timely fashion. Synthetic fuels should not be a priority for government policy, but if industry wants to pursue them it should focus on demonstrating that these fuels, used in aviation, would be genuinely low-carbon, could become cost-competitive and are scalable in a global market.
- **Measures to manage growth in demand.** The Further Ambition scenario allows for a 60% growth in passenger demand by 2050 compared to 2005 levels (25% from now). Without additional policies being put in place, government projections suggest demand could be higher than this (e.g. their central case is for around a 90% growth in demand by 2050 on 2005 levels). New UK policies will therefore be needed to manage growth in demand. These could include carbon pricing, reforms to Air Passenger Duty, or policies to manage the use of airport capacity. Recent research commissioned by the DfT[171] shows that UK policies to manage demand in aviation would not lead to carbon leakage from the UK to other countries in aggregate, given the relatively small amount of emissions affected. Policies to manage demand can therefore be pursued without significant risk of perverse impacts.

Action is also needed on non-CO_2 effects from aviation. These cause additional warming but should not be included within targets at this stage given their short-lived effects and uncertainty over how to measure and report their impact in the emissions inventory (Chapter 2). However, the Government should develop a strategy to ensure that these effects can be mitigated over the coming decades (e.g. by 2050-2070 for pathways that meet the Paris Agreement) without increasing CO_2 emissions. Demand-side measures are one way to reduce these effects.

The Government is aiming to publish an Aviation Strategy later in 2019, and published a consultation on this in December 2018. The consultation commits to regular updates of the Aviation Strategy. These regular reviews will provide an opportunity to respond to a future decision by Parliament to meet the UK's commitments under the Paris Agreement. The final White Paper should aim to set more specific time-points for these reviews, and align them to developments in government climate strategy overall.

Policy for international shipping is also led at the international level, by the International Maritime Organisation (IMO). The IMO have set a target to halve global shipping emissions by 2050. That would require a significant roll-out of low-carbon fuels (e.g. ammonia), but not enough to meet our Further Ambition scenario. Increased ambition will therefore be required for shipping, along with a set of tangible policies to deliver that ambition.

(h) Potential options for funding UK CO_2 removals

For some 'hard to reduce' sectors (e.g. aviation and agriculture), even with strong policies, it is highly likely that there will be significant remaining emissions in 2050. In achieving net-zero emissions overall, these emissions will need to be balanced with greenhouse gas removals (Figure 6.5).

One potential way to achieve this would be to place requirements on each sector to reach net-zero emissions through a combination of emissions reduction and funding of removals. We note

[171] ATA and Clarity (2018) *The carbon leakage and competitiveness impacts of carbon abatement policy in aviation*.

that the sectors already partially or fully involved in emissions trading at EU level (i.e. industry, energy generation and aviation) together would have net emissions below zero in 2050 under our Further Ambition scenario if removals from bioenergy with carbon capture and storage (BECCS) were attributed to the energy generation sector.

Requiring sectors to offset residual positive emissions by paying for removals would provide both a financial incentive for emissions to be as low as possible in those 'hard to reduce' sectors and a mechanism to fund greenhouse gas removals that are genuinely additional to those that would occur otherwise:

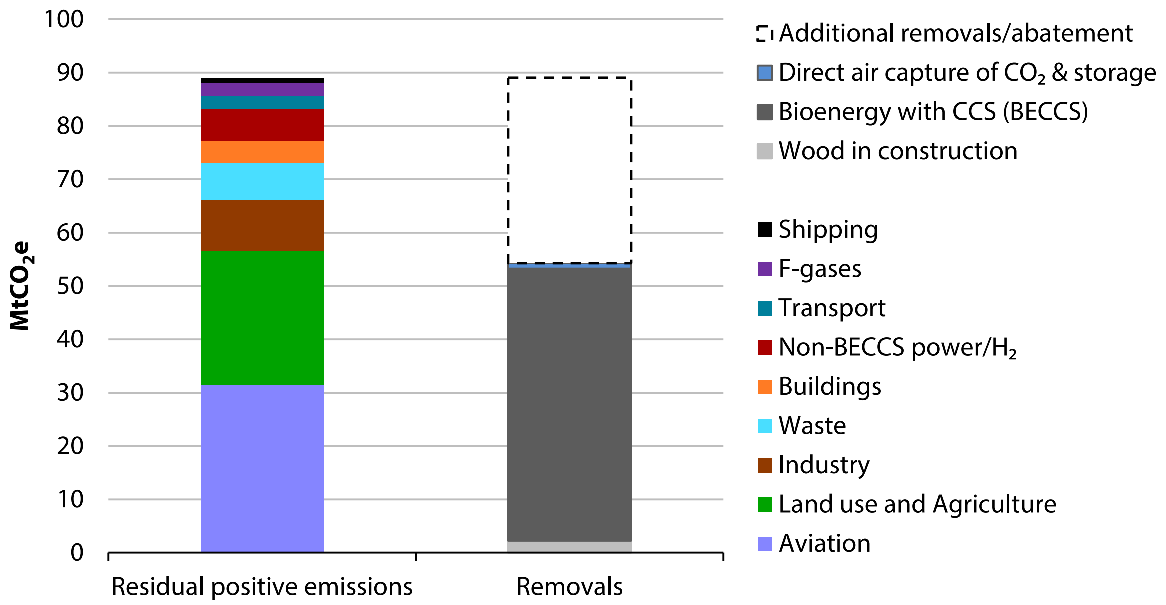
- The sector could be required to achieve net-zero emissions, which could be achieved through a combination of measures to reduce emissions (e.g. as in our Further Ambition scenario) and then getting to net-zero by paying for greenhouse gas removal (GGR):
  - The need to pay for removals to offset remaining emissions effectively places a carbon price on activities that remain carbon-intensive, providing a financial incentive to drive supply-side measures to reduce emissions as well as potentially dampening demand.
  - Any remaining emissions in the sector would then need to be matched by GGR deployment that is genuinely additional to what would have occurred otherwise.
- Alternatively, the Government could impose a carbon price on emissions in order to generate revenues that can be used to pay for Government-procured greenhouse gas removals. This could be done either through a trading scheme with a suitably tight cap or via a tax of a sufficient level to generate the necessary revenues.
- As some GGR options (e.g. afforestation) have relatively low costs but are limited in scope, it should be assumed that these opportunities will be taken in any case and will not provide additional scope to offset positive emissions elsewhere. The GGR options appropriate to offset 'hard to reduce' emissions will therefore generally be those that are highly scalable and towards the higher end of GGR costs, for example use of BECCS or direct air capture of CO_2 with storage (DACCS).
- Removals could in principle either be based in the UK or overseas. However, for CCS-based removals it would make sense for a substantial proportion of these to occur domestically, given the UK's advantages relating to availability of CO_2 storage capacity, offshore engineering expertise, and market regulation and design. Regardless of location, there would need to be appropriate criteria to ensure that removals are additional to what would have happened otherwise, together with strong governance arrangements to ensure that the removal of greenhouse gases occurs in the intended way. For BECCS, this includes strong sustainability criteria on the biomass used, whether produced in the UK or overseas.

In principle, rather than offsetting remaining emissions with BECCS or DACCS, the aviation industry could instead use synthetic carbon-neutral fuels, thereby reducing the sector's emissions to zero on a 'gross' basis rather than a 'net' basis. However, such synthetic fuels are likely to be expensive, entailing recycling captured CO_2 (e.g. via direct air capture) into a drop-in replacement for kerosene. As set out in Chapter 5, we expect these synthetic fuels to be significantly more expensive than achieving the same emissions outcome by sequestering the same amount of CO_2 geologically to offset remaining fossil kerosene use. However, given the equivalence of these options in terms of emissions, it is not necessary for the policy framework to prefer one or the other.

For the agriculture sector, in addition to the actions to reduce positive emissions there will need to be added focus on enhancing sinks on farmland (e.g. by planting trees). It is very encouraging that the National Farmers' Union has stated an ambition to achieve net-zero greenhouse gas emissions by 2040.

In order to deliver removals sustainably and at lowest cost, it will be necessary to have a suitable governance framework and policy that enables their development and deployment. Policy will need to support development and deployment of removals, by providing financial incentives, CO_2 transport and storage infrastructure to enable deployment of BECCS and DACCS, and innovation support (see section 2(c)).

Figure 6.5. Greenhouse gas removals required to balance positive emissions in 2050



Source: CCC analysis.
Notes: Sectoral emissions and contributions from removals presented for the Further Ambition scenario. The contribution from 'additional removals/abatement' refers to the options to go beyond the Further Ambition scenario and achieve net-zero emissions, which can be done with additional removals and/or further reductions of positive emissions (see Chapter 5).

5. Implications for policy made in Scotland, Wales and Northern Ireland

Delivering extensive decarbonisation by 2050 in the UK will require a strong policy framework at both UK and devolved level. Scotland, Wales and Northern Ireland have (fully or partially) devolved powers in a number of areas relevant to emissions reduction. These vary by administration, but key areas include planning, demand-side transport measures, energy efficiency, agriculture, land use and waste (Box 6.5).

Welsh, Scottish and Northern Irish policies are essential in the areas where powers are largely devolved:

- **Demand-side transport measures.** Devolved administrations must implement effective policies to provide low-carbon public transport and encourage active travel.
- **Buildings energy efficiency.** Meeting the earliest possible date for net-zero emissions will require major improvements to the energy efficiency of new and existing buildings, in order

to improve comfort levels, lower energy bills and prepare the building stock for a switch to low-carbon heating. Policy to achieve these results in Scotland, Wales and Northern Ireland will largely be delivered through devolved buildings standards and policy.

- **Agriculture and land use.** Low-carbon farming practices, afforestation, agroforestry and peatland restoration all have a crucial role to play in reducing emissions by 2050. The devolved administrations should ensure that effective policy is in place to support afforestation, agroforestry and peatland restoration on both private and public land. The framework to follow the Common Agricultural Policy in each devolved administration provides an opportunity to more closely link financial support to agricultural emissions reduction and increased carbon sequestration.
- **Waste.** Devolved administrations are responsible for reducing emissions from waste, with a focus on reducing, reusing and recycling waste, diverting biodegradable waste from landfill, and capturing methane from landfill and wastewater.
- **Energy in Northern Ireland.** Unlike Scotland and Wales, Northern Ireland has devolved control of the power sector, although the Northern Irish network can be affected by both UK and Republic of Ireland policy. For the UK to achieve net-zero emissions, Northern Ireland must achieve equally ambitious decarbonisation in the power sector.

Where powers are reserved to the UK level, the devolved administrations have an important role in ensuring that the emissions reductions take place. In particular, the devolved administrations should focus on the following areas:

- **Planning.** Planning frameworks are another useful lever over infrastructure that needs to be well aligned to objectives for emissions reduction in devolved administrations (e.g. through encouraging walking, cycling and use of public transport, ensuring readiness for or installation of electric vehicle charging points in new developments, and a favourable planning regime for low-cost onshore wind).
- **Procurement.** The public sector in devolved administrations can use procurement rules positively to help drive emissions reductions in a number of areas (e.g. uptake of ultra-low-emission vehicles, energy efficiency and low-carbon heat in buildings, low-carbon products).
- **Convening role.** It is important the devolved administrations maximise their potential to bring stakeholders together, and facilitate dialogue and strengthen relationships, to enable the development of mutually-beneficial projects that contribute to decarbonisation.
- **Working with the UK Government** to ensure that UK-wide policies work for devolved administrations.
- **Access to UK-wide funding.** The devolved administrations should seek to ensure that households and businesses have good access to UK-wide funding opportunities where possible and appropriate.

This report recommends that the long-term emissions targets in Wales and Scotland are updated to align to our recommended UK net-zero target (Northern Ireland does not currently have a long-term emissions target). Actions by the UK Government will be necessary to deliver the Welsh and Scottish targets and actions by the devolved administrations will be necessary to deliver the UK target.

Box 6.5. Devolved and reserved policy areas

Powers that are reserved (i.e. issues upon which only the UK Parliament can make laws) and devolved vary by type:

- **Economic and fiscal:** Mostly reserved.
- **Energy:** In Scotland and Wales energy supply policy is mostly reserved. Energy (apart from nuclear) is devolved to Northern Ireland.
- **Planning:** Mostly devolved, with the exception of nationally significant infrastructure in Wales. The Welsh Government has the power to grant or refuse planning permission for power plants up to 350 MW.
- **Local government and housing:** Including domestic and public energy efficiency and fuel poverty is mostly devolved.
- **Industry:** Mostly reserved, but significant devolved competency through planning and consenting activity.
- **Transport:** Demand-side measures are mostly devolved.
- **Agriculture and land use:** Fully devolved.
- **Waste:** Fully devolved.

Chapter 7: Costs and benefits of a net-zero target for the UK

Introduction and key messages

The UK has established a track record of reducing greenhouse gas emissions (GHGs) while growing the economy, and the Government has put clean growth at the heart of its industrial strategy.

In this chapter we explore the costs and benefits of climate action generally and specifically the additional impact of moving to a net-zero GHG target for the UK in 2050. We consider overall costs, costs to the Exchequer and costs to the consumer as well as the challenge of ensuring a smooth and fair transition.

Our estimates are based on the actions to reduce emissions set out in Chapter 5.

We conclude that:

- **Action is preferable to inaction.** The overall economic impact of cutting emissions and the costs of increasing ambition to net-zero are likely to be small globally and in the UK and could turn out to be positive. Accepting this cost is preferable to inaction given the range of risks from unchecked climate change globally and in the UK, both directly and indirectly.
- **A net-zero GHG target by 2050 can be achieved within the cost that was previously expected for current targets:**
  - Rapid cost reductions for key technologies like offshore wind and batteries for electric vehicles mean the expected cost for the current target to reduce emissions by 80% by 2050 relative to 1990 has fallen significantly – our 2008 estimates suggested annual costs in 2050 of 1 - 2% of GDP while our current estimates put costs at less than 1% of GDP.
  - Our central estimate for the resource costs of a more ambitious net-zero GHG target in 2050 are in line with the expected cost accepted by Parliament when the current target was set – an annual cost of between 1 - 2% of GDP in 2050. If innovation exceeds expectations again this cost could be lower.
  - If the rest of the world were not to materially increase effort in order to meet the temperature goal of the Paris Agreement, technology progress could be much slower and costs correspondingly higher. This is particularly concerning for global technologies like low-carbon HGVs. However, in such a situation cheap international carbon units ('credits') are likely to be available and if needed a revision to the UK target could be permitted by the Climate Change Act.
- **Co-benefits are likely to be extensive.** Achieving net-zero GHG emissions in the UK will result in significant benefits to human health from better air quality, less noise, more active travel and a shift to healthier diets. Changes to land use and farming practices that cut GHG emissions can also improve air quality and water quality and benefit biodiversity, resilience to climate change and bring recreational benefits. Benefits could partially or fully offset costs.
- **There may be industrial opportunities.** The shift in resources from imported fossil fuels to UK investment could stimulate further economic activity. In addition, it is possible that with appropriate policy and support there could be an industrial boost to the UK from being one of the early movers in some key sectors (e.g. carbon capture and storage, specialised supporting services for low-carbon technologies like finance and engineering) with potential benefits for exports, productivity and employment. However, we do not factor these potential benefits into our cost calculations.

- **The distribution of costs during the transition is important.** Despite low overall costs some industries, regions and households could suffer if appropriate policies are not put in place to mitigate the effects of what will be major structural changes, particularly in the transitional years. HM Treasury should undertake a thorough review of costs and benefits and their distribution, and the appropriate policy levers to achieve an efficient and fair transition.

Our conclusions are based on reaching net-zero GHG emissions in 2050 and setting out on that pathway immediately. Attempting to reach this end point earlier, or delaying policies to get there, would risk significantly increasing the costs.

We set out our analysis in this chapter in six sections:

1. Background to our analysis of costs and benefits
2. The importance of innovation
3. Additional costs from pursuing a net-zero emissions target in the UK
4. Additional benefits from pursuing a net-zero emissions target in the UK
5. The distribution of costs and impact on other factors in the Climate Change Act
6. Ensuring a just transition to a zero-carbon economy

1. Background to our analysis of costs and benefits

We concluded in 2008, when recommending the UK's current climate targets, that the case for climate action was clear – the dangers of significant climate change could reasonably be judged to be so great that the potential cost for reducing emissions of a few percentage points of GDP was a reasonable price to pay, given the severity of the consequences of inaction. That echoed the conclusions of HM Treasury's Stern Review.[172]

Having committed to decarbonise our economy and meet our commitments under the Paris Agreement, the decision we now need to make is when to reach net-zero emissions, rather than whether to get there.[173]

Our assessment of costs and benefits in part reflects the conclusions of an expert Advisory Group appointed for this report to provide advice on the costs and benefits of achieving a net-zero target in the UK (see Box 7.1). The Advisory Group supported a net-zero GHG target for the UK around 2050:

- A mid-century date provides a good balance between starting early with a clear target, which may deliver lower costs (investing in low-carbon technologies and approaches now gives more scope for cost reductions from learning-by-doing), while still allowing time for high-carbon capital stock turnover without extensive early write-offs.
- It would place the UK amongst the global leaders in decarbonisation, which may result in economic advantages while reducing the risk of being too far ahead of the rest of the world.

This chapter therefore assesses the costs and benefits of achieving a net-zero GHG target in 2050, to the UK (and globally where relevant) quantitatively where possible and also qualitatively. It is not, however, a full cost-benefit analysis, which is not appropriate in this case.

[172] HM Treasury (2006) *Stern Review on the Economics of Climate Change.*
[173] The UK Government confirmed this understanding to Parliament in 2016 (Climate Change Convention: Paris: Written question - 34423). Accordingly, the Government request for advice in October 2018 asked for advice on the appropriate date for a net-zero target.

While it may be tempting to set the monetised benefits of incremental avoided warming against the costs of incremental effort in moving to a net-zero GHG target in the UK, the Committee's judgement is that this is not a sensible approach:

- The link from increased UK effort to reduced global warming is complicated – for example it is not clear whether to consider a reduction in warming from the 3°C that the world is currently on track for or the 2°C that was the basis for the UK's existing target. However, we can say with confidence that a UK net-zero GHG target will support increased international action and reduced overall warming, which is in the UK's and the world's interest (see section 4 for more on this).
- The incremental cost for a tighter UK target is based on a relatively static cost assessment. In reality, cost development is much more dynamic (see section 2). We therefore have more confidence in the overall magnitude than the increment between two levels of ambition. That is illustrated by the fact that a decade ago we expected the last 10 - 20% abatement to reach 80% to be expensive and now we expect the last 10 - 20% to reach net-zero emissions to be expensive (see section 3).
- More generally, the uncertainties, irreversibility and complex political economy involved in climate change mean that decisions over effort are ill-suited to this sort of marginal cost-benefit analysis. That was also the clear feedback from our expert Advisory Group.

The key to a successful transition does not lie solely in its aggregate cost or impact, but how it affects different segments of society. Therefore, in addition to aggregate impacts, distributional and transitional impacts of a net-zero target have also been considered in this chapter (see sections 5 and 6).

2. The importance of innovation

Many technologies which are crucial for the low-carbon transition have proved cheaper than the most optimistic assumptions made a decade ago, when the UK's existing long-term target was set. These cost reductions have made tighter emissions targets achievable at the same costs as previous looser targets.

This section briefly summarises some of the historical experience and sets out assumptions for the future, which we consider to be cautious. It is in three sections:

(a) Innovation and historical falls in technology costs

(b) The impact of innovation on the costs of achieving carbon targets

(c) Assumptions on innovation in the future

(a) Innovation and historical falls in technology costs

Cost reductions to date have generally resulted from the mass deployment of technologies, often backed by subsidies and international supply chains (see Figure 7.1):

- **Offshore wind.** The most recent auctions for 'established' technologies procured contracts for offshore wind at around £69/MWh for delivery in the early 2020s – 40% below where we had expected the cost of the technology would be by 2030.[174] Cost reductions have been

[174] Corresponds to the average price of offshore wind auctions in 2018 prices. The lowest winning auction bid was £57.50/MWh in 2012 prices. CCC (2011) *The Renewable Energy Review* expected prices over £100/MWh in 2030 (2012 prices).

attributed to multiple factors, such as innovation in design (including the move to larger turbines), operation and maintenance, streamlined supply chains and development of suitable financing arrangements. Subsidy-driven deployment and good policy (i.e. auctions of long-term contracts) have combined to reduce risks for investors and to drive competition, supplemented by public-private partnerships to support innovation (e.g. the Offshore Renewable Energy Catapult).[175]

- **Solar.** Germany has been investing in solar power since its Renewable Energy Act was established in law in 2000. Germany's deployment of solar when the technology was expensive led to significant increases in production capacity worldwide, leading to falling prices globally and in the UK. This early investment, alongside open global markets, has allowed second-mover countries such as China to start installing and producing solar panels on an even larger scale, further bringing down costs.
- **Batteries for electric vehicles.** Global demand for consumer electronics led to considerable investment into the research, development and manufacturing of lithium-ion batteries. This has resulted in significant cost reductions and improved battery performance over the last ten years, enabling the use of lithium-ion batteries in the automotive sector. Strong policy pushes in countries like Norway and China have resulted in high levels of take-up of electric vehicles in recent years, which are expected to accelerate and should result in further cost reductions.

These deployment-led technology cost reductions are very valuable in the long run, but can come at a significant cost initially. German compensation payments to solar power averaged close to €5 billion a year between 2000 - 2018[176] and payments to offshore wind generators in the UK averaged £1.5 billion a year over the last five years (and are set to increase to £3.5 billion a year on average by 2030 before declining).

Cost reductions in low-carbon technologies is not a universal story. Several technologies which have not been deployed at scale – such as nuclear power, carbon capture and storage (CCS) and heat pumps – have failed to come down in cost.

- The lack of deployment in part relates to the nature of these technologies – small modular technologies such as batteries and solar panels can be deployed at scale more easily, while nuclear power or CCS require large coordinated investments, which are more difficult to replicate. If these projects could be replicated, some cost reduction could be expected.
- It also relates to a lack of support for their deployment, which reduces the scope for innovation and learning-by-doing.

As has been the case so far, future technology cost reductions will be a direct result of actions taken globally to deploy technologies. But the dynamics of innovation are complex, with the possibility of innovation occurring far faster than typically assumed (Box 7.2).

[175] The Offshore Renewable Energy Catapult is one of 11 technology and innovation Catapult Centres that connect businesses with the UK's research and academic communities, through a combination of public and private funding.

[176] Average compensation payment over the period estimated by the CCC based on data published by the German Federal Ministry of Economics and Energy. Bundesministerium für Wirtschaft und Energie (2018) *EEG in Zahlen:Vergütungen, Differenzkostenund EEG-Umlage 2000 bis 2019.*

Box 7.1. The CCC Expert Advisory Group on the costs and benefits of a UK net-zero emissions target

The Advisory Group (AG) was appointed to independently support and critically evaluate the CCC's assessment of the costs and benefits of a net-zero emissions target. Expert input was particularly valuable given the presence of issues at the boundaries of traditional analysis of costs and benefits.

The group's members were drawn primarily from the academic community and also included economists from business and industry. The group's chair, Professor Paul Ekins of UCL, provided a summary report setting out the group's key conclusions, which are as follows:

Costs and benefits of climate action generally

- **Relevant costs and benefits of climate action** include (avoided) climate damage costs, (avoided) climate adaptation costs, (avoided) other damage costs (e.g. air pollution, when they are called co-benefits of GHG emission reduction) and the costs of emission reduction. The costs of emission reduction are dynamic (they change over time) and endogenous (how they change depends on the actions of government, business, other social groups and individuals).
- **Static cost-benefit analysis (CBA) is not suitable in this case.** Working incrementally up a marginal abatement cost (MAC) curve cannot capture dynamic effects that can reduce costs of MAC curve technologies. Uncertainties, irreversibility and potential tipping points in the climate response to GHG emissions cannot be captured by a static CBA.
- **The costs and benefits of deep decarbonisation are unknowable with any precision**. They depend too fundamentally on uncertain outcomes, such as the damages from climate change in the long term, and the evolution of the costs of low-carbon technologies over several decades.
- **The structural changes underlying aggregate costs will be very large** even though macroeconomic costs of deep decarbonisation are likely to be small (or negative for a fossil fuel importing country like the UK). The beneficiaries from the structural changes are unlikely to be the same as the losers. The transition through these structural changes will need careful handling if they are to be politically acceptable.

Specific case of a net-zero target versus an 80% target

- **Arguments for climate action in general still stand for a net-zero target.** There are no grounds for thinking that it will have a significant impact on economic growth provided policy is designed appropriately.
- **Mitigation action to achieve a net-zero target by 2050 is fully justified.** Even if costs of achieving a net-zero target in the UK are large relative to an 80% target, the avoided climate damages from limiting temperature increase to 1.5˚C as opposed to 2˚C are likely to be large. The UK is well placed to be among the economies most likely to benefit from a transition to net-zero emissions.
- **The clarity of a net-zero goal could help stimulate innovation.** Under a net-zero target all sectors need to decarbonise or offset their emissions. This removes uncertainty and the temptation of sectors to lobby for a larger share of the remaining 20% of emissions. This clarity could cut the cost of capital as well as stimulating innovation, thereby bringing down the overall cost of mitigation.

Reflections on the CCC's approach to assessing the costs and benefits of a net-zero target

- **The CCC's approach is robust and realistic, but resource costs should not be confused with GDP impacts**. Macro-modelling is required to generate GDP impacts. Macro-modelling in this area suggests GDP costs of a net-zero target are likely to be small and could even be positive. It is not clear that the CCC could have materially improved the evidence base with further macro-modelling.

Box 7.1. The CCC Expert Advisory Group on the costs and benefits of a UK net-zero emissions target

- **Considering transitional impacts and the distribution of costs and benefits is crucial.** Vulnerable households should not be adversely affected by the transition. Co-benefits such as reduced air pollution are likely disproportionately to favour low-income and vulnerable people, the former of whom tend to live in areas worst affected by air pollution. It is important that this is both analysed and communicated properly.
- **Good policy design is vital to keeping costs low and maximising benefits**, including a stable long-term direction with clear governance, regular reviews for flexibility, use of markets to find the best solutions, support for large-scale deployment and research and development of new technologies. Approaches should be tailored to the needs of each sector while maintaining consistency across the system.

Source: Adapted by CCC from Costs and Benefits Advisory Group report, available at www.theccc.org.uk.
Notes: The AG was chaired by Prof Paul Ekins (UCL) and included Mallika Ishwaran (Shell), Rain Newton-Smith (CBI), Philip Summerton (Cambridge Econometrics), Prof Karen Turner (University of Strathclyde) and Dimitri Zenghelis (UCL).

Box 7.2. The dynamics of innovation

The expert Advisory Group on costs and benefits emphasised that the dynamics of innovation are more wide ranging than described in section 2a:

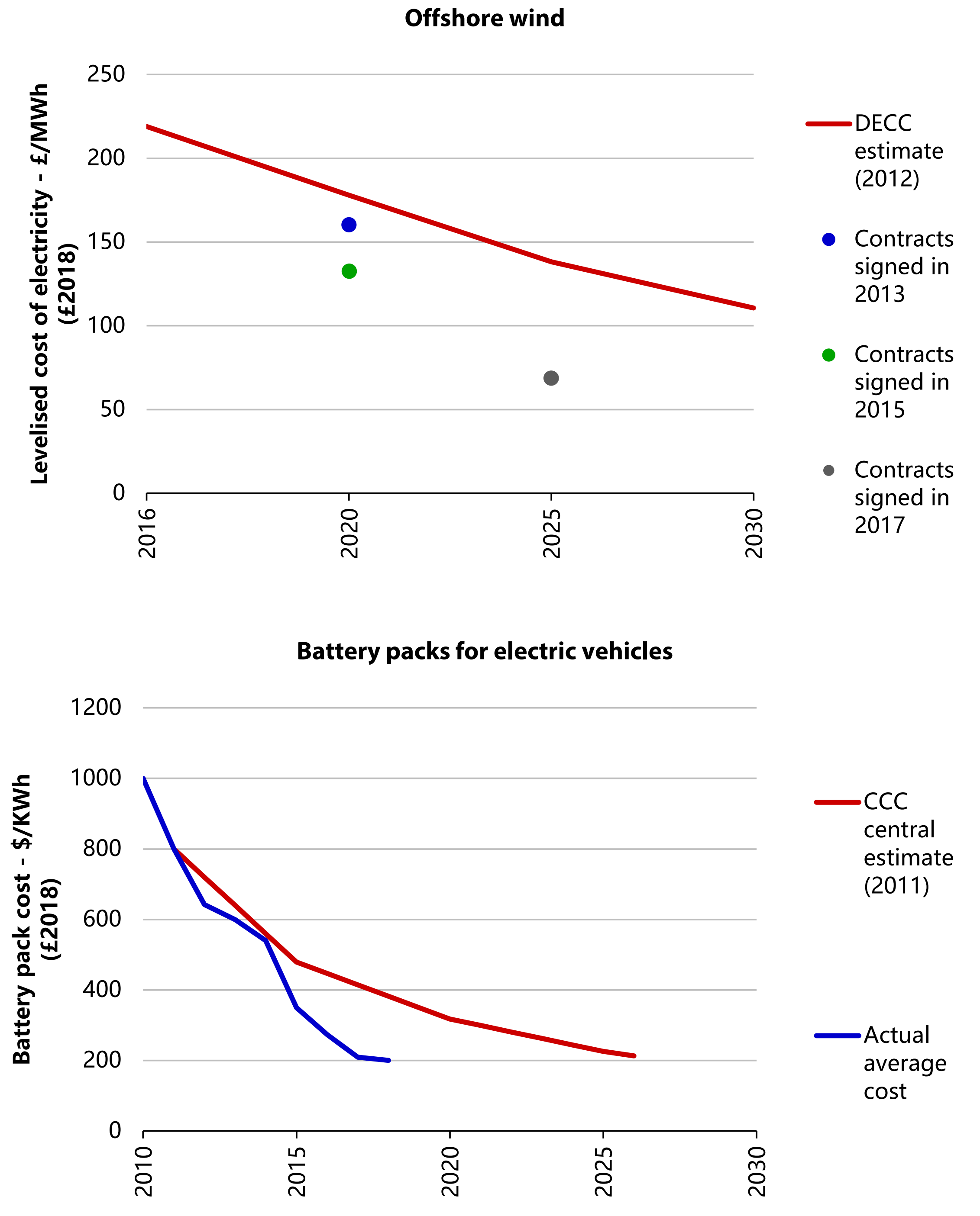
- New supply chains are created, and changing behaviours result in new business lobbies and a push for more policies to support new technologies.
- Falling costs and increasing expectations of market size and future opportunities result in additional investment and lower costs of financing, as the perceived risk of the technology is reduced. There are fewer political and commercial barriers. New institutions are needed and old ones repurposed.
- These factors can culminate in a tipping point, where incumbent technologies and networks become redundant. Embracing the transition too late risks exposure to stranded or devalued assets.

This points to the possibility of innovation occurring far faster than typically assumed, given the right policy environment:

- Investing in these technologies can result in multiple dynamics that can push them past tipping points and bring down costs far more than anticipated.
- Innovation in commercial arrangements, financial instruments and system management tools will also be needed to adapt to the changing environment.
- As the future is inherently uncertain, pursuing a flexible decarbonisation strategy is key to bringing down the costs of the challenge. If some options prove cheaper and others more expensive than expected, a flexible approach can adjust to focus on the cheaper alternatives (for areas of the economy with more than one low-carbon option).

Source: Adapted by CCC from Costs and Benefits Advisory Group report, available at www.theccc.org.uk

Figure 7.1. Costs of example low-carbon technologies compared to past projections



Source: Offshore wind costs from CCC analysis based on DECC (2012) *Electricity generation costs* and LCCC (2019) *CfD register*. Battery pack cost forecasts from 2011 published in CCC (2015) *Sectoral scenarios for the Fifth Carbon Budget*, outturn costs from BNEF (2018) *Electric cars to reach price parity by 2022*.

(b) The impact of innovation on the costs of achieving carbon targets

Overall, innovation and falling technology costs mean we now estimate that the UK's 80% emissions target could be met at a lower cost than we estimated in 2008 – under 1% of GDP in 2050, rather than 1 – 2% of GDP (see section 3).

That continues the historical experience in which emissions targets have been strengthened but cost estimates have not increased (Table 7.1):

- The 2003 Energy White Paper set the ambition for the UK to reduce its carbon dioxide emissions by 60% from 1990 levels by 2050 (equivalent to around a 55% reduction in greenhouse gases). The report estimated that the annual economic costs of achieving this target would be between 0.5 – 2.0% of GDP in 2050.
- In 2008, when the Committee recommended the UK's existing 2050 target to cut GHG emissions by at least 80% relative to 1990 we estimated annual costs of 1 – 2% of GDP in 2050.
- As set out in section 3 of this chapter, updated estimates for this report suggest that the annual costs of meeting a stronger net-zero GHG target would be between 1 – 2% of GDP in 2050.

Falling cost estimates over time emphasise the uncertainty inherent in predicting costs 30+ years into the future and the potential for rapid technological innovation to cut the costs of climate action.

Table 7.1. Changes in cost estimates for long-term emissions goals

GHG emissions reduction target (relative to 1990)	Year and report	Cost range estimated for 2050
60% reduction in CO_2 (~55% reduction in GHG)	2003 - *Energy White Paper*	0.5 - 2.0% of GDP
80% reduction in GHG	2008 - *Building a low-carbon economy – the UK's contribution to tackling climate change*	1 - 2% of GDP
100% reduction in GHG	2019 - this report	1 - 2% of GDP

Source: Department for Trade and Industry (2003) *Our energy future - creating a low carbon economy;* CCC (2008) *Building a low carbon economy – the UK's contribution to tackling climate change.*

(c) Assumptions on innovation in the future

What is needed for a net-zero GHG target

Chapters 5 and 6 set out the low-carbon technologies and behaviours that will be needed to achieve a net-zero GHG target. In summary, it will involve:

- Resource and energy efficiency (e.g. in production processes, home appliances) and some societal choices that cut demand for carbon-intensive activities (e.g. more active travel and public transport, healthier diets with less reliance on livestock).

- Extensive electrification of heat and transport (resulting in around a doubling of electricity demand by 2050) supported by a major expansion of low-carbon power generation.
- Development of a hydrogen economy to service demands for energy in peak periods or energy-dense applications like long-distance HGVs, shipping and industry. By 2050, UK hydrogen production capacity is needed of comparable size to the UK's current fleet of gas-fired power stations.
- CCS in industry, with bioenergy and potentially for fossil hydrogen and electricity production, requiring CO_2 transport and storage infrastructure (capturing 75 – 175 $MtCO_2$ a year).
- Changes in the way we farm and use our land to put much more emphasis on carbon sequestration and diverse agriculture, while shifting away from livestock (a fifth of UK agricultural land shifting to tree planting, energy crops and peatland restoration).

These measures do not require technological breakthroughs to be feasible, but where they are technology-dependant some improvement is assumed.

Costs of technologies to achieve net-zero emissions

While there is significant uncertainty over future technological innovation, some low-carbon technologies have more scope for innovation than others. We make conservative assumptions about future technology cost reductions in our analysis (Table 7.2):

- **Renewable power generation.** We have assumed modest reductions in the cost of renewables, although there is scope for costs of technologies such as offshore and onshore wind and solar PV to fall further through learning-by-doing during deployment, which continues to increase globally.
- **Nuclear power.** Nuclear is a mature technology, but we assume cost reductions for future plants after Hinkley Point C from utilising similar plant design and lower cost financing arrangements (which the Government are currently considering).
- **Batteries.** Batteries, like renewables, are commercialised at scale and have come down in costs significantly in recent years. With significant increases in expected roll-out of electric vehicles globally, cost reductions should continue.
- **Heat pumps.** Heat pumps are prevalent in other countries and the technology is fairly well-established, so we do not assume major technology cost reductions. However, future cost savings should arise from efficiencies in installation as the UK industry scales up. This may be a conservative assumption overall, as equipment costs could also fall, for example if different heat pump technologies are developed.
- **Hydrogen**. The costs of hydrogen depend on how it is produced (e.g. gas reforming, electrolysis, gasification) and whether it is produced in the UK or imported. The hydrogen used in our net-zero scenarios is assumed to come mainly from natural gas reformation in the UK with CCS. While this currently appears to be the lowest cost option, we do not expect large cost reductions. This is an area where breakthroughs could occur and other technologies end up playing a much larger role.
- **Carbon capture and storage.** CCS is still at the technology development and demonstration phase, although 43 large-scale projects are now operating or under development around the

world.[177] Commercialisation and wide scale development of CCS is likely to be needed globally as decarbonisation efforts increase. There is scope for cost reductions in capture plants as the technology enters this development stage and less scope for cost reductions in CCS transport and storage infrastructure. We have conservatively assumed constant CCS costs, although clearly the starting point for these costs is uncertain and it will depend on how wholesale fuel (e.g. gas) prices evolve.[178]

- **Bioenergy with CCS (BECCS).** Sustainable low-carbon harvested biomass used with CCS results in net emissions reductions. The costs shown in Table 7.2 are costs of BECCS for electricity generation but there are a range of other BECCS applications (e.g. hydrogen production, industrial combustion, production of aviation biofuels) which can provide similar overall net emissions reductions. As for CCS, we assume no cost reduction.
- **Direct air capture of CO_2 with storage (DACCS).** DACCS is currently at the pilot stage, with a small number of pilot scale test facilities in operation globally. As costs of pilot technologies are very difficult to assess, costs of DACCS both now and in future are highly uncertain. The costs in Table 7.2 are based on a review undertaken by UKERC alongside this report. The modular nature of DACCS methods could see faster cost reductions with mass roll-out, although energy requirements are likely to remain high.

Some abatement measures which may be required to achieve net-zero emissions are less technology-dependant (e.g. tree planting). The costs of these measures are not reflected in Table 7.2 but are discussed in the following section.

Our technology cost estimates are inherently static and do not attempt to predict dynamic interactions between global actions and cost reductions. Although deployment of some of these technologies (e.g. offshore wind, heat pumps) will be significantly larger for a net-zero target than for an 80% target, we have not assumed that unit costs become cheaper as a result. Clearly there is scope for that to occur in reality with increased learning-by-doing, provided policy is sufficiently well designed and forward looking to avoid supply chain bottlenecks.

It is also possible that the pace and breadth of low-carbon innovation could be greater under a net-zero emissions target that clearly signals the value of low-carbon technologies and practices in every sector of the economy.

As set out in Chapter 6, whilst some decarbonisation challenges are fairly similar across different countries (e.g. transport) others are UK-specific (e.g. potentially switching the gas grid to hydrogen) and will require more UK action to develop the necessary technologies.

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[177] Global CCS Institute (2018) *Global Status Report.*

[178] CCS costs based on Wood Group (2018) *Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology.*

Table 7.2. Assumed costs and cost reductions in key low-carbon technologies

Technology	Cost in 2025	Cost in 2050	Percentage cost reduction
Power generation			
Offshore wind	69 (£/MWh)	51 (£/MWh)	26%
Solar PV	47 (£/MWh)	41 (£/MWh)	13%
Nuclear	98 (£/MWh)	71 (£/MWh)	28%
Gas CCS	79 (£/MWh)	79 (£/MWh)	0%
Heating			
Air source heat pumps	6,500 (£)	5,800 (£)	11%
Hybrid heat pumps			
With hydrogen	7,300 (£)	6,600 (£)	10%
With biofuels	7,500 (£)	6,900 (£)	8%
Transport			
Batteries (for electric vehicles)	73 (£/kWh)	50 (£/kWh)	32%
Fuel cells (for HGVs)	500 (£/kWh)	300 (£/kWh)	40%
Removals			
Bioenergy with CCS			
From UK biomass	125 (£/t)	125 (£/t)	0%
From imported biomass	300 (£/t)	300 (£/t)	0%
Direct air capture with CCS	450 (£/t)	300 (£/t)	33%
Hydrogen production	44 (£/MWh)	39 (£/MWh)	11%

Source: CCC analysis.
Notes: Heat pump costs are rounded to the nearest £100, costs correspond to capital and installation costs (they do not include costs of installing a hot water cylinder or heat battery or upgrading radiators). Hydrogen production costs correspond to hydrogen production using natural gas reformation which can then be used as a low-carbon fuel (hydrogen costs are therefore not comparable to the power generation costs). Gas prices in 2050 are assumed to be 69p/therm (compared to 46p/therm in 2017), based on BEIS (2017) *Fossil Fuel Price Assumptions*.

3. Additional costs from pursuing a net-zero emissions target in the UK

Our estimates based on the updated evidence set out in this report suggest that the annual costs of reducing GHG emissions to net-zero are in the same range as our 2008 estimates of achieving an 80% target – between 1 – 2% of GDP in 2050. This is the same cost that Parliament accepted when the Climate Change Act was passed in 2008, with significant cross-party support.

We set out the analysis in the following sections:

(a) Marginal abatement cost estimates

(b) Total resource cost estimates

(c) Uncertainty in cost estimates

(a) Marginal abatement cost estimates

Table 7.3 shows abatement costs (per tonne of abatement) of key emissions sources in 2050 to achieve a net-zero scenario, and the weighted average abatement costs in each sector in 2050. It highlights that there are many actions with low costs and some actions that are more expensive.

Many sectors have low or negative average abatement costs:

- **Power.** Even with network reinforcements resulting from extensive electrification, average marginal abatement costs in the power sector in 2050 are low at around £20/tCO_2e. Much of the high marginal costs from CCS (£80 – 120/tCO_2e) and hydrogen for peak power are offset by cost savings from renewables relative to high-carbon alternatives (-£5/tCO_2e).
- **Transport.** Electric cars are expected to be cheaper to purchase than conventional cars by 2030 and yield considerable savings in their running costs (without existing subsidies or advantageous tax treatment). Although there may be barriers to deploy low-carbon HGVs (e.g. roll-out of low-carbon refuelling infrastructure) new analysis for this report suggests it could result in cost savings from lower fuel costs (-£35/tCO_2e). This results in negative average marginal costs in the transport sector (-£35/tCO_2e).
- **Agriculture and Land use.** Although some land-use measures have positive and sometimes high abatement costs (e.g. peatland restoration), many of the abatement measures in agriculture are productivity-enhancing and cost saving (e.g. nitrogen use efficiency which costs -£80/tCO_2e). Shifting towards healthier diets and reducing our reliance on livestock would not result in resource costs.
- **Aviation.** Average abatement costs in aviation are negative in our scenarios, as cost saving fuel efficiency improvements (-£50/tCO_2e) more than offset higher costs from biofuels (£125/tCO_2e). Aviation demand reduction is not assumed to result in resource costs, although there could be a welfare loss to individuals from flying less than they might otherwise wish to.
- **Waste.** Abatement measures include a ban on waste sent to landfill and increase in recycling rates (with a cost of £30 – 100/tCO_2e, reflecting the higher cost of alternative waste treatment approaches compared to landfill), and a reduction in household food waste (which represents a cost saving).

Table 7.3. Average abatement costs by sector and measures (2050)

Sector or measure	Abatement cost (£/tCO_2e)	Sector or measure	Abatement cost (£/tCO_2e)
Power	**20**	**Agriculture**	**-55**
Variable renewables	-5	Agricultural soils	-80
Firm low carbon power	50	**Land use**	**85**
CCS for mid-merit generation	80 – 120	Tree planting	10
Residential buildings	**155**	Forestry management	-50
New homes	70	Peatland restoration	See note
Heat in space constrained homes	310	**Waste**	**10**
Heating in homes off the gas grid	-20	**Transport**	**-35**
Non-residential buildings	**95**	Cars	-40
Industry	**120**	Buses	200
Iron and steel	100	HGVs	-35
Cement	95	**Aviation**	**-10**
Stationary combustion	120	Fuel efficiency	-50
Engineered removals	**-**	Biofuels	125
Bioenergy with CCS	125 – 300	**Shipping**	**200**
Direct air capture with CCS	300	**F-gases**	**-10**

Source: CCC analysis.
Notes: Costs correspond to the Further Ambition scenario and are rounded to the nearest £5/tCO_2e. Not all sectoral emissions sources are included. Costs of demand measures (aviation demand, diet shift and transport modal shift) are assumed to be zero. CCS cost range reflects different uses of CCS (lower bound is cost of CCS for firm power and upper bound for peak power).
Peatland restoration costs vary significantly, between £75 – 5,885/tCO_2e (depending on e.g. type of peatland restored, ease of access to the location), but these estimates ignore significant co-benefits resulting from restoration. Lower bound BECCS costs correspond to costs using domestically produced bioenergy, while upper bound corresponds to imported bioenergy.

Average abatement costs are higher for buildings, industry and engineered GHG removals:

- **Buildings.** Although some energy efficiency measures are cost saving, the switch to low-carbon heating (e.g. heat pumps or hydrogen gas) is expected to be expensive in new and existing homes (average cost of £155/tCO_2e for abatement in residential buildings) and in non-residential buildings (average cost of £95/tCO_2e). Costs will be lower (but still positive) for new homes and there could be savings off the gas grid, but compared to gas heating in existing homes, heat pumps involve much higher installation costs and similar running costs.
- **Industry.** Decarbonising industry relies on measures like switching to low-carbon fuels and adding CCS to industrial emissions, which result in relatively high costs, often around £100/tCO_2e. Resource and energy efficiency would reduce costs by reducing requirements for material and energy inputs.
- **Engineered removals.** BECCS and DACCS are both expected to be expensive. The costs of BECCS are assumed to vary depending on the bioenergy source, with BECCS using domestically produced bioenergy costing less (£125/tCO_2e) than that using imported bioenergy (for which we assume the price increases to £300/tCO_2e to reflect its carbon content and potential to offer an emissions removal credit). Based on the mix of feedstocks in our Further Ambition scenario BECCS has a weighted average cost of around £160/tCO_2e.

Our aggregate cost estimates below are therefore dominated by costs of decarbonising buildings and industry and of large-scale engineered removals of CO_2 from the atmosphere.

(b) Total resource cost estimates

Costs of decarbonisation have been estimated based on the scenarios set out in Chapter 5, and the estimated costs of low-carbon approaches shown in Table 7.3.

These *resource costs* represent the technical cost of delivering abatement measures. We frequently express resource costs as a percentage of GDP to provide a point of comparison, but resource costs are not necessarily equivalent to GDP impacts. Box 7.3 provides a description of our approach to estimating costs and the distinction between resource costs and GDP impacts.

Figure 7.2 shows annual resource costs of meeting a UK net-zero GHG target in 2050 and costs of meeting the current 80% reduction target:

- **Costs of an 80% target.** Our central estimate is that the existing 80% target could be met at an annual resource cost of around 0.3% of GDP in 2050:
  - This is the cost of meeting our Core scenario, based on low-cost, low-regret options that combined achieve a 77% emissions reduction relative to 1990 levels.
  - We assume that the extra 3% of abatement can be achieved in a cost-neutral way (e.g. by adding some abatement from HGVs, which we expect to be cost-saving but which are not included in the Core scenario given the significant barriers to their uptake).
  - Costs could be higher if a more expensive set of measures were pursued (e.g. if BECCS using imported biomass were pursued instead of tackling barriers to low-carbon HGVs costs would increase to 0.6% of GDP in 2050.

Box 7.3. How we calculate the costs of emissions abatement

The Committee has assessed the costs of decarbonisation in the past by looking at the technical costs of delivering abatement measures (resource costs) and by assessing wider economic effects of decarbonisation, using economic models (GDP impacts).

Resource costs

We have tended to focus on 'resource costs' when quantifying the impact of emissions reduction targets:

- Resource costs are estimated by adding up costs and cost savings from carbon abatement measures, and comparing them to costs in an alternative scenario (generally of a hypothetical world with no climate action or climate damages).
- For example, installing energy efficiency measures (e.g. loft insulations, cavity wall insulations) in homes has an upfront cost but reduces demand and emissions. There is an investment cost from installing the measures (e.g. labour costs, costs of building materials), followed by an ongoing stream of fuel and cost savings. The total resource cost of the measure will be the sum of its annualised costs and cost savings. This exercise would be applied to all abatement measures in the economy to estimate total resource costs.

GDP impacts

We frequently express resource costs as a percentage of GDP to provide a point of comparison, but resource costs are not necessarily equivalent to GDP impacts:

- The transition to a low-carbon economy will result in multiple adjustments in the balance of economic activity (i.e. dynamic effects) which are not captured by resource cost estimates, and will depend on policies put in place to achieve carbon targets.
- As resource costs show net cost differences between high and low-carbon alternatives they can mask the structural change required. For example, a wind farm over its lifetime may generate power at similar cost to a gas-fired power station and hence have zero resource cost, but will require a structural shift from annual spending on fuel (gas) to an upfront investment in building the wind farm (and no future fuel costs). Although our resource cost estimates of decarbonisation are relatively small, the structural change required to meet targets is large.

Despite the limitations of resource costs they are a useful approach to assess the scale of the likely impacts of decarbonisation. The Advisory Group appointed for this project support this approach, while pointing out that:

- To assess GDP impacts of decarbonisation economic models should be used. Different models provide different results – some suggest that decarbonisation will result in negative GDP impacts, while others suggest positive impacts.
- Differences arise from the economic theory underpinning a model and assumptions such as the economy's starting point in terms of spare capacity (e.g. relative to sources of finance, or spare labour capacity) and whether dynamics of innovation are factored in.

The Advisory Group Chair's report accompanying this publication describes these mechanisms in detail. We do not take a view on the merits of different models or economic schools of thought. However, whether positive or negative, models tend to agree that the economic impacts of low-carbon scenarios are a few percentage points of GDP – in the same range as our resource cost estimates.

- **Costs of a net-zero GHG target.** Our central estimate is that a net-zero GHG target could be met at an annual resource cost of around 1.3% of GDP in 2050 (i.e. around 1% higher than the costs of the existing 80% target):
  - This estimate is based on our Further Ambition scenario, which includes more challenging or more expensive abatement options than the Core scenario and achieves a 96% reduction in GHG emissions from 1990. The cost of these additional measures is equivalent to around an extra 0.6% of GDP in 2050 (relative to the cost of measures in the Core scenario).
  - For our total resource cost estimates, we assume that the remaining 4% of emissions are offset with imported BECCS and DACCS at a cost of £300/tCO_2e (with a total cost of around 0.3% of GDP in 2050). If none of the Speculative options could be delivered and international carbon units were needed instead, then this is also a reasonable estimate for the cost of offsets that reflect genuinely additional action overseas (e.g. based on CO_2 removals).
  - This is a cautious approach. If instead the extra 4% of abatement could be achieved with cost-neutral Speculative options (e.g. a further shift towards healthier diets, reduction in aviation demand and additional afforestation) then the estimated annual costs of reaching net-zero GHGs would reduce to 1% in 2050.

Given broader uncertainties (discussed further below) this annual cost for a net-zero GHG target is best described as around 1 – 2% of GDP:

- **Long-term GDP growth.** We use the Office for Budget Responsibility's (OBR) baseline GDP growth assumption to estimate GDP in 2050, which assumes annual GDP growth of 2.2% from 2027 to 2050.[179] If GDP growth were lower out to 2050 (e.g. continuing the OBR's medium-term trend of 1.6% per annum in the longer term) the annual costs of achieving a net-zero target would be 1.5% of GDP in 2050. This estimate does not allow for any reduction in the absolute abatement cost that could follow from lower energy demand under a lower GDP growth rate.
- **Lower fossil fuel prices.** The central cost estimates above use BEIS's central values for future gas and oil prices. If fossil fuel prices were at the lower end of the BEIS estimates then the relative costs of low-carbon technologies would be higher. That would increase our annual cost estimate to 1.8% of GDP in 2050 (or 2.1% of a lower 2050 GDP). High fossil fuel prices would reduce the estimated cost to 0.9% of GDP.
- **Technology costs.** We discussed above the potential for innovation to bring technology costs down faster than expected. Sensitivities on technology costs for our 2012 analysis of the 2050 target suggested that they would add +/- 0.3 – 0.4% of GDP to the central cost estimate.[180]

This cost of 1 – 2% of GDP reflects annual costs in 2050 of all abatement measures that are in place in that year. Annual cost profiles leading up to 2050 will vary across the sectors, but are likely to be lower in earlier years of the transition:

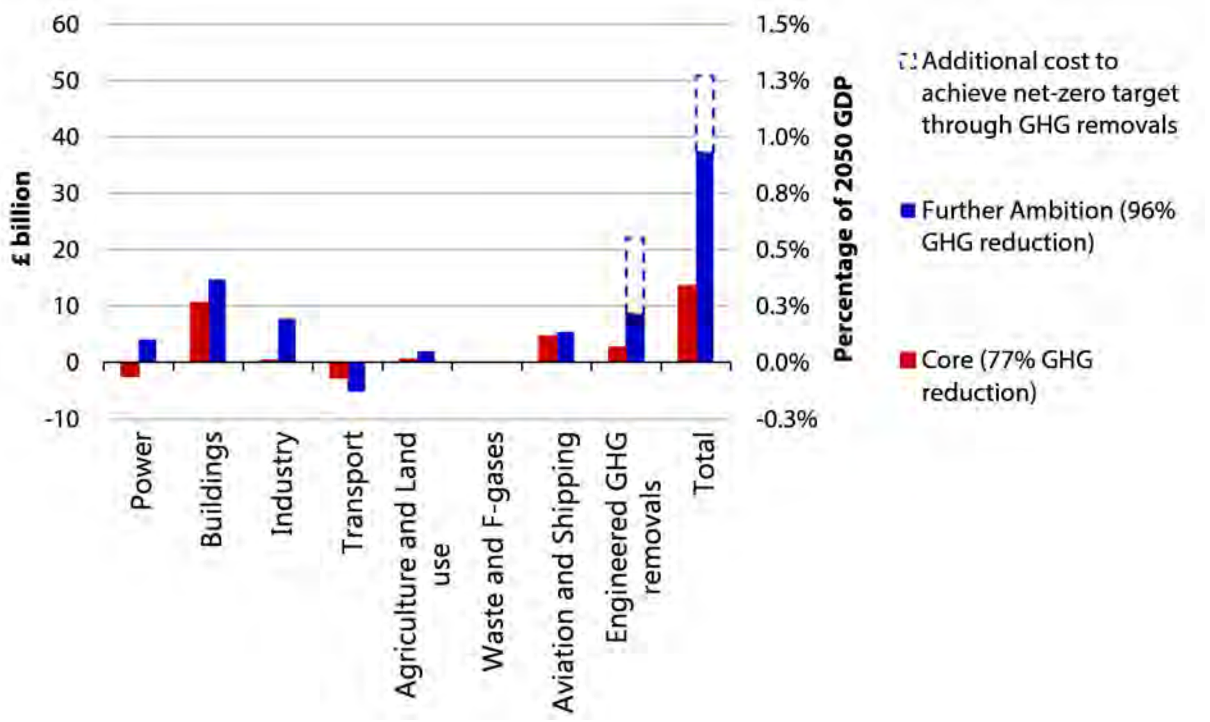
- In our fifth carbon budget analysis we estimated total annual costs in 2030 of under 1% of GDP.

[179] OBR (2018) *Fiscal Sustainability Report*.
[180] CCC (2012) *International Aviation & Shipping Review*. We estimated annual costs of achieving an 80% reduction target relative to 1990 levels of 0.1-1.0% of GDP in 2050, with central case estimates of 0.5% of GDP.

- Our fifth carbon budget scenarios are based on higher renewable and battery costs than those observed in recent years, so these costs are likely to be an over-estimate.
- However, a pathway to net-zero GHG emissions in 2050 is likely to require further decarbonisation in 2030 than our fifth carbon budget scenario, which could result in higher costs.

The balance of resource costs across Scotland, Wales and Northern Ireland is broadly in line with their shares of emissions (Box 7.4). However, where it is paid will depend on the policies used to deliver it (e.g. currently subsidies for low-carbon power are socialised across energy bill payers across the whole of the GB energy market).

Figure 7.2. Central estimates for annual resource cost of meeting a net-zero GHG target (2050)



Source: CCC analysis.
Notes: Costs are attributed to sectors where low-carbon actions occur (e.g. costs of low-carbon hydrogen production are included in the sector where it is used); policy will determine where the costs actually fall (e.g. some costs might be taxpayer funded; some removals might be paid for by the aviation sector). Co-benefits (e.g. health benefits from improved air quality) are not included. 2050 GDP is assumed to be around £3,900 billion in line with baseline GDP growth assumptions from the Office for Budget Responsibility.

Box 7.4. Resource costs in the devolved administrations

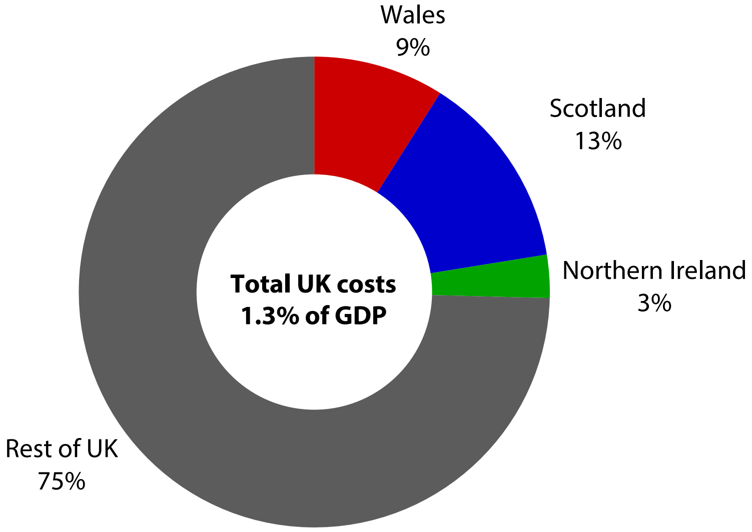
In assessing the economic costs to society of reducing emissions in the UK, we have considered the costs of abatement in Scotland, Wales and Northern Ireland on a social basis, but have not carried out separate, detailed cost analyses for each nation.

It is important to recognise that the average costs of reducing emissions will vary across the devolved administrations, as the pattern of measures to reduce emissions will be different compared to the UK as a whole. For example, a higher share of UK costs will go towards decarbonising industry in Wales, whereas there are higher costs associated with peatland restoration and engineered removals in Scotland. Up to 11% of the total costs of Speculative options to achieve net-zero may be spent on actions to reduce emissions in Scotland.

Most of these costs will be socialised across the whole of the UK. Many of the actions to reduce emissions will be paid for at UK level, and therefore any social costs for Scotland and Wales cannot be interpreted as fiscal costs to the devolved governments or to Scottish and Welsh businesses and consumers.

Based on the total change in sectoral emissions between 2016 and 2050 in our Further Ambition scenario, 10 – 13% of total UK costs would go towards reducing emissions in Scotland, 6 – 9% to reducing emissions in Wales and 2 – 3% in Northern Ireland (Figure B7.4). This is broadly in line with their current share of emissions.

Figure B7.4. Estimated costs of decarbonising Scotland, Wales and Northern Ireland



Source: CCC analysis.
Notes: UK costs refer to central cost estimates for achieving a net-zero target. The proportion of costs for the devolved administrations relative to the UK total shown is the upper limit of the range.

(c) Uncertainty in cost estimates

The costs set out in Figure 7.2 represent our best assessment on a range of future assumptions such as technology costs and availability, costs of financing capital investment and behaviour change. They are of course uncertain, but the broad order of magnitude of the aggregate annual cost (1 – 2% of 2050 GDP) is likely to be robust.

Uncertainties

There is, inherently, significant uncertainty when making assumptions of this type so far into the future (as past cost estimates suggest) and several factors could result in lower or higher costs:

- **Technology costs.** Our estimates are relatively conservative on future cost reductions compared to recent experiences of renewable power and batteries (see section 2). The dynamics of innovation described in the previous section could mean that the technologies required to achieve net-zero emissions (including GHG removals) end up costing less than we assume, bringing down total costs of meeting targets.
- **Demand reductions.** We have also been cautious on the extent to which behavioural change and digitisation/automation can drive down demand across sectors. For example, a greater shift to a sharing economy could reduce demand for carbon-intensive goods and reduce the cost of decarbonising their production.
- **Ineffective policy.** Our cost estimates assume policy is able to deliver decarbonisation efficiently. Poorly designed policy could result in higher costs – for example, uncertainty in the direction of future policy support for a technology can increase the policy risk premium, resulting in higher financing costs.
- **Policy delay.** Scenarios are designed and costs estimated on the basis that action starts without delay, allowing time for decisions to be made, for innovation and market penetration, and stock rollover. Delayed decisions could lead to early scrappage of investments that are made despite being inconsistent with emissions targets.
- **Innovation and investment risk.** Conversely, setting a revised long-term target now and ensuring a stable policy framework to achieve it could help to stimulate innovation and to reduce investment risk, which could bring down the cost of capital of low-carbon technologies. For many low-carbon options where capital costs are a significant part of overall costs, such as renewable generation, the benefits of this have already been observed.

These uncertainties mean it is not sensible to be overly precise in reporting cost estimates (e.g. we emphasise our estimate of 1 – 2% of GDP, rather than our central estimate of 1.3%). However, provided policy is developed in an effective and timely manner, there appears to be more opportunity for upside of lower costs than downside risk of higher costs.

Risks and flexibilities

A key difference between achieving the current target and a net-zero GHG target is some loss of flexibility. Under an 80% target some of the more expensive or harder-to-abate elements of the economy may not need to be decarbonised, but under a net-zero target, all sectors need to be decarbonised (or their emissions offset by removing an equivalent amount of emissions from the atmosphere).

Although our cost estimates are based on reasonable assumptions over plausible scenarios, and do not involve excessive costs for the additional 20% abatement, there could be a risk that the last few million tonnes of emissions (e.g. the last 5%) end up much costlier than we expect.

There are several mitigating factors that make this risk a manageable one:

- Experience to date suggests that the most expensive measures could be the early actions as much as the later ones, as innovation takes effect. For example, in 2008 we expected offshore wind to remain an expensive technology, but despite significant costs early on, it is now expected to be low cost or cost-saving in future.

- Even if the last 5% is expensive on a per unit basis, the overall costs will be limited. Our cost estimates already assume a high unit cost (£300/tCO_2e) based on conservative assumptions over cost reductions for removal technologies. Even if all of the additional 20% of abatement (i.e. 170 Mt) costs £300/tCO_2e, overall annual costs still would not exceed 2% of GDP in 2050.
- The last few tonnes of emissions are only likely to be very expensive to abate if the rest of the world has not pursued significant decarbonisation efforts. If the rest of the world is decarbonising, global deployment can be expected to bring down technology costs.
- In the case that the rest of the world has not kept up with the UK's decarbonisation efforts, and technology costs are excessively high for marginal abatement in the UK, it is likely that marginal costs in other countries will remain low. In that case the UK could avoid excessive costs by purchasing international carbon units instead. The Climate Change Act would also allow the target to be revisited in such a case as it would involve a significant change from international circumstances today where there is widespread commitment to the Paris Agreement.

There should be reasonable confidence therefore in the overall magnitude of our cost estimates – and flexibility to respond if actual costs turn our much higher as a result of lack of action elsewhere.

External cost estimates

External estimates of the costs of reducing emissions to net-zero also support the conclusion that costs are unlikely to be more than a very small fraction of GDP (and there could be benefits):

- **European Union.** The European Commission's 2050 long-term strategy estimated that a net-zero GHG scenario for 2050 could be achieved at an annual GDP impact to the European Union of between a 1% GDP cost and a 0.6% GDP boost in 2050, relative to an 80% reduction scenario. The impact relative to a current policies baseline ranged from a cost of 1.3% to a boost of 2.2% of GDP in 2050. The range of estimates is driven by the use of different models (see Box 7.3).[181]
- **G20.** The OECD's modelling also suggests a small impact to GDP from climate change mitigation. It estimated an average annual GDP cost across G20 countries of 0.3% in 2050 for a scenario with 66% probability of limiting temperature rise to 2°C, relative to a scenario with 50% probability, and benefit of 2.5% of GDP in 2050 relative to a baseline.[182] These estimates assume a 'decisive transition', where structural reform, fiscal initiatives and green innovation accompany carbon abatement policies.
- **The Energy Transitions Commission** estimates that decarbonising the 'hard-to-treat' sectors (heavy industry and heavy transport) would cost less than 0.5% of global GDP by mid-century.[183]

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[181] European Commission (2018) *In-depth analysis in support of the Commission Communication COM(2018) 773 - A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.*
[182] OECD (2017) *Investing in Climate, Investing in Growth.*
[183] Energy Transitions Commission (2018) *Mission Possible - Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century.*

While these analyses suggest a range of uncertainty they all point to a small overall effect and suggest that it is possible that GDP could end up higher under scenarios with strong action to cut emissions.

4. Additional benefits from pursuing a net-zero emissions target in the UK

Set against the costs, there will be significant benefits, including avoided costs. These are not as straightforward to monetise, but nevertheless important. We consider those in this section, which has three parts covering the three main benefits likely to follow from a net-zero GHG target:

(a) Avoided climate damages

(b) Economic opportunities

(c) Health and environmental impacts

(a) Avoided climate damages

Chapter 2 described the global impacts of climate change and the benefits of global action to reduce risks more rapidly and limit future increases in climate risks.

The maximum level of warming reached will depend on the total CO_2 emitted before global CO_2 emissions reach net-zero. This means that all countries will have to reduce emissions rapidly to avoid high levels of future warming and large climate risks. Chapters 3 and 4 suggest that an ambitious net-zero GHG emissions goal in the UK can help support the global efforts to reduce emissions faster and limit future increases in climate risk.

Any efforts to keep future warming closer to today's levels than the current 3˚C trajectory will bring benefits by limiting increases in climate risks globally (Chapter 2). It would also help limit future climate risks to the UK:

- **Direct climate risks in the UK** include increasing risks of flooding, extreme heat and coastal erosion. Heat waves such as in summer 2018 created wildfires and impacted on agricultural output. The UK winter floods of 2013/14 were made more likely by climate change and caused an estimated £450 million in insured losses. These risks will increase in the future, but can be limited by global emissions reduction. For example, water deficits would be expected in around 25% of water resource zones if global warming increases to 4˚C by 2100, but only in 15% of zones if warming is restricted to 2˚C.[184]
- **Indirect climate impacts abroad** will also affect the UK as climate change could disrupt interconnected global systems:
  - Increasing risks from extreme weather events could lead to large numbers of people being affected by weather disasters and displaced from their homes, possibly increasing **migratory pressures** elsewhere in the world and risks of conflict.
  - Climate change has already had an impact on **crop yields** around the world, and severe risks to global food systems could occur if warming continues unchecked. These risks could affect the UK as a net food importer. Action to reduce emissions will help limit the increases in these risks as long as land is managed effectively to avoid conflicts with food

[184] CCC (2017) *Climate Change Risk Assessment 2017 Evidence Report.*

production (e.g. ensuring increased demand for bioenergy crops does not push up food prices by competing for land with agriculture).

Monetising the benefits of keeping climate risks to lower levels is challenging:

- Modelled costs involve many embedded assumptions and considerable uncertainties, including uncertainty over the extent of climate adaptation actions. There are also difficult ethical and economic judgements over the appropriate weighting given to costs far in the future and to the risks of irreversible and far-reaching impacts.
- Modelled costs vary significantly between the model and methodology used, with different ranges of sectors and impacts included in each.
- Abrupt future changes in the climate (such as ecosystem collapse) can be difficult to predict with their economic consequences challenging to model if they were to occur.

Despite these challenges, recent studies have begun to look at the economic impacts of keeping warming to the lower end (1.5˚C) of the Paris Agreement long-term temperature goal, compared to higher levels of warming. One study finds that limiting warming to 1.5°C rather than 2°C would avoid annual worldwide damages in the range of 1.5 – 2.0% of global GDP by mid-century.[185] An additional study highlights that keeping warming to 1.5˚C is expected to be particularly beneficial to poorer countries in the tropics, which are generally impacted the most by climate change.[186]

(b) Economic opportunities

Reducing GHG emissions to net-zero by 2050 will involve major shifts within the UK economy, as spending on fossil fuel imports is reduced and UK investment increases. These changes are set against a changing global economy, where demand for low-carbon goods and services are increasing rapidly and old carbon-intensive business models are under threat.

This section considers what that means for UK economic opportunities, beginning with the experience to date. We also consider potential implications for productivity and financial stability.

The story of clean growth in the UK so far

The UK has successfully reduced emissions whilst growing its economy in recent decades:

- UK emissions have fallen far more quickly than the G7 average, while the UK economy has broadly matched average economic growth in these countries (Figure 7.3).
- Some of the progress in decoupling of economic growth and energy use reflects energy efficiency improvements.

The Government's *Industrial Strategy* has identified the global shift to a green economy as a major industrial opportunity and its *Clean Growth Strategy* recognises the potential for this to be a positive contribution to the economy, rather than a burden to be minimised.

[185] Burke et al. (2018) Large potential reduction in economic damages under UN mitigation targets. *Nature* 557, 49-553.
[186] Pretis, F. (2018) Uncertain impacts on economic growth when stabilizing global temperatures at 1.5 C or 2 C warming. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376 (2119), p.20160460.

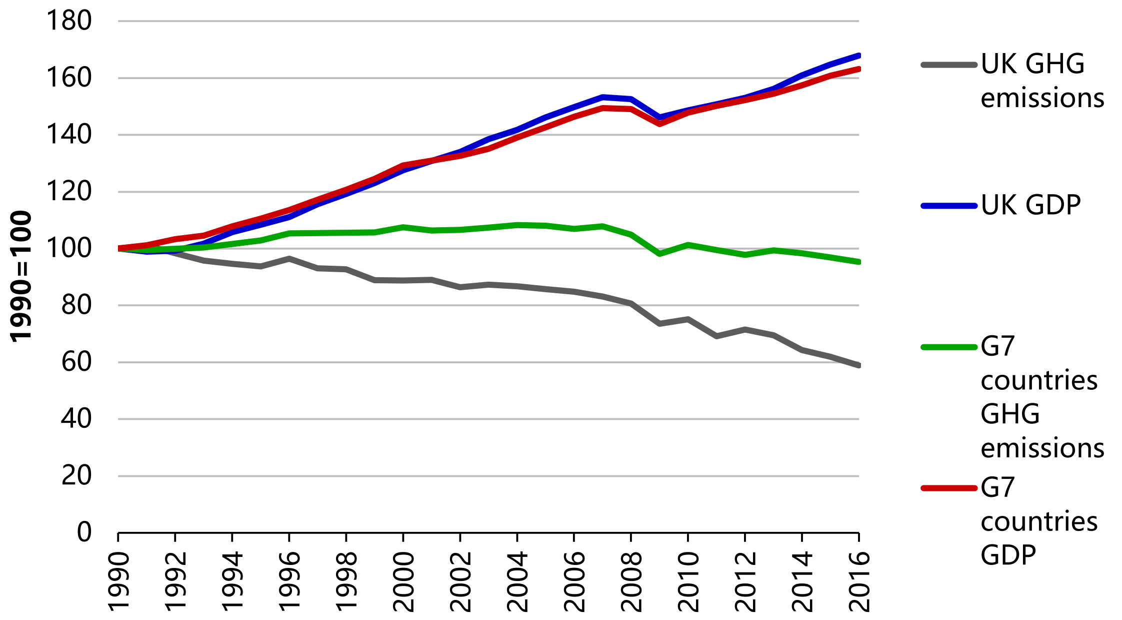
Growth in low-carbon industries has outpaced overall economic growth in the UK in recent years. As decarbonisation efforts ramp up globally there is scope for significant further growth in the low-carbon sectors:

- The UK's low-carbon and renewable energy economy directly generated £44.5 billion in turnover in 2017 (less than 1% of the UK non-financial business economy), an increase of 6.8% when compared with 2016.[187] These estimates are limited to direct activity only (i.e. excluding the supply chain) and use a narrow definition of the low-carbon sector (e.g. excluding financial services) which suggests that there is a bigger low-carbon economy than these numbers indicate.
- Figures including both indirect and direct activity (though still using the same narrow definition) put turnover in the low-carbon economy at £79.6 billion in 2017, an increase of 8.2% on the previous year.[188] Turnover in the whole of the UK business economy grew by 5.6% over the same period.[189]
- Delivering the goals of the Paris Agreement will require annual global investment in energy markets of $1.6 – 3.8 trillion on average until 2050, with most of this redirected to low-carbon technologies (see Chapter 3).[190] The UK is well placed to tap into many of these markets and continue to grow its low-carbon economy.

The higher growth in low-carbon sectors in part represents a shift in resources to these sectors from other productive uses, so does not necessarily imply a boost to overall economic growth. Rather it signifies the growing importance of the low-carbon sectors to the economy more generally.

[187] Defined as economic activities that deliver goods and services that generate significantly lower emissions of greenhouse gases; predominantly carbon dioxide. ONS (2019) *Low carbon and renewable energy economy, UK: 2017.*
[188] Indirect low-carbon economy activity statistics are experimental.
[189] UK business economy turnover corresponds to provisional estimates of the non-financial business economy. ONS (2018) *Non-financial business economy, UK (Annual Business Survey): 2017 provisional results.*
[190] Corresponds to supply-side energy market investments, in 2010 prices. IPCC (2018) *Chapter 2 - Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development.*

Figure 7.3. Change in greenhouse gas emissions and in real GDP in the UK and in G7 countries



Source: IEA (2018) *CO_2 Emissions from Fuel Combustion Statistics: Indicators for CO_2 emissions;* IMF DataMapper; BEIS (2018) *2017 UK Greenhouse Gas Emissions, Provisional Figures;* ONS (2018) *Gross Domestic Product: chained volume measures: Seasonally adjusted £m; CCC calculations.*

Industrial opportunities for the UK

As decarbonisation efforts strengthen internationally (see Chapters 2 and 3) there will be growing global markets for low-carbon goods, services and related knowledge. There is scope for the UK to capture some of this opportunity.

In 2017, the Committee commissioned Ricardo to assess the potential economic opportunity of a global transition to a low-carbon economy, consistent with keeping global temperature rise to 2°C.[191] Ricardo's assessment suggests that global markets for low-carbon goods and services, in a world taking actions to reduce emissions, will expand many times over:

- The global market for products and services related to the production of low-carbon electricity could expand at an annual average rate of 5 – 7% between 2015 and 2030, and 4 – 5% from 2030 to 2050.
- The global market for products and services related to low emission vehicles (including battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles) could grow at an average annual rate of 25 – 30% to 2030, and then around 7% from 2030 to 2050.
- The global market for low-carbon financial services could grow at annual average rates exceeding 10% to 2030, before settling back to annual growth around 2 – 3% from 2030 to 2050.

The increase in worldwide ambition suggests even more and faster growth in global low-carbon markets than that estimated in Ricardo's analysis.

[191] Ricardo (2017) *UK business opportunities of moving to a low-carbon economy*, available at www.theccc.org.uk.

If the UK reduces GHG emissions to net-zero by 2050 it will be amongst the early-movers in deploying many key low-carbon technologies and services (see Chapters 3 and 4). In a world where demand for low-carbon goods and services is rapidly expanding, being an early mover could mean developing expertise in some of these areas early on, providing export opportunities to other countries as their demand continues to grow.

Experience from Denmark (wind) and Germany (solar) demonstrates that local industries can develop to service local demands. However, these will not necessarily be sustained (e.g. Denmark still has a large wind industry, but much of solar production has moved from Germany to China).

Industrial benefits from developing low-carbon markets are possible, but not guaranteed and often depend on effective industrial policies.

The are several areas where decarbonisation could provide industrial opportunities to the UK, many of which are more likely to occur if the UK is aiming to achieve net-zero GHG emissions (Box 7.5):

- **Finance and insurance.** The UK is already a world leader in finance and insurance. The investment requirements of the transition to net-zero emissions will be significant worldwide and the UK is well-placed to lead on developing products to finance low-carbon investment (e.g. green bonds, green mortgage products) and on emissions credit markets, which are likely to be needed under global decarbonisation efforts. The UK is also already at the forefront in thinking about these issues – the Government has set up a Green Finance Taskforce to provide recommendations on delivering the investment needed to decarbonise and on maximising the UK's share of the global green finance market.
- **Low-carbon power and vehicles.** The extensive global deployment of low-carbon power and electric vehicles needed under ambitious decarbonisation efforts will require products and services in specialised industries that the UK has existing expertise in, like low-carbon finance, insurance and consulting, power systems transmissions, membranes and catalysts. This does not mean that the UK will be the main manufacturer of these products, but parts of these supply chains fit with the high-value added industries where the UK has a comparative advantage.
- **Greenhouse gas removal and storage.** Greenhouse gas removals (GGR) are an important feature of most global scenarios that meet the Paris Agreement's temperature goals and will be crucial for the UK if it is to achieve net-zero emissions. The UK has a potential advantage in these areas due to its existing supply chains, infrastructure and geological storage capacity.
- **Low-carbon production inputs.** Deeper decarbonisation of industries like steel and cement will be needed in the UK to achieve net-zero emissions. Greater international demand for low-carbon industrial products could be an opportunity for UK firms, if they start to decarbonise their manufacturing processes sooner.

Realising these economic benefits will depend on good policy alongside a net-zero target. In particular, it requires policies to support UK supply-side developments to deliver the technologies demanded by the net-zero transition.

Funding for development of early-stage low-carbon technologies has already been identified as a priority by the Government (e.g. through the Industrial Strategy Challenge Fund).[192] For early-

[192] The Industrial Strategy Challenge Fund pledges to invest in areas where the UK already has a comparative advantage and where global markets are fast-growing and sustainable, and has shortlisted areas such as electric

stage funding to translate to actual economic benefits it will need to be followed up with a coherent, predictable and stable policy regime that supports further roll-out. A stable and credible funding stream could also result in further crowding in of private investment, leading to additional economic benefits.

Innovation and productivity opportunities

While there is an upfront cost to shifting investment from slow-growing, high-carbon sectors to new low-carbon technologies, doing so also increases possibilities for innovation and productivity improvements:

- Technologies and practices in many high-carbon sectors are well established with limits to further innovation and productivity gains, whereas less mature technologies like renewables have more scope for learning-by-doing and productivity improvements.
- Emissions targets that limit carbon-intensive practices could encourage businesses to adopt more productive technologies and processes, resulting in productivity improvements. For example, resource and energy efficiency in manufacturing could result in cheaper unit production costs, resulting in higher productivity.
- We have had clear feedback from our Call for Evidence on the value of clarity. A net-zero target would increase clarity of the Government's intent and direction of travel and increase confidence in future markets for low-carbon products. This could in turn reduce the perception of risk and bring down the cost of capital of financing these products.
- Benefits are likely to extend beyond the technology or area that receives investment. There is evidence to suggest that spillovers from green investment and innovation are much greater than those from high-carbon spending.[193]

These benefits are of course not guaranteed, and will again depend on good policy to drive them.

transport (including the future of flight), smart sustainable packaging and industrial decarbonisation to receive a combination of Government and industry funding.

[193] Dechezlepretre et al. (2017) Knowledge spillovers from clean and dirty technologies. *Grantham Research Institute Working Paper series* ISSN 2515-5717.

Box 7.5. UK business opportunities in the global transition to a low-carbon economy

Ricardo developed a methodology to assess the potential scale of UK business opportunities from decarbonisation, based on estimated timelines for deployment of technologies in markets where the UK has strengths, in a world committed to a low-carbon transition. The assessment is necessarily uncertain, but identified a number of areas of potential business opportunities for the UK (Table B7.5).

Table B7.5. Assessment of UK potential to capture market share and examples of current UK strengths

Low-carbon economy sector	Potential to capture market share	Examples of current UK strengths
Energy efficient products	Medium	Smart Grids, advanced building design, materials and manufacturing systems
Energy from waste and biomass	Low to Medium	Biofuels, waste recycling techniques
Low-carbon electricity	Medium	Off-shore wind, energy storage, solar PV
Low-carbon services	High	Finance, insurance, consultancy
Low emission vehicles, infrastructure, fuels cells and energy storage	Medium to High	Power systems and transmissions, batteries, logistics, telematics
Other products and services	Medium to High	Membranes, catalysts, bioprocessing

Source: Ricardo (2017) *UK business opportunities of moving to a low carbon economy*, available at www.theccc.org.uk

Financial stability

One of the benefits of achieving a net-zero GHG target is a reduction in the financial sector's exposure to physical risks from climate-related damages. It could also reduce systemic exposure to the risks of being unprepared for the necessary transition in capital and investments.

The Bank of England has highlighted two potential risks to the financial system arising from climate change:

- Physical risks of climate change (e.g. climate damages resulting in financial losses or high insurance claims).
- Transitional risks to the financial system arising from the adjustment towards a low-carbon economy, prompting a reassessment of asset values.

The Bank is already taking measures to manage the financial risks of climate change by enhancing the Prudential Regulation Authority's approach to supervising these risks and the resilience of the UK financial system to climate change.[194] It will soon set out how it wants banks, insurers and investment companies to manage financial risks from climate change.

(c) Health and environmental impacts

Many of the actions to cut GHG emissions will also tend to cut other pollutants associated with the burning of fossil fuels. These and other measures will bring co-benefits, such as more comfortable homes (from energy efficiency), improved health (from reduced red meat consumption and more active travel choices) and ecosystem benefits (from afforestation).

The co-benefits from reaching net-zero GHG emissions in 2050 will be significant and could partially or fully offset the resource costs of achieving the target. We first consider those impacts that can be monetised and then impacts that are harder to quantify.

Monetised impacts

We commissioned Ricardo in 2013 to undertake a survey of the health and environmental impacts of a low-carbon scenario in 2030, on the pathway to the current target:

- The greatest co-benefits of low-carbon measures were found to be congestion reduction and health improvements from a reduction in car travel (and corresponding increase in walking, cycling and public transport use), health benefits from a shift towards less meat-intensive diets and air quality and noise benefits from low-carbon vehicle roll-out.
- Monetising these impacts in line with the Government's *Green Book* guidance identified annual net benefits of 0.1 – 0.6% of GDP in 2030 from deploying measures needed to meet the fifth carbon budget, for benefits that could be quantified.[195]
- These estimates suggest that monetised benefits offset up to half of the estimated resource cost of meeting the fifth carbon budget in 2030.

Comparing our new net-zero scenarios to those considered by Ricardo in 2013 gives an indication of some of the important actions that would result in significant quantifiable co-benefits:

- **Shift away from car travel:**
  - Moving from car travel onto other modes of transport (walking, cycling and public transport) is an effective way of reducing emissions from vehicles and also results in less time spent in congestion and health benefits from more physical activity.
  - Ricardo's 2013 estimates found that a 5% shift in travel from cars to other modes resulted in a monetised annual benefit of 0.5% of GDP in 2030.
  - Our net-zero scenarios assume a 10% transport modal shift, which suggests benefits by 2050 would be greater.

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[194] Batten, Sowerbutts and Tanaka (2016) Let's talk about the weather: the impact of climate change on central banks. *Bank of England Staff Working Paper* No. 603.
[195] CCC (2013) *The Fourth Carbon Budget Review – part 2: the cost effective path to the 2050 target.*

- **Healthier diets:**
  - A shift towards healthier diets, more in line with Government guidance, would result in reduced reliance on livestock and lower emissions from agriculture as well as benefits to human health.
  - In 2013, Ricardo estimated the health impacts of reducing red meat consumption by 50% and found annual monetised benefits to be 0.5% of GDP in 2030.
  - Our net-zero scenarios include a 20% reduction in beef, lamb and dairy consumption (for the Further Ambition scenario, which has some increase in less carbon-intensive meat like pork and chicken) so would likely result in lower, though still significant, health benefits. We include a 50% reduction as one of the Speculative options that could be needed.
- **Air quality and noise reduction:**
  - Air quality improvements follow from low-carbon measures that reduce or replace fossil fuels. Health benefits from reductions in air pollution will be more pronounced in populated areas so decarbonising transport is likely to have a significant impact (as power plants and heavy industry tend to be located farther away from population-dense areas). Electric vehicles are also quieter than combustion engine alternatives, resulting in further health and environmental benefits from the reduction in noise (which can result in heart problems, sleep disturbance, slower learning and annoyance, and can disrupt the natural environment).
  - Other low-carbon measures such as use of bioenergy could result in negative air quality impacts. Whether or not this is a net cost depends on the technology it replaces and where it is located, with use of biomass for heat in buildings potentially resulting in net costs. Our scenarios primarily use biomass with CCS and decarbonise heating with heat pumps and hydrogen, so should not result in air quality costs that exceed benefits.
  - Ricardo's 2013 estimates suggest that air quality and noise impacts of a low carbon scenario result in annual monetised benefits of close to 0.1% of GDP in 2030. New evidence published by the World Health Organisation in 2016[196] strengthening the link between negative air quality and burdens to human health suggests that benefits are likely to exceed this estimate.
  - Our net-zero scenarios would result in higher air quality and noise benefits by 2050 as they assume a far greater reduction in combustion engine vehicles than the scenarios assessed by Ricardo in 2013 (to close to zero by 2050).

A simple scaling of the Ricardo estimates in line with the proportionately higher roll-out in our scenarios would imply a value to these co-benefits of the order of 1.3% of GDP. That should be treated with caution however, given the complexities involved and the age of the Ricardo analysis. Furthermore, the estimated benefit is dominated by the assumed modal shift in transport, which has a minimal effect on 2050 emissions in our scenarios. Further analysis would be desirable in this area.

[196] World Health Organisation (2016) *Ambient air pollution: A global assessment of exposure and burden of disease.*

Non-monetised impacts

There are many other positive impacts of reducing GHG emissions to net-zero that are more difficult to monetise in a comparable way to the above:

- **Comfortable homes.** Our net-zero scenarios imply a significant roll-out of energy efficiency measures in new and existing homes (around 6 million cavity walls, 6 million solid walls and 21,000 loft insulation measures). As set out in our recent report *UK Housing: Fit for future?*[197], high efficiency in new homes and retrofitted to existing homes can address poor thermal efficiency, overheating, indoor air quality and moisture in the round. This would result in thermally comfortable homes, reducing the risk of heat and cold related deaths. The health cost to the NHS of conditions exacerbated by poor housing is currently estimated to be £1.4 – 2.0 billion per year in England alone.
- **Land use and agriculture.** The agriculture and land use measures required to achieve net-zero emissions have multiple benefits across climate change adaptation, health and wider environmental goals:[198]
  - **Restoration of peatlands.** Peatland restoration in our net-zero scenarios of around 20,000 hectares a year by 2050 (compared to no peatland restoration in an 80% emissions reduction scenario) would increase the likelihood that upland peat biodiversity could withstand shifts to the hotter, drier conditions we can expect over the rest of this century. It would also bring benefits for air and water quality, biodiversity and habitat creation and further climate change adaptation benefits (flood alleviation and water quality).
  - **Increased woodland and hedgerow planting.** Compared to our scenarios for the 80% target our net-zero scenarios involve almost twice as much tree planting (including on-farm). They also involve extending hedges by 40%, which is not assumed in scenarios that achieve current targets. Both these measures result in benefits to biodiversity through habitat creation (as we assume mixed planting rather than monocultures, which could negatively impact biodiversity) and can help towards flood alleviation. There could also be air quality benefits depending on which trees are planted and where. More woodland close to populated areas would also bring recreational benefits, while increased tree cover in agricultural land could improve animal welfare (providing shade for livestock on hot days). It will be crucial that the choice of species being planted takes into account future climatic suitability under a changing climate.
  - **Changes to farming practices.** Practices that optimise the efficient use of nitrogen on cropland and grassland, which are assumed in our net-zero scenarios, can reduce N_2O emissions on agricultural soils. There are also air quality improvements to be gained from a reduction in ammonia. If farms are located near water courses, these measures can help reduce water pollution with benefits for water quality, biodiversity, habitat condition and resilience to climate change.

There are therefore considerable co-benefits of a net-zero target beyond those that can be monetised.

The Welsh Government has taken steps to ensure that the wider benefits from long-term decarbonisation are recognised. Wales has developed a comprehensive approach to sustainable

[197] CCC (2019) *UK Housing: Fit for the future?*
[198] CCC (2018) *Land use: Reducing emissions and preparing for climate change.*

development with the Well-being of Future Generations (Wales) Act 2015, which put in place seven goals to improve the social, economic, environmental and cultural well-being of Wales. The Act also established the Future Generations Commissioner for Wales, who identified climate change as one of four emerging priorities (Box 7.6).

5. The distribution of costs and impact on other factors in the Climate Change Act

The overall costs and benefits of achieving a net-zero target have been our focus for the first four sections of this chapter. We have highlighted that annual costs are not expected to be large, particularly in the context of economic growth, and there are many benefits (quantified or otherwise) that could outweigh costs.

However, aggregate impacts are only one part of the story. The structural change required to achieve a net-zero target is large and will affect different segments of the economy and groups in society differently. Considering the distribution of costs (and benefits) of a net-zero target is therefore vital.

Some of the cost of decarbonisation will fall to the Exchequer (**fiscal impacts**), some will fall to households (for example through **energy bills**, which could have regressive impacts), and some to businesses (which where these are trade-exposed could result in **competitiveness risks**). The Climate Change Act highlights the need to give due consideration to these issues when assessing the impact of emissions targets, which we address in this section.

The Climate Change Act also raises the importance of considering the impact of emissions targets on energy supplies – we therefore also assess the **energy security implications** of a net-zero target in this section.

The precise split of costs and benefits of decarbonisation between households, businesses and the Exchequer will depend on how Government chooses to design and fund policies to achieve a net-zero target. As such, we have not attempted to estimate this split, and recommend that HM Treasury undertake a thorough review of the distribution of costs and benefits of meeting a net-zero target and the appropriate policy levers to achieve an efficient and fair transition.

Section 6 further addresses distributional impacts, looking into the potential effects of the transition to net-zero emissions on jobs.

This section covers the issues set out above as follows:

(a) Fiscal balance

(b) Energy bills

(c) Competitiveness risks

(d) Energy security

Box 7.6. Well-being of Future Generations (Wales) Act

Our 2017 advice on Welsh carbon targets[199] provided an extensive assessment of the impacts of climate policy against the wellbeing goals of the Well-being of Future Generations Act. In particular, this focused on the wider wellbeing benefits of decarbonisation in Wales:

- Fuel poverty benefits associated with lower energy consumption and improved comfort.
- Air quality benefits from eliminating coal combustion, switching to ultra-low emissions vehicles (ULEVs), switching away from polluting fuels used for heating and afforestation.
- Active travel measures that bring multiple health and wellbeing co-benefits.
- Wider economic benefits including job creation, supply chain and social benefits from the renewable energy and low-carbon manufacturing sectors.
- Natural capital benefits, as defined by the 2016 State of Natural Resources Report[200] (SoNaRR):
  - Provisioning services (products obtained from ecosystems) including renewable energy generation and the efficient use of food and timber.
  - Regulating services (benefits obtained from the regulation of ecosystem processes) including air quality and flood control benefits from afforestation.
  - Cultural services (non-material benefits people obtain from ecosystems) including the recreational and amenity benefits of afforestation.
  - Supporting services necessary for the production of all other ecosystem services, such as habitat creation and water and soil quality.

That advice was based on scenarios to prepare for Wales's existing long-term target of an 80% reduction in GHGs from 1990 to 2050. In our Further Ambition scenario, Wales can credibly achieve a 95% reduction in GHGs by 2050, relative to 1990 levels.

Achieving a 95% reduction will require Wales to deliver all the Core measures associated with an 80% reduction, which will bring the wellbeing benefits previously described. In addition, areas where the largest amount of additional abatement potential has been identified for Wales can deliver further wellbeing benefits to Wales:

- **Industry.** Further abatement in industry could come from resource and energy efficiency improvements and depending on the policy levers could result in international competitive advantages in low-carbon manufacturing in Wales.
- **Afforestation and hedgerow planting.** A higher rate of planting in Wales can provide further air quality, biodiversity, flood control and recreational/cultural co-benefits.
- **Agriculture**. More efficient use of nitrogen on cropland and grassland can bring air quality benefits through reduced ammonia emissions, and reduce water pollution with benefits for water quality, biodiversity, habitat condition and resilience to climate change. There are additional health and wellbeing benefits associated with a shift to healthier diets in our Further Ambition scenario.
- **Engineered GHG removals**. The production of biomass and timber grown in Wales to deliver GHG abatement will deliver additional 'provisioning services' as defined in SoNaRR.

[199] CCC (2017) *Building a low-carbon economy in Wales - Setting Welsh carbon targets.*
[200] Natural Resources Wales (2016) *The State of Natural Resources Report (SoNaRR) 2016.*

(a) Fiscal balance

Our analysis suggests that the costs of achieving a net-zero target are no higher than the costs expected for current targets when they were set in 2008. Net fiscal impacts of net-zero should not significantly exceed what the UK has already signed up for when agreeing to set an 80% reduction target.

This does not mean that shifts in public spending and receipts will not occur. As our estimates suggest high costs of decarbonisation in some sectors (i.e. buildings, industry and GHG removals) careful consideration of where funding will come from is needed:

- Switching homes to **low-carbon heating** remains a major challenge. It is currently funded by Exchequer spending, but roll-out is limited and less than £100 million was spent in 2018. Our estimates imply an annual cost, reflecting higher upfront costs, for switching to low-carbon heating of the order of £15 billion. Large-scale deployment must begin before 2030. It would be regressive, and probably restrict progress, to pass the cost on fully to households. There may therefore be a continued role for taxpayer funding in low-carbon heating (see section 5b for more on the impact of a net-zero target on energy bills and fuel poverty).
- **Industry** decarbonisation in our scenarios has an annual cost of the order of £5 – 10 billion. Some of this could be passed onto industry, where it is not exposed to international competition or where the incremental costs are small. However, trade-exposed industries will require a level playing field to ensure that emissions are reduced, not offshored. That could involve schemes similar to those in place today – free allocation of allowances within the EU Emissions Trading System (ETS) and compensation for costs resulting from UK climate policies. It could also involve new schemes such as border tariff adjustments or product and building standards that drive demand for low-carbon goods (see section 5c for more on mitigating competitiveness risks to industry).
- **Electric vehicles** currently benefit from capital subsidies and lower fuel and vehicle taxation. Each of these can be phased out in the long run as electric vehicles reach cost parity. By 2050, we expect the shift to low-carbon options like electrification to cut the annual costs of UK transport by around £5 billion. That can be achieved while maintaining transport's tax contribution and allows for the costs of charge-points and other infrastructure.
- **Farmers** and land managers currently receive large subsidies from the EU's Common Agricultural Policy (CAP), but not for reducing GHG emissions. The UK Agriculture Bill intends to redirect subsidies towards public goods and could support the major transition in land use and farming practices required by a net-zero GHG target. Our cost estimates for land and agriculture in our scenarios (under £2 billion annually) are lower than UK payments under CAP (over £3 billion).
- The annual costs of **removing emissions** from the atmosphere are potentially large in our scenarios (e.g. of the order of £10 billion, possibly as high as £20 billion). We assume these will be primarily paid by industries, like aviation, that have not reduced their own emissions to zero. Rather than impacts on the Exchequer that would imply increasing costs for flights from 2035, as emission removals scale up in our scenarios.
- Low-carbon **electricity** is currently funded by bill payers (households and businesses) who currently pay around £7 billion a year towards the roll-out of low-carbon power. This is expected to rise to around £12 billion by 2030 then fall to 2050 as contracts for existing renewable generators come to an end and they are replaced by newer cheaper generation

(e.g. our scenarios involve an annual resource cost of around £4 billion in 2050). The impact of this on bill payers is covered in the following section (5b).

Most changes to the Government balance sheet will be gradual. There is time and scope within annual budgets to make adjustments to the fiscal framework, and develop suitable policy and funding instruments to avoid fundamentally changing the burden of taxation.

(b) Energy bills

Consideration of the impacts of carbon policies on energy bills is important as they make up a much larger proportion of low-income households' spending. We first set out what has happened historically, then consider prospects for bills in future and the required policy response.

Impact of past and current climate policies on household energy bills

We assessed the impact of climate policies on household energy bills in our 2017 report on *Energy Prices and Bills - impacts of meeting carbon budgets*:[201]

- **Current bills.** The annual bill for a typical dual-fuel household (using gas for heating and electricity for lights and appliances) in 2016 was around £1,160, around £105 (9%) of which was the result of low-carbon policies.[202]
- **Changes in bills to date.** Total bills in 2016 were £115 lower in real terms (i.e. adjusting for general price inflation) than in 2008, when the Climate Change Act was passed. Higher household energy prices resulting from low-carbon policies and network costs were more than offset by reductions in energy use over this period.
- **Changes in bills to 2030:**
  – Our analysis suggests that meeting the fifth carbon budget will add between £85 – £120 to the annual dual fuel bill between 2016 and 2030.
  – Households could more than offset this increase with energy efficiency improvements, which could save around £150 on average each year (if prices remain at current levels). The majority of this saving (85%) is possible by replacing appliances, lights and boilers at the end of their lives with the latest equivalent models.
  – Factors unrelated to climate policies, particularly rising wholesale gas prices, are expected to add over £200 to bills, increasing the typical bill in real terms to between £1,220 – £1,410 by 2030. If wholesale prices do rise, savings from improving energy efficiency would be even larger.

Impact of net-zero emissions scenarios on household energy bills

Shifting to low-carbon approaches to heat residential buildings is likely to be one of the more costly challenges in reaching net-zero emissions across the economy. However, offsetting falls in costs are expected for other parts of the economy: the shift to electric vehicles is expected to cut costs of motoring, whilst between 2030 and 2050 the costs of low-carbon electricity are expected to fall.

[201] CCC (2017) *Energy Prices and Bills - impacts of meeting carbon budgets.*
[202] Low-carbon policy costs comprise: the carbon price, support for renewable electricity generation and costs associated with improving energy efficiency for carbon reduction; the majority are levied on electricity.

Our cost estimates indicate that scope for falling power costs and transport savings could fully offset extra costs from heat decarbonisation (see Figure 7.4):

- **Transport.** Driving electric vehicles becomes cheaper than driving petrol or diesel equivalents by the mid-2020s in our net-zero scenarios, due to continued reductions in battery costs and lower fuel costs. Our analysis suggests annual savings of up to £6 billion per year in switching away from diesel and petrol cars towards low-carbon transport between 2030 and 2050. This conclusion stands even without existing subsidies when purchasing electric vehicles or the higher tax rates levied on petrol and diesel sales.
- **Power.** Beyond 2030, electricity costs should fall as renewables become even cheaper, higher payments to legacy projects cease as their contracts come to an end (payments under the Levy Control Framework, which covers the total payments to low-carbon generators, are due to peak in the mid-2020s) and further savings from energy efficiency occur. In total we expect a reduction in annual power sector costs in our net-zero scenarios of £7 billion per year between 2030 and 2050. We note that those costs are currently recovered from all consumers, including business and industry as well as households.
- **Heat.** Reducing heating emissions to close to zero looks likely to remain more expensive than burning natural gas in boilers. Low-carbon heating systems (including household conversion) add up to £10 billion a year to annual heating costs in our net-zero scenarios. While installing energy efficiency measures costs up to £7 billion annually it results in annual fuel savings of £5 billion.

The aggregate impact of these changes would be broadly neutral by 2050, as Figure 7.4 illustrates. That suggests it is possible to deliver against a tighter carbon target without increasing costs to consumers. Achieving this will depend on how policy is designed to deliver the required carbon abatement, and costs and savings will not automatically fall to the same consumers.

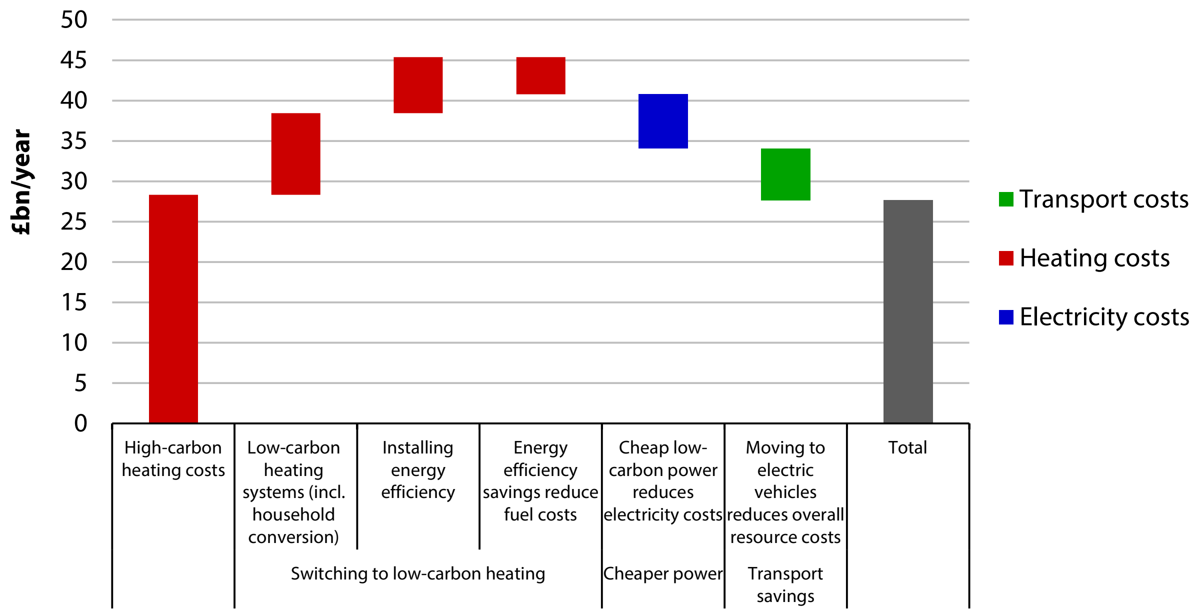
Policy implications

A challenge for Government is to design policies that drive required changes without creating too many winners and losers.

It could be regressive to pass the full costs of heat decarbonisation to households. One option would be to fund a large part of the cost from the charges on consumer bills that currently subsidise renewable power, which will not be needed by 2050 as renewable power costs fall.

Addressing fuel poverty (Box 7.7) should continue to be a priority. Successful targeting of measures is not easy (e.g. due to issues like data availability and people moving in and out of fuel poverty) but could help to achieve carbon reduction and fuel poverty targets at lower costs. Regional distribution of impacts should also be considered.

Figure 7.4. Falling costs for zero-carbon power and transport have the scope to offset heating costs



Source: CCC analysis.
Notes: Figures represent costs between 2030 and 2050. Transport savings are pre-tax and do not relate to the fact that electric vehicles in the UK currently do not pay fuel duty. They represent savings from passenger cars only - if vans were included savings would be higher.

Box 7.7. Decarbonisation and fuel poverty

A household is considered to be fuel poor if they cannot afford to keep their home adequately warm at a reasonable cost, given their income. Fuel poverty is caused by a combination of low household income, high energy requirements and high energy costs, with energy-inefficient housing being a key driver.

Although overall energy bills have not increased between 2008 and 2016, despite low carbon levies, it is important to understand how low-carbon policy costs could affect fuel poverty in the future. In 2014 the Centre for Sustainable Energy assessed the impact of low-carbon policy on fuel poverty across the UK to 2030 for the Committee:

- A scenario without further energy efficiency improvements, where costs were passed onto energy bills, resulted in an increase in fuel poverty from 2.9 million in 2013 to 3.1 million in 2030, or from 5.6 million in 2013 to 8 million in 2030 (depending on the definition of fuel poverty used).
- In a scenario including support for home insulation and low-carbon heat targeted towards fuel poor homes fuel poverty levels were significantly reduced.

This points to the importance of targeting energy efficiency measures to fuel-poor households.

Our net-zero scenarios assume almost 3.3 million solid wall insulation measures for wider fuel poverty benefits, though further targeted measures may be needed to ensure decarbonisation does not disproportionately affect fuel poor homes.

Source: CCC analysis; CSE (2014) *Research on fuel poverty: The implications of meeting the fourth carbon budget,* available at www.theccc.org.uk

(c) Competitiveness risks

Decarbonisation could bring many opportunities for UK businesses, as set out in section 4b. But there are also risks to the competitiveness of UK firms which need to be considered.

Businesses that rely on energy-intensive or carbon-intensive practices and compete in international markets may face competiveness challenges if they are exposed to significant cost changes from decarbonisation not faced by international competitors:

- If this results in changing the location of production to other countries ('offshoring' or 'carbon leakage') it would be undesirable for the economy, could increase the UK's consumption emissions and potentially global emissions.
- While the main objective of UK carbon targets is to reduce territorial emissions, consumption emissions should not increase as a result of national mitigation efforts (as discussed in Chapter 5).

We first consider the impacts of current targets, and then what a net-zero target could imply.

Impacts of current targets

We considered this issue in depth in our 2013 report on *Managing competitiveness risks of low-carbon policies*[203] and in our 2017 report on *Energy Prices and Bills*[204] and concluded that:

- Low-carbon policies have not had a major impact on the competitiveness of UK manufacturing to date. That reflects the fact that industries at risk have been largely protected from increased carbon costs.
- Competitiveness risks of carbon budgets are limited to a small part of the economy (sectors that are both energy-intensive and reliant on international trade) and are manageable. To ensure that remains the case the Government should ensure compensations and exemptions for firms at risk of carbon leakage are predictable, reliable and timely.

Impact of a net-zero emissions target

The updated evidence base for this report highlights significant opportunities for industry decarbonisation, which go much farther than our previous decarbonisation scenarios. Our analysis suggests that it is possible to reduce industry emissions to 10 $MtCO_2e$ by 2050, while a scenario that achieves current targets could have as much as 56 $MtCO_2e$ remaining.

The costs of achieving this level of emissions abatement are amongst the highest across all the sectors of the economy (annual costs of £8 billion, equivalent to 0.2% of GDP in 2050). It could present a real challenge if industry were to bear the entirety of the cost.

There are, however, mitigating factors against this risk:

- As highlighted in our previous analysis, this should only be a genuine risk for a fraction of UK industries: those that are both trade-exposed and carbon-intensive.
- Competitiveness risks posed by the transition to a low-carbon economy depend in part on how fast the UK moves relative to others. As highlighted in Chapter 2, global ambition on climate change is increasing – more ambition elsewhere means fewer locations for carbon leakage and a larger global market for low-carbon industrial products.

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[203] CCC (2013) *Managing competitiveness risks of low-carbon policies.*
[204] CCC (2017) *Energy Prices and Bills - impacts of meeting carbon budgets.*

The higher costs faced by industry to achieve a net-zero target and the decarbonisation of a greater number of industries mean that new solutions for safeguarding the competitiveness of UK industries will be needed, both industry- and Government-led.

A recent review for BEIS of business models for supporting industrial CCS has set out some options which largely draw on comparable existing policies, these include a contract for difference on the CO_2 price, regulated asset base and tradeable CCS certificates.[205]

There are other known options which could support industry decarbonisation in general (i.e. beyond CCS):

- **UK compensations and exemptions.** Compensations and exemptions are currently offered to UK industries to offset most of the increased electricity costs that result from UK carbon pricing and support for renewable generation. These could be carried forward and applied more broadly (e.g. to cover costs of CCS) in the transition to net-zero if competitors continue to apply lower costs. The Government should signal this intention and continue to review the set of industries requiring exemption/compensation.
- **Emissions trading schemes.** Should the UK leave the EU ETS it will need to develop its own policy to drive emissions reduction from industry without creating competitiveness risks (e.g. a regional emissions trading scheme, or UK scheme linked to the EU ETS). Regional trading schemes help address competitiveness concerns by applying a similar carbon price across jurisdictions and bring the option of allocating some emissions allowances for free to the most trade-exposed industry sectors.
- **Standards to create markets for low-carbon products.** Policy could aim to incentivise/create markets for low-carbon products, through public procurements or regulations on products and materials (e.g. by requiring buildings in the UK to use low-carbon materials in construction). These would drive end-user demand for low-carbon products, creating a level playing field for UK and overseas firms provided they have decarbonised sufficiently to meet the standards.
- **International sectoral agreements.** International agreements between businesses in industries at risk of carbon leakage could mitigate competitiveness risks, in the absence of uniform climate policies across countries. This involves collective industry agreement to reduce the emissions intensity of their production practices (normally by target dates), and could also involve knowledge sharing to achieve emission reductions. Some sectors, such as cement, chemicals and textiles (along with shipping and aviation) have already started to set up these types of agreements (see Box 7.8); more action will be needed for a net-zero target.
- **Border tariff adjustments**:
  - As the UK negotiates new trade deals outside the EU, the possibility of using border tariff adjustments (a carbon tax on domestically consumed products based on their footprint and imposed at the border on imported products) should be considered.
  - Whilst there are both political and practical challenges with implementing this type of tariff (e.g. it would require certification of the carbon content of all imported products, which currently does not exist) it has recently gained some traction internationally in both developed and developing countries – for example, the European Commission's 2050 long-term strategy and Mexico's Nationally Defined Contribution (NDC) to the Paris

[205] Element Energy (2018) *Industrial carbon capture business models*. Report for BEIS.

Agreement refer to border tariff adjustments as one possible mechanism through which trade policy could contribute towards decarbonisation.

A net-zero GHG target can only be met with deep reductions in emissions from industry. For the good of the UK economy and of the climate that requires low-carbon approaches to be adopted in the UK, not high-carbon business to be driven offshore. Designing effective policy to ensure this happens, and doing it far enough ahead for businesses to plan and respond must be a key priority for Government in adopting a net-zero GHG target.

Box 7.8. International sectoral agreements for cutting emissions

Global Cement and Concrete Association (GCCA)

The GCCA was launched in 2018 with the objective to drive responsible industry leadership in the manufacture and use of cement and concrete, and improve the social and environmental impact of the sector's activities.

It's membership accounts for around 30% of the world's cement production capacity, and is expanding.

The GCCA's Sustainability Charter sets out five pillars of sustainability which all full members are expected to develop initiatives against. It also includes sustainability guidelines with measures which members must monitor and report performance against, in order to achieve the organisation's sustainability compliance. These include guidelines for monitoring and reporting of emissions from cement manufacturing.

In addition to publishing measures and monitoring progress, full GCCA members are also expected to develop climate change mitigation strategies.

International Council of Chemical Associations (ICCA)

The ICCA published a Statement on Climate Policy following the Paris Climate Change Agreement. The Statement explicitly states the ICCA's aim to 'achieve net global GHG reductions and avoid shifting emissions between regions or countries'.

ICCA members account for more than 90% of global chemical sales.

As part of its sustainability drive the ICCA published guidance for the industry on conducting life-cycle emissions assessments, and technology roadmaps outlining how governments and industry can accelerate innovation in chemicals products to improve sustainability.

Fashion Industry Charter for Climate Action

The Fashion Industry Charter for Climate Action, launched at the 2018 COP24 climate conference, sets out a vision to achieve net-zero emissions in the industry by 2050.

The Charter includes an intermediate target of 30% greenhouse gas emission reductions by 2030 and a commitment to set a decarbonisation pathway for the fashion industry. The Charter's signatories will aim to increase collaboration and share best practice.

Signatories include 43 leading global fashion companies as well as supporting organisations (e.g. the International Chamber of Commerce, World Wildlife Fund, Sustainable Apparel Coalition).

(d) Energy security

The transition to a low-carbon economy will reduce the UK's reliance on imported fossil fuels, but will also bring new challenges for energy security that can and should be managed.

Import dependency of UK energy supplies

A diverse energy mix contributes to maintaining security of supply. The more reliant the UK is on imported fuels, the more exposed the economy is to price fluctuations.

Achieving a net-zero target would enhance the UK's energy sovereignty by reducing demand for imported fossil fuels, and provide a hedge against price volatility and the associated risk of damaging economic impacts:

- **Natural gas:**
  - Natural gas consumption in the UK was 875 TWh in 2017 with net gas imports close to 400 TWh.[206] UK natural gas production is expected to continue to decline from 416 TWh in 2017 to less than 85 TWh in 2050 (an 80% reduction).[207]
  - Our scenarios that achieve a net-zero target suggest a decline in gas consumption of 32% by 2050 (reaching close to 600 TWh). Significant reductions in natural gas consumption across buildings, industry and power in our net-zero scenarios are somewhat offset by new demand for gas to produce hydrogen.
  - Given this reduction in gas consumption, achieving a net-zero scenario target is likely to result in lower UK gas import dependency than in a high-carbon world.
- **Oil:**
  - UK consumption of petroleum products was 752 TWh in 2017 and net imports were 121 TWh. UK oil production, like natural gas, is projected to continue its decline from 592 TWh in 2017 to around 130 TWh in 2050 (a 78% reduction).
  - Our net-zero scenarios result in a reduction in oil consumption of 82% by 2050 (reaching around 140 TWh). This suggests that a net-zero target is likely to reduce the UK's oil import dependency relative to a high-carbon world.

Maintaining reliable electricity supplies

Electricity systems need to match electricity supply to demand in real-time. As more weather-dependent sources of electricity supply come online, matching supply to demand can become more challenging.

All of our scenarios are built with a requirement that supply meets demand at all times and our power costs include the costs of backup requirements to maintain security of supply.

Experience and evidence is making it increasingly clear that systems with a high proportion of intermittent renewables can be managed (e.g. the UK's System Operator is already planning to manage the grid to operate 'safely and securely at zero carbon' for parts of the year as early as 2025).[208]

Nevertheless, we take a cautious approach in limiting the share of variable renewables in our scenarios to under 60%, even though they are the cheapest generation options. If higher

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[206] BEIS (2018) *Digest of UK Energy Statistics*.
[207] Based on the Oil and Gas Authority's (OGA) 2035 net natural gas production forecast and long-term projected decline out to 2050. OGA (2019) *UK Oil and Gas production and Projections of UK Oil and Gas Production and Expenditure 2018 Report.*
[208] National Grid (2019) *Zero Carbon Operation 2025*.

renewable shares were possible, this would likely reduce system costs, given the lower costs we expect for renewables compared to nuclear and CCS.

For further details on power system intermittency see Chapter 2 of the Net Zero technical report and the accompanying technical Appendix.

6. Ensuring a just transition to a zero-carbon economy

Economies are always in transition. The UK energy sector has seen transitions prompted by the industrial revolution, by the decline of UK coal mining and rise of natural gas and oil extraction in the North Sea, by privatisation and most recently by the need to decarbonise.

Broader transitions currently underway include the ongoing digital revolution and the accompanying wave of new disruptive technological developments (often referred to as the 'Fourth Industrial Revolution') including artificial intelligence, automation and robotics. Globalisation has shaped the global and UK economies, as will the UK's future trading relationships.

The transition to a zero-carbon economy differs to other transitions as much of it will need to be policy-led, rather than a reaction to changing technologies and circumstances. The required speed of the transition is fast and the scale large, spanning across most aspects of the economy.

Like past transitions, the transition to net-zero GHG emissions will result in the creation of new markets and industries and a shift away from old industries, with consequences for employment. It will also bring down costs of some goods and services, while increasing the cost of others.

This shift should be managed so that burdens and benefits are fairly distributed amongst society, ensuring a just transition.

(a) A just transition

The concept of a 'just transition' was introduced by the International Labour Organisation (ILO) in recognition of the impact of the transition to a decarbonised world on current generations, and putting forth the idea that decent work for all should be a building block of sustainable development.[209]

The concept is now widely recognised as a crucial element of a low-carbon transition – a just transition declaration was signed by 53 governments (including the UK) at the COP24 climate conference in 2018, followed by an investor statement backed by over 100 institutions worldwide with more than US$6 trillion in assets combined.

Scotland has already made progress. The Scottish Government recently set up a Just Transition Commission specifically to provide advice on a low-carbon economy that is fair for all (Box 7.9).

Although the focus of the just transition concept is largely on its impact on jobs and job quality, the term also often encompasses cost of living considerations (i.e. the impacts of the transition on fuel costs and fuel poverty). As these issues have been addressed in section 5, this section focuses on the employment aspects of the transition.

[209] International Labour Organisation (2015) *Guidelines for a just transition towards environmentally sustainable economies and societies for all.*

Box 7.9. Scottish Just Transition Commission

Alongside Scotland's Climate Change Bill (currently being considered by the Scottish Parliament), the Scottish Government created the Just Transition Commission to advise on a low-carbon economy that is fair for all. The Commission aims to advise Scottish Ministers on how to apply the International Labour Organisation's Just Transition principles to Scotland.

The Commission will produce a written report to Scottish Ministers that provides recommendations for action that will:

- Maximise the economic and social opportunities that the move to a carbon-neutral economy by 2050 offers.
- Build on Scotland's existing strengths and assets.
- Understand and mitigate risks that could arise in relation to regional cohesion, equalities, poverty (including fuel poverty) and a sustainable and inclusive labour market.

(b) Jobs affected by the transition

There is potential for more jobs in some areas, and a decline in jobs in others. Employment needs may change in terms of location and skills. Whilst the Committee has not undertaken a full review of the possible changes, our scenarios in this report point to some of the likely effects:

- Our scenarios involve a major move away from fossil fuels, which is likely to result in fewer jobs in oil and gas in future (extraction, power generation and heat), affecting wider supply chains in these sectors.
- Although our scenarios still involve a large fleet of gas-fired power stations, these could be in different locations and require different skills as they will need to run using hydrogen or CCS and generally at much lower load factors. Coal-fired stations are already expected to close or convert to alternative fuels.
- There would be more jobs in renewable power generation, particularly development and construction (operation of renewables is not labour-intensive). There will also be jobs in the supply chain. Although the UK is currently an importer of renewable technology,[210] Government's recently announced Offshore Wind Sector Deal sets the ambition to increase jobs in the offshore wind industry from 7,200 today to 27,000 by 2030, much of this relating to growth in manufacturing and exports.[211]
- The automotive industry will also be affected by the transition to electric vehicles. The sector is currently facing a number of wider challenges; success in the long-term will depend on a transition to provide good quality cars for the growing electric vehicle market in the UK and internationally.
- Retrofitting homes with energy efficiency measures and installing low-carbon heat into new and existing homes will require new skills and could generate more high-skilled jobs in the construction industry.

[210] ONS (2019) *Low carbon and renewable energy economy, UK: 2017.*
[211] HM Government (2019) *Industrial Strategy - Offshore Wind Sector Deal.*

- There will also be more service jobs linked to low-carbon industries, in areas like carbon markets and climate finance and consultancy services (including engineering consulting), where the UK could also have a competitive advantage given its existing expertise.

A recent report by the LSE estimates that around 10% of workers have skills that the transition to a decarbonised world will require more of, while 10% could need reskilling. The sectors highlighted as most affected are manufacturing, construction and transport.[212]

Job losses and gains will not impact all areas of the country uniformly, with some more likely to be impacted than others:

- The LSE's report flags that the West Midlands, East Midlands and Yorkshire and the Humber have the greatest proportion of jobs which are likely to be exposed to the transition.
- The Institute for Public Policy Research estimates that there could be 28,000 job losses in coal, oil and gas in the north of England by 2030.[213] Currently 75% of oil and gas extraction jobs are in Scotland[214] suggesting a risk of job losses there as well. We note that these are also regions with significant potential for renewable energy deployment (onshore and offshore wind) and that are well suited to development of CCS clusters given their access to offshore CO_2 storage in the North Sea.
- Wales has a higher proportion of emissions from industry than the UK as a whole (30% of Welsh emissions came from industry in 2016 compared to 22% in the UK). That emphasises the importance for Wales of appropriate supportive policies for decarbonising these industries to mitigate any potential impacts on competitiveness and jobs.

(c) Conclusions and further work

Ensuring a just transition is more important for a net-zero GHG target than for a less ambitious target, given the large and rapid changes implied.

If the impact of the move to net-zero emissions on employment and cost of living is not addressed and managed, and if those most affected are not engaged in the debate, there is a significant risk that there will be resistance to change, which could lead the transition to stall.

We will give this issue further consideration in our sixth carbon budget, when we consider the path from now to 2050 in more detail.

Managing the impacts of decarbonisation (along with automation) on jobs and job quality should be a priority for policy design to deliver decarbonisation, which Government should start addressing immediately. These impacts can be managed and should not be used as an excuse for inaction.

[212] LSE Grantham Research Institute (2019) *Investing in a just transition in the UK: How investors can integrate social impact and place-based financing into climate strategies.*
[213] Institute for Public Policy Research (2019) *Risk or reward? Securing a just transition in the north of England.*
[214] CCC analysis based on provisional 2017 figures, ONS (2017) *Business Register and Employment Survey.*

Chapter 8: Recommendations

Introduction and key messages

The governments of the UK, Wales and Scotland requested advice from the Committee on setting net-zero emissions targets, and on connected questions.

This report has set out the latest evidence on climate science, the international context and the opportunities for deep reductions in emissions across the UK. Based on that evidence, this chapter sets out the Committee's recommendations:

- The UK should legislate as soon as possible to reach **net-zero greenhouse gas emissions by 2050**. The target can be legislated as a 100% reduction in greenhouse gases (GHGs) from 1990 and should cover all sectors of the economy, including international aviation and shipping.
- The aim should be to meet the target **through UK domestic effort**, without relying on international carbon units (or 'credits'). In the situation that, despite appropriate policy and effort, the expected emissions reduction does not ensue, credits could provide a contingency.
- **This target is only credible if policy to reduce emissions ramps up significantly:**
  - The target can only be delivered with a strengthening of policy to deliver emissions reductions across all levels and departments of government. This will require strong leadership at the heart of Government.
  - Policies must be designed with businesses and consumers in mind. They must be stable, long-term and investable. The public must be engaged, and other key barriers such as low availability of necessary skills must be addressed.
  - In this report, we highlight particular priorities where progress has been too slow: low-carbon heating, hydrogen, carbon capture and storage (CCS) and agriculture and land use. As well as driving deployment, Government must ensure that the necessary infrastructure is delivered.
- HM Treasury should undertake a review of how **the transition** will be funded and where the costs will fall. It should develop a strategy to ensure this is, and is perceived to be, fair. A broader strategy will also be needed to ensure a **just transition** across society, with vulnerable workers and consumers protected.
- The UK can benefit from the international influence of setting a bolder target, using it as an opportunity for further **positive international collaboration**.
- **Wales** has less opportunity for CO_2 storage and relatively high agricultural emissions that are hard to reduce. On current understanding it could not credibly reach net-zero GHGs by 2050. Wales should set a target for a 95% reduction in emissions by 2050 relative to 1990.
- **Scotland** has proportionately greater potential for emissions removal than the UK overall and can credibly adopt a more ambitious target. It should aim for net-zero GHGs by 2045. Interim targets should be set for Scottish emissions reductions (relative to 1990) of 70% by 2030 and 90% by 2040.

Other climate leading nations have set or are considering net-zero GHG targets by 2050 or before. Were the UK to adopt a later date or a weaker target it would undermine these discussions and the UK's broader climate leadership. Such a decision would result in less effort globally and greater levels of global warming, resulting in increased direct and indirect damages for the UK and around the world.

If a net-zero GHG target for 2050 is replicated in other leading countries alongside net-zero CO_2 emissions in the rest of the world, and coupled with ambitious near-term reductions in emissions, there would be a greater than 50% chance of limiting global temperature increase to **1.5°C**. Even with some delayed effort elsewhere and/or GHGs remaining slightly above net-zero, temperature rise could be limited to well below 2°C.

We set out our recommendations in five sections:

1. Why now is the right time to set a net-zero target in the UK
2. Recommended net-zero target for the UK
3. Recommended targets for Wales and Scotland
4. Leveraging a UK net-zero target internationally
5. Delivering a net-zero target in the UK

1. Why now is the right time to set a net-zero target in the UK

In 2016 we advised that the Government should not set a net-zero target at that time, but should instead keep a target under review as the evidence develops.

We now conclude that it is the right time to set a net-zero GHG target in the UK. The required evidence is now available and the evidence is robust. It is also an important moment for the UK to make a positive international impact:

- The IPCC Special Report on 1.5°C significantly strengthened the evidence base on what is required globally to meet the ambition of the Paris Agreement to limit global temperature increase to well below 2°C and to pursue efforts towards 1.5°C. Chapters 2 and 3 of our report summarise that evidence.
- Updated external evidence and analysis that the Committee has commissioned and compiled for this report mean we have an understanding of how a net-zero target could be met in the UK and what it would cost. Chapters 5, 6 and 7 summarise that evidence.
- The Paris Agreement began a process of ratcheting up climate ambition, with the intention of closing the ambition gap from current pledges of effort to the levels required to meet the Paris temperature goal. Parties to the Agreement are currently developing revised pledges, which need to be submitted next year. Setting a net-zero GHG target for 2050 in the UK would send a strong signal to support increasing ambition in those pledges (see Chapter 4).

The UK has also further developed its plans for meeting existing targets, providing a stronger base from which to increase ambition. Although the *Clean Growth Strategy* does not fully close the policy gap to the UK's existing carbon budgets, it represents a material step forward in the UK's approach to emissions reduction. Intentions set out in the Clean Growth Strategy still need to be backed up by detailed policy designs in many cases, but they cover most of the areas where action is needed to deliver a net-zero target and the strategy continues to offer an appropriate framework for action.

2. Recommended net-zero target for the UK

(a) Timing and scope of the net-zero target

Our overall recommendation is that the UK should set a target to **reduce greenhouse gas emissions to net-zero by 2050**. The target should cover all sectors of the economy, including international aviation and shipping.

Why 2050?

A net-zero GHG target by 2050 (i.e. a 100% reduction from 1990) corresponds with the latest climate science and would meet the UK's international commitments, while supporting increased global ambition. Our analysis suggests it would be feasible to deliver it alongside other government objectives. Figure 8.1 summarises our conclusion.

- **Climate science.** A net-zero GHG target for the UK (i.e. a 100% reduction in emissions) would go beyond per capita emissions reductions in global pathways that are necessary to limit temperature rise to well below 2°C and would be towards the high end of the estimated range of necessary reductions for a limit of 1.5°C. It would imply that by 2050 the UK will be actively *reducing* its large historical contribution to global warming.
- **International commitments.** The Paris Agreement requires developed countries to lead and the UK is well-placed to do so. All parties are expected to submit their 'highest possible ambition'. Other leaders have set or are considering ambition to reach net-zero GHG emissions around 2050 or before (e.g. the European Union, Sweden, France and California).
- **UK scenarios.** Given a significant strengthening of policy, our scenarios in Chapter 5 demonstrate that the UK could reduce GHG emissions to close to net-zero without relying on speculative options and at a cost comparable to the cost expected for the current 80% target when it was adopted by Parliament (i.e. around 1 – 2% of GDP in 2050, and similar or lower costs during the transition).

A later or weaker target would not represent the UK's 'highest possible ambition' as required by the Paris Agreement. Since our scenarios demonstrate that a net-zero GHG target can credibly be reached by 2050 at acceptable cost, the Committee recommend against setting a later or weaker target.

Any later or weaker net-zero target could undermine UK leadership and attempts to increase ambition in other countries. It is strongly in the UK's interest to play a leadership role and encourage and support other countries to increase their ambition given the large risks for the UK and every other country from climate change if global targets are not met.

Why all greenhouse gases?

We recommend setting a net-zero GHG target rather than a CO_2 target given the importance of reducing all GHGs and the clarity of the signal that it provides:

- This would align to the requirement for a balance between sources and sinks of GHGs in *Article 4* of the Paris Agreement.
- It would send a much stronger signal internationally. Other climate leaders, including the EU, are considering targets for net-zero emissions for all GHGs. If the UK were to adopt a weaker ambition it could undermine these negotiations.

- Within the UK, a 100% all-GHG target sends a clear signal that all GHGs matter and all need to be reduced. No sources of emissions can qualify for special treatment. All emissions from all sectors must be eliminated or offset with removals.

A net-zero target for all GHGs would imply that the UK will be actively *reducing* our large historical contribution to global warming.

Why not earlier than 2050?

We have considered whether an earlier date than 2050 should be targeted. An earlier date has been proposed by some groups[215] and might send a stronger signal internationally to those considering increasing their own ambition, but only if it is viewed as credible.

While our scenarios demonstrate that some sectors (e.g. the power sector) could reach net-zero emissions by 2045, for most sectors 2050 currently appears to be the earliest credible date. An earlier date would also give less time to develop currently speculative options as alternatives to make up for any shortfall from other measures. That could lead to a need for punitive policies and early capital scrappage to stay on track to the target.

Part of the strength of the Climate Change Act – as a tool for driving change in the UK and as an international signal – is that it sets legally-binding, evidence-based and credible targets, which must be delivered against. Setting a legal target to reach net-zero GHG emissions significantly before 2050 does not currently appear credible and the Committee advises against it at this time.

A legally-binding net-zero GHG target for 2050 that covers all sectors of the economy and does not rely on international carbon units would be world leading, especially for an economy like the UK's that does not have a large land sink but does have high emissions from international aviation. Crucially it would be supported by the strong statutory emissions framework of the Climate Change Act.

[215] For example, a cross-party group of over 180 MPs have proposed reaching net-zero GHG emissions before 2050 and a coalition of NGOs have proposed 2045.

Figure 8.1. The analysis in this report supports the setting of a UK net-zero GHG target for 2050

Science & International context

Global 2050 per capita emissions aligned to Paris: -0.4-1.7 tCO_2e for 1.5°C; 0.8-3.2 tCO_2e for well below 2°C

The UK can and should go further than the world's average

Other climate leaders are aiming for net-zero GHG emissions by 2050 or before

Reaching net-zero emissions in the UK

Credible scenarios can reduce UK GHG emissions to net-zero by 2050

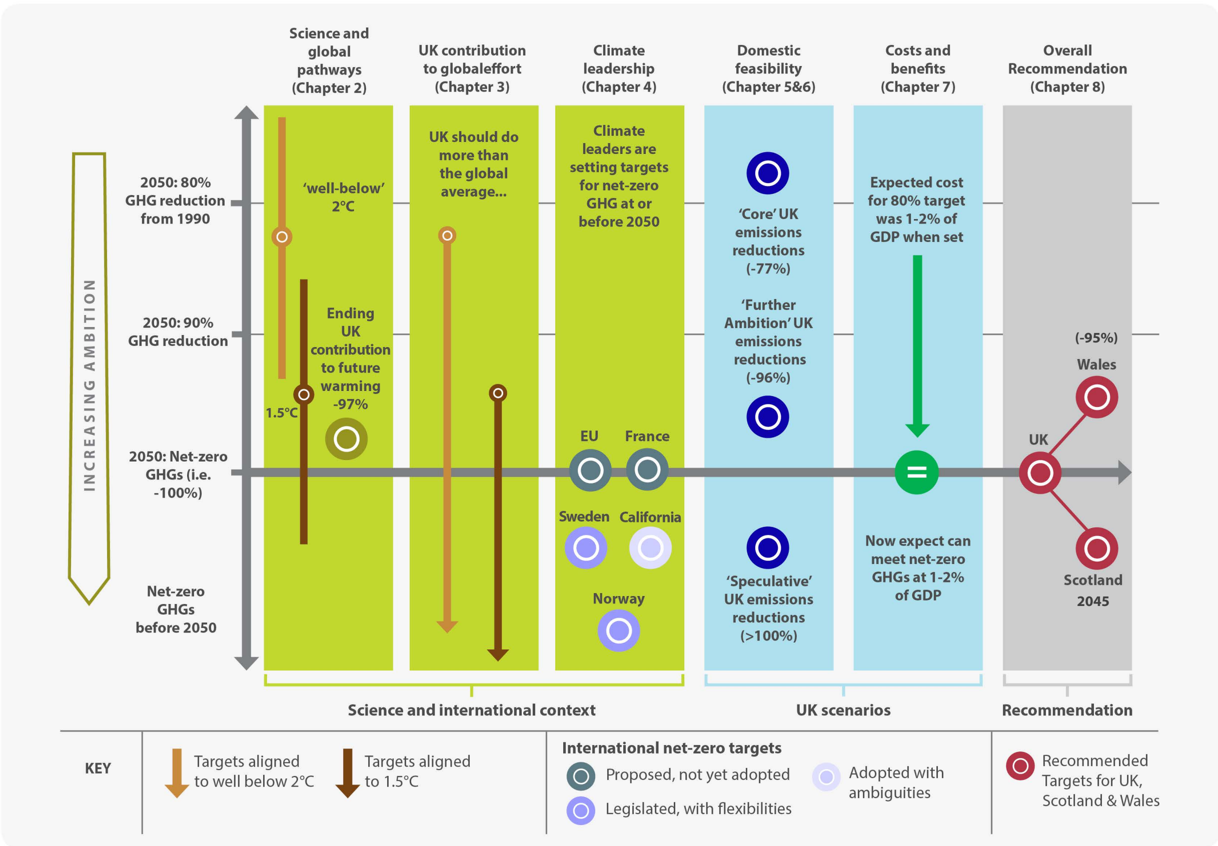
The foundations for the change are in place, but a major ramp-up and acceleration in policy effort is required

Expected cost of a net-zero target is the same as the cost accepted by Parliament when the existing 80% target was set

UK should target net-zero GHG emissions by 2050 / Scotland 2045 / Wales -95% in 2050

Backed by significant policy strengthening

HM Treasury should review where the costs of the transition fall



Source: CCC analysis.
Notes: Sweden and Norway allow offsetting towards their targets; California have not been explicit that their target covers all GHGs or whether offsetting will be allowed.

(b) Use of international carbon units

The aim should be to meet the target through UK domestic effort, without relying on international carbon units (or 'credits'):

- All countries will need to make deep reductions to their emissions if the Paris goals are to be met. Therefore there should be no expectation that international carbon units will be plentiful or cheap.
- The UK has a responsibility to deal with its own emissions and should not seek to outsource the solution by paying others to cut their emissions instead. Our scenarios in Chapter 5 demonstrate that the UK has the capability to meet a net-zero GHG target itself.
- Historically, markets for international carbon units have experienced difficulties in driving genuinely additional effort and have often offered poorer returns than direct climate finance without transferred mitigation effort attached.

However, we do not completely rule out international carbon units as a useful contingency, should there be under-delivery from genuine plans to meet the target domestically:

- The Paris Agreement initiates a central process for carbon units and allows for bilateral trades between Parties.
- Carbon units could be useful in providing an ongoing income stream for more expensive measures to cut emissions (or remove emissions from the atmosphere) in developing and middle-income countries.
- Meeting a UK net-zero GHG target in 2050 requires full delivery across all sectors of established abatement options and some delivery of more speculative options. Carbon units could provide contingency for scenarios in which particular options prove extremely expensive or impossible to deliver at the margin.
- The UK scenarios also involve significant emissions removal from the atmosphere. Some of the technologies to achieve that may be better deployed in other countries, with the same effect on the global climate (e.g. direct air capture may be well-suited to sunnier countries that can access cheap solar electricity and heat). Alternatively, given its access to extensive CO_2 storage under the North Sea, the UK could itself be a seller of carbon units attached to removals in the UK.

If carbon units are required, only those offering genuinely additional and permanent emissions reduction or removal should be allowed, and these must be part of schemes that also support sustainable development. That is particularly important for projects involving bioenergy or affecting land use, given the concerns raised by the IPCC that extensive land use changes across the world could bring international food security issues.

The UK is well-placed to help develop global markets for carbon units and should actively engage in rule-setting, capacity-building and early market development.

(c) Legislating the net-zero target

The Government should consider when and how to announce the new target to maximise its influence internationally. For example, by linking it to a point in the diplomatic timeline for the Paris Agreement or a major international summit.

Subject to those considerations, the target should be adopted as soon as possible and legislated in the Climate Change Act, by revising the 2050 target (*section 1* of the Act) from a reduction of at least 80% relative to 1990 to a reduction of at least 100%. That will send a strong signal to the international community and would embed the new target in the UK legal framework.

It is vital that the target is set as soon as possible so that follow-up actions can begin on that basis:

- The Committee will recommend the level of the sixth carbon budget in 2020, and would expect to develop our analysis on the path to the new target once it has been legislated.
- New and strengthened policies will be needed swiftly to prepare for the new target. This is a precondition of achieving a net-zero GHG target for 2050, and preparations cannot be delayed. We set out the major policy outcomes that should be achieved in Chapter 6 and summarise them below.

The Climate Change Act does not require limits on carbon units to be set until shortly before a carbon budget begins (e.g. by 2046 for the carbon budget covering 2050, *section 11*). It requires that the Committee advise on the suitability of any new types of carbon unit before they can be used (*section 28*). We set out the sort of criteria we would expect to apply in Chapter 4, but do not recommend that these are legislated now.

The Government must develop and publish policies and proposals to meet the carbon budgets and 2050 target (*section 13*) with regard to the need for domestic action on climate change (*section 15*). We recommend that this is interpreted as requiring plans that would meet the net-zero GHG target entirely through domestic effort without recourse to purchase of international carbon units.

The net-zero target should cover all sectors of the economy, including international aviation and shipping. That requires a new statutory instrument alongside the Climate Change Act:

- Since all emissions contribute to climate change, the Committee has always been clear that UK emissions targets should apply to all sectors of the economy. That is the basis on which the analysis in this report has been developed and on which the recommendations are made.
- The Climate Change Act (*section 30*) allows for emissions from international aviation and shipping to be included from any future year. Since the current carbon budgets have been set without these emissions, we recommend their inclusion from the first year of the sixth carbon budget (i.e. 2033).
- Emissions should be included based on the 'bunker fuels' methodology.[216]

We have not developed a full cost-effective path to the net-zero target for this report. We intend to provide that in our advice on the sixth carbon budget, which is due in 2020. We do not recommend changes to the fourth or fifth carbon budgets at this time, but note that they have been set on the path to the existing 80% target and therefore are likely to be too loose. We already recommend a cost-effective path that would take emissions beneath the level of the fourth and fifth carbon budgets.[217]

[216] Bunker fuels is the convention used for estimating and reporting international transport emissions to the UN. It is based on the amount of aviation and shipping fuel sold in the UK.
[217] This largely reflects changes to the Government's emissions projections (energy demand and emissions are now expected to be lower). See CCC (2018) *Progress Report to Parliament* for more details.

We reiterate the recommendation from our 2018 Progress Report that the goal should be to outperform the currently legislated budgets and we will consider whether they should be tightened in legislation as part of our advice on the sixth carbon budget. The priority now should be to strengthen policy to ensure that the fourth and fifth budgets are outperformed in preparation for a tougher sixth carbon budget on the path to the net-zero GHG target in 2050.

3. Recommended targets for Wales and Scotland

We have considered the appropriate targets for Wales and Scotland based on their respective capabilities. For example, Scotland's higher land area per person allows for more CO_2 sequestration through afforestation, but its high share of UK peatland makes emissions reduction more challenging.

In aggregate, these capabilities allow Scotland to reach a net-zero target slightly before the UK overall whilst for Wales they mean that we have not been able to identify a credible scenario for reaching net-zero GHG emissions.

Our approach also reflects that the scenarios in Chapter 5 have been constructed to reflect the target-setting criteria in the Welsh Environment Act (2016) and Well-being of Future Generations Act (2015) and the Scottish Climate Change Act (2009) as well as the UK's Climate Change Act (2008).

(a) Recommended target for Wales

We recommend that Wales increases the ambition in its 2050 target to require a **95% reduction in greenhouse gases**, relative to 1990. This is contingent on our recommendation for a UK net-zero greenhouse gas target being accepted and legislated. Achieving this target would cut net emissions of long-lived GHGs to below zero (the remaining 5% would be methane emissions, largely from agriculture), ending Wales's contribution to rising global temperatures.

Under the Further Ambition scenario that underpins our advice on setting a net-zero target at UK level, Wales and the UK as a whole decarbonise to very similar extents. However, Wales is less able than the UK as a whole to go beyond the Further Ambition scenario to reach net-zero GHG emissions, due to limited opportunities to deploy additional GHG removals (i.e. due to lower access to suitable sites to store captured CO_2) or to use synthetic fuels to reduce aviation emissions (as Welsh aviation emissions are already near zero).

This target represents Wales's fair contribution to the UK target and hence to the Paris Agreement. It does not imply lower policy ambition or effort in Wales, but reflects the large share of agriculture emissions in Wales and lower access to suitable sites to store captured CO_2.

This is a large change in our assessment for how low Welsh emissions can go by 2050, which we previously assessed at an 85% reduction on 1990 emissions.[218] Whilst our assessments have been revised across all sectors, the largest change is evidence of greater potential to reduce emissions from industry (see Chapter 5 and the Appendix to the technical report), which is particularly important for Wales. Alongside small changes in other sectors, this enables Wales to increase ambition significantly for 2050.

[218] CCC (2017) *Building a low-carbon economy in Wales – Setting Welsh carbon targets*.

Should the UK not pursue the Committee's recommended net-zero GHG target, however, it is very unlikely that achieving a 95% reduction in 2050 will be possible in Wales, given the number of areas in which Welsh decarbonisation depends on UK Government policy.

Contingent on increased ambition at the UK level, the new target could be placed into legislation in 2020, together with the setting of Wales's third carbon budget (covering 2026-2030).

(b) Recommended targets for Scotland

We recommend that Scotland legislates now for **net-zero greenhouse gas emissions by 2045**, contingent on the UK adopting our recommended 2050 net-zero GHG target.

Scottish circumstances

Recommending targets for Scotland is complicated by two factors, one relating to future decisions over scientific methodology and one legislative:

- There are methodological choices about how the full scope of peatland emissions should be reflected in the emissions inventory in future (see Chapter 5). These particularly affect Scotland, due to its high share of UK peatland. The way the UK Government decides to include it in the emissions inventory affects the feasibility of achieving net-zero emissions by a given date. The UK Government must decide this by 2022, but may choose to do so earlier.
- A new Climate Change Bill is partway through its passage through the Scottish Parliament at present. This has two key implications for how we recommend targets:
  - Our recommendations affect a fluid situation, and we recognise that it is unlikely to be possible to wait for a definitive decision on our recommended UK net-zero target before an updated Scottish target is set.
  - The Bill requires not only the setting of a 2050 and/or net-zero target, but also decadal interim targets for 2020, 2030 and 2040.

We have aimed to maximise the transparency of target-setting and avoid the risk that targets must later be changed in a way that may be perceived to be loosening them:

- We recommend a net-zero target date of 2045 and interim targets for 2030 and 2040 on the basis that peatland emissions are fully included. This will avoid a change to the 'headline ambition' of Scottish targets once the inventory changes. We think this is the most transparent approach to setting the targets.
- We include in our analysis the upper estimate for the amount of emissions that would be added to the emissions inventory once the full scope of peatland emissions is included. If the lower estimate were to be chosen, the targets may need to be revised.

This approach is in line with the spirit of the Paris Agreement that there should be a 'progression' in pledged effort over time, with no back-sliding from previous commitments.

Setting a net-zero target for Scotland

Scotland can go further in reducing emissions than the UK as a whole by 2050, due primarily to its large land area that can be used for carbon sequestration, both through afforestation and through use of sustainable Scottish bioenergy combined with carbon capture and storage (BECCS), with the CO_2 being stored off the Scottish coast. The detailed analysis for the

Committee's 2018 report *Land use: Reducing emissions and preparing for climate change* has strengthened our understanding of opportunities for carbon sequestration in Scotland.

Under the Further Ambition scenario that underpins our advice on setting a net-zero target at UK level, by 2050 Scotland can reach a reduction of between 104% and 110% on 1990 emissions[219] (i.e. removals would be greater than emissions). A 110% reduction in 2050 would be consistent with net-zero GHG emissions in 2045, assuming a straight-line trajectory from 2020.

Given potential in Scotland to go beyond the Further Ambition scenario (which achieves a 95-96% reduction for the UK from 1990 levels), through additional afforestation, peatland restoration and/or 'engineered' greenhouse gas removals, we are therefore confident that Scotland could feasibly achieve net-zero GHG emissions by 2045.

Again, should the UK not legislate the Committee's recommended UK net-zero target it is very unlikely that Scotland would be able to achieve such a large reduction by 2045, given the number of areas in which Scottish decarbonisation depends on UK Government policy.

As the Climate Change Bill is currently passing through the Scottish Parliament, we recognise the need for a target that can be legislated immediately without waiting to find out whether a UK net-zero target has been adopted.

We therefore recommend that Scotland legislates for net-zero GHG emissions by 2045. This date is contingent on the UK adopting our recommended target. If the UK Government does not commit to a net-zero GHG target for 2050 then Scotland may need to revise its own net-zero date to 2050.

Interim targets for Scotland

The Scottish Climate Change Bill requires 'interim' targets to be set for 2020, 2030 and 2040.

The focus of the analysis presented in this report has been on the appropriate level of emissions in mid-century and the implications for setting net-zero dates. It has not yet been possible to undertake a detailed analysis across the economy of the cost-effective path for emissions in the years prior to these targets. We will undertake detailed analysis of the path for emissions in 2020, for our advice on the UK sixth carbon budget (2033 – 2037) – at that point we will have a clear view on what a net-zero target implies for the path for emissions in earlier years.

However, we recognise that the current legislative process in Scotland cannot wait for this detailed analysis. We have therefore identified prudent interim targets to be set, but on the basis that these may need to be revised in future, once the UK-wide pathway has been determined and further corresponding analysis of Scotland's pathway can be undertaken.

Our assessment of the interim targets takes the approach of drawing a straight line from emissions in 2020[220] to the date of net-zero (Figure 8.2). This is clearly a simplification, but reflects that our previous detailed bottom-up analysis identified a roughly straight-line trajectory as the cost-effective path to Scotland's current long-term target. A later net-zero date (i.e. 2050)

[219] The range of 104% to 110% reflects the potential impact of future choices over which numbers from the IPCC's fifth assessment report for the global warming potentials of non-CO_2 greenhouse gases, and over precisely which methodology is used to include the full range of peatland emissions.
[220] As we are proposing post-2020 targets on the basis that they will include the full range of peatland emissions, the starting point for the line in 2020 is based on the existing 56% target in 2020, adjusted to include the additional peatland emissions. This gives a 49.5% reduction in 2020 on the basis of these extra emissions being included.

would imply looser interim targets, but still requires percentage reductions at least as high as those currently in the Bill (Table 8.1).

For our recommended 2045 net-zero GHG target for Scotland, the interim targets should be set at reductions from 1990 of 70% by 2030 and 90% by 2040.

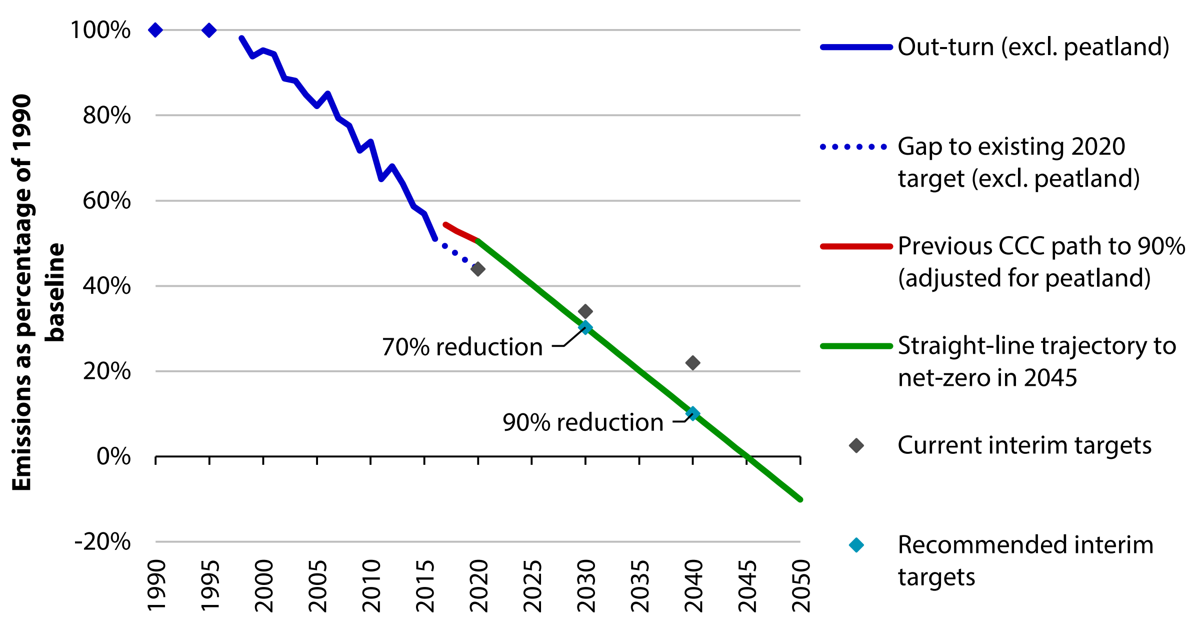
We anticipate that we will be in a position to provide updated advice once:

- We have undertaken the pathway analysis for our advice, due in 2020, on the UK's sixth carbon budget; and
- The precise methodology for inclusion of peatland emissions has been decided.

We expect this to be no earlier than the end of 2020 (the deadline for the advice on the UK sixth carbon budget), and could be 2021 or 2022 depending on the timing of inclusion of full peatland emissions in the emissions inventory.[221]

We do not propose any change to the 2020 interim target, as there would be no time to implement additional policies to meet it. Therefore we recommend that this stays at a 56% reduction on 1990 emissions, on the accounting basis of the emissions inventory published in June 2018.

Figure 8.2. Indicative pathway for Scottish emissions on the way to net-zero



Source: CCC analysis.
Notes: The interim targets for 2030 and 2040 have been calculated on a straight-line trajectory to net-zero emissions in 2045 from emissions in 2020, on the basis of the upper estimate of peatland emissions and current global warming potentials (i.e. implying that emissions in 2020 are 49.5% below those in 1990).

[221] Full emissions from peatland are required to be included in the emissions inventory at the latest by 2022 (i.e. by the time of publication of the inventory detailing 2020 emissions).

Table 8.1. Interim Scottish targets for 2020, 2030 and 2040 as reductions on 1990 emissions			
	2020 interim target	**2030 interim target**	**2040 interim target**
Proposed targets in the Scottish Climate Change Bill	56%	66%	78%
Recommended targets to prepare for net-zero GHG emissions in 2045	56%	70%	90%
Recommended targets to prepare for net-zero GHG emissions in 2050	56%	66%	83%

Source: CCC analysis.
Notes: The interim targets for 2030 and 2040 have been calculated on a straight-line trajectory to net-zero emissions in 2045 from emissions in 2020, on the basis of the upper estimate of peatland emissions and current global warming potentials (i.e. implying that emissions in 2020 are 49.5% below those in 1990).

4. Leveraging a UK net-zero GHG target internationally

UK emissions, in line with our population, are only 1% of global emissions. It is therefore vital for the UK to maximise the impact of any new target on actions beyond the UK in order to tackle climate change and avoid some of the largest risks that would involve. This will also make the UK's task easier by stimulating the innovation and cost reduction for low-carbon technologies that global roll-out can bring.

A 2050 net-zero GHG target would be commensurate with the most ambitious interpretation of Article 2 of the Paris Agreement, aiming to keep warming levels at or below 1.5°C. However, whether the increase in global average temperatures is limited to well below 2°C or 1.5°C will depend on action by the world overall (see Chapter 3). Global emissions would need to peak very soon and then fall rapidly, which requires a major increase in ambition compared to existing pledges and policies.

By continuing to act as a climate leader and taking the opportunity of setting an ambitious net-zero target, the UK can help support others in setting and meeting more ambitious targets of their own.

In Chapter 4 we set out many of the opportunities for UK leadership to support increased global ambition in support of other elements of the Paris Agreement. These include:

- **Leading by example.** The Climate Change Act set the world's first legally-binding long-term emissions target, with a supporting framework to deliver it – it has been the model for climate legislation in many other countries. The UK also trialled the first major emissions trading scheme – a pilot for the EU Emissions Trading System (EU ETS). More broadly, the UK has demonstrated that a major nation can reduce its emissions (down over 40% from 1990 to 2018) while growing its economy (GDP grew over 70% from 1990 to 2018). Setting a net-zero GHG target and aiming to meet it domestically is the next step for the UK to keep leading by example.

- **Diplomacy and capacity building.** The UK has consistently played an important and positive role in climate negotiations: in the UN, in the EU and in the international aviation and shipping agencies (ICAO and IMO). It has also launched (with Canada) the Powering Past Coal Alliance and helped initiate the High Ambition Coalition. The UK Foreign and Commonwealth Office has run sustained climate engagement activities for over a decade to support other countries on the politics, economics and practicalities of tackling climate change. Setting a strong net-zero target will enhance the UK's diplomatic influence, and it should continue to use this positively, to strengthen governance for bioenergy and removals, on sustainable finance and potentially as the host of the key UN talks in 2020 (COP26).
- **Technology development.** The UK has taken a lead role in the development and deployment of some of the key low-carbon technologies. For example, becoming the largest market for offshore wind in the world, driving down costs through deployment. Such developments can now support decarbonisation elsewhere, at these low costs. In Chapter 3 we consider global pathways where a group of leadership countries like the UK reduce emissions and deploy key technologies a decade or so ahead of the global average. A net-zero GHG target would be consistent with these pathways, which look more plausible than pathways without developed country leadership.
- **Climate finance.** The UK, through the aid budget, spends around £1 billion a year on climate finance activities. A recent performance review by the Independent Commission for Aid Impact reports that the UK positively influences the international agencies it engages with and increasingly contributes to transformational impact.[222] Effective use of climate finance will continue to be vital to help move developing countries onto low-carbon development paths.

Although the aim should be to meet the net-zero GHG target without international carbon units, the UK should take steps to develop markets for carbon units as a potentially useful mechanism to support increased effort internationally and as a contingency mechanism for the UK:

- **The Paris Agreement allows for some international transfer of mitigation outcomes.** It also allows for bilateral arrangements between countries, which would allow the UK to set its own criteria for effective carbon units if central rules are not satisfactorily negotiated.
- **Carbon units could be useful in supporting required global action.** Scenarios that meet the goals of the Paris Agreement involve costly measures in developing and middle-income countries. These are likely to need an ongoing income stream, which carbon markets and transfers of carbon units could provide.
- **Some use of carbon units could prove cost-effective.** Our recommended UK target involves lower GHG emissions per person than the global pathways consistent with limiting temperature rise to 1.5°C. That opens the possibility that even if the UK does a little less and buys carbon units from elsewhere it would still be doing at least as much as the world overall. Our scenarios in Chapter 5 also involve a significant amount of emissions removals, some of which may be cheaper to deploy in other parts of the world (e.g. where there is more land, solar or biomass resource), although sustainability concerns would need to be carefully managed.

[222] ICAI (2019) *International Climate Finance: UK aid for low-carbon development. A performance review.*

- **The UK is well-placed to help develop global markets for carbon units:**
  - The UK has already been influential in rule-setting negotiations on Article 6 and CORSIA (the carbon trading scheme being developed for the international aviation industry).
  - The UK is engaged in projects such as the Partnership for Market Readiness and bilateral partnerships to help build capacity for effective carbon markets, including skills, rules and know-how (e.g. for monitoring, reporting and verification).
  - The UK already supports improvements in systems design, including through pilot projects (e.g. the Transformative Carbon Assets Facility).
  - If the UK develops a domestic market for CO_2 removals, this could form the basis for a wider international market.

Any use of international carbon units for target compliance should be conditional on their integrity and robustness:

- The UK should set out clear principles to ensure carbon units reflect an amount of emissions abatement that is at least equivalent to what would have been otherwise achieved through domestic effort.
- Carbon units should support genuine and permanent emissions reductions or removals.
- Any mechanism needs to ensure that credits are compatible with environmental and sustainable development objectives.

In the shorter term, the UK should support the development and improvement of international markets for carbon units. This would develop the option to use these in the future if needed. Even if carbon units are not needed to meet UK goals, some purchase could be valuable as part of the UK's broader collaboration (e.g. some UK climate finance is already directed through carbon credit markets, with the units then written off).

Currently the UK's official contribution to the Paris Agreement is set through the EU's collective pledge to reduce emissions by at least 40% by 2030 relative to 1990. Outside the EU, the UK would need to submit its own Nationally Determined Contribution (NDC) to the UN. For now that could be based on the higher ambition in the UK's fifth carbon budget (which was set to require a 57% reduction in UK emissions from 1990 to 2030) but ultimately it should be based on the more ambitious pathway that the Committee will advise on next year, on the path to net-zero GHG emissions in 2050.

The Paris Agreement asks countries 'to formulate and communicate long-term low greenhouse gas emission development strategies'. The UK has previously submitted the Government's *Clean Growth Strategy*. Setting a net-zero GHG target and introducing long-term plans to meet it would provide a basis for a strengthened strategy.

5. Delivering a net-zero target in the UK

A UK net-zero GHG target in 2050 is feasible, but will only be deliverable with a major strengthening and acceleration of policy effort. Challenges across sectors must be tackled vigorously and in tandem, beginning immediately. That should be the clear understanding for the Governments and Parliaments of the UK, Scotland and Wales when considering the recommended targets.

(a) Feasibility of delivering a net-zero target in the UK

It is impossible to predict the exact mix of technologies and behaviours that will best meet the challenge of reaching net-zero GHG emissions, but our analysis in this report gives an improved understanding of what a sensible mix might look like. Chapter 5 set out scenarios to reach net-zero GHG emissions in the UK by 2050 based on known technologies. The scenarios include:

- **Resource and energy efficiency** and some **societal choices** that cut demand for carbon-intensive activities.
- Extensive **electrification,** particularly of transport and heating, supported by a major expansion of renewable and other low-carbon power generation.
- Development of a **hydrogen** economy to service demands for some industrial processes, for energy-dense applications in long-distance HGVs and ships, and for electricity and heating in peak periods.
- **Carbon capture and storage (CCS)** in industry, with bioenergy (for GHG removal from the atmosphere), and very likely for hydrogen and electricity production. CCS is a necessity not an option.
- Changes in the way we farm and use our **land** to put much more emphasis on carbon sequestration and biomass production, while shifting away from livestock.

The scenarios are highly challenging, but given sufficiently ambitious and well-designed policies, they can be delivered in practice:

- **Overall costs are manageable.** We estimate total costs of meeting a net-zero GHG target at around 1 – 2% of GDP in 2050 based on a conservative set of assumptions. Many of these costs will be spread over the economy, implying relatively small changes set against a growing economy. A key policy challenge is to ensure that costs are (and are seen to be) spread fairly and do not disadvantage UK industry.
- **UK citizens can benefit from the changes.** The scenarios involve technologies that can provide an equivalent or superior service for customers:
  - Many of the changes (e.g. industry and power decarbonisation) occur in the production chain and will not impact directly on consumers.
  - Electric vehicles with large enough batteries and sufficient recharging infrastructure provide a superior driving experience. Energy-efficient homes with heat pumps and smart controls, possibly supplemented by back-up hydrogen boilers, can be as comfortable or more comfortable than homes today.
  - Where our scenarios involve changes in behaviour they are associated with wider benefits, for example improved health from more cycling and walking and from lower average consumption of red meat.
- **Good policy can tackle the barriers to change.** Barriers include low public engagement in some of the challenges, the need for supporting infrastructure and coordinated decisions, misaligned incentives, access to capital, slow technical innovation and availability of workers with the required skills. All of these can be overcome over time with good policy design, and in many cases governments have begun to consider these challenges and to design policies to address them.

Our conclusion that the UK can achieve a net-zero GHG target by 2050 and at acceptable cost is entirely contingent on the introduction of clear, stable and well-designed policies. Government must set the direction and provide the urgency.

(b) Overcoming obstacles to net-zero emissions

Our analysis points to a number of priorities for the Government if it is to overcome the obstacles to reaching net-zero GHG emissions:

- **Strengthening policy-making.** The net-zero challenge must be embedded and integrated across all departments, at all levels of Government and in all major decisions that impact on emissions. It must also be integrated with businesses and society at large. Since many of the solutions cut across systems (e.g. hydrogen has a role in electricity generation, transportation, industry and heating), fully integrated policy, regulatory design and implementation is crucial. That may require new frameworks, for example to ensure that departments, other than BEIS alone, sufficiently prioritise net-zero GHG emissions. Policy teams across departments must be sufficiently resourced to develop and implement the changes required.
- **Ensuring businesses respond.** Some previous policies have delivered the desired business response in full (e.g. the banning of inefficient gas boilers in the 2005/06 Building Regulations, the offering of long-term contracts to offshore wind farms). Others, like the Green Deal and vehicle emissions standards, have not. For a net-zero GHG target, standards will need strict enforcement and incentive schemes must be designed with businesses and investors in mind. The ends (i.e. stopping GHG emissions) should be clear, but there should be flexibility to meet them in the most effective way. Crucially, there should be a stable and long-term approach.
- **Engaging the public to act.** Much of the success so far in reducing emissions (e.g. power sector decarbonisation and even the phase-out of inefficient gas boilers) has happened with minimal change or awareness needed from the public. However, this cannot continue if the UK is to reach net-zero emissions. Public engagement and support will be particularly vital for the switch to low-carbon heating – people will need to make changes inside their homes and coordinated central decisions must be taken on the balance between electrification and hydrogen. People should understand why and what changes are needed, to see a benefit from making low-carbon choices and to access the information and resources required to make the change happen.
- **Determining who pays.** If policies are not sufficiently funded or their costs are seen as unfair, then they will fail. HM Treasury should undertake a review of how the transition will be funded and where the costs will fall. The review should cover the use of fiscal levers and Exchequer revenue, costs from carbon trading schemes, the impact on energy bill-payers and motorists, and the costs to industries especially where they are carbon-intensive and trade-exposed. It should cover costs from now through to 2050.
- **Providing the skills.** The Government has recognised the importance of developing skills in its Industrial Strategy and sector deals. These should be used to tackle any skills gaps that would otherwise hinder progress. For example, new skills support for designers, builders and installers is urgently needed for low-carbon heating (especially heat pumps), energy and water efficiency, ventilation and thermal comfort, and property-level flood resilience.

- **Ensuring a just transition.** Building on the reviews of who pays and of skills, the Government should assess more broadly how to ensure that the overall transition is perceived as fair and that vulnerable workers and consumers are protected. That must include analysis at the regional level and for specific industrial sectors. We note that Scotland has already appointed an independent Just Transition Commission to advise on 'a carbon-neutral economy that is fair for all'.
- **Developing the infrastructure.** Reaching net-zero emissions will require development or enhancement of shared infrastructure such as electricity networks, hydrogen production and distribution and CO_2 transfer and storage. Government, in partnership with the National Infrastructure Commission, should give urgent consideration to how such infrastructure might best be identified, financed and delivered. Regional coordination will be required, including for transport where powers are devolved.

(c) Recommendations for policy in specific areas

Specific policies are now required to address the key areas of emissions across the economy. This is a pre-condition of achieving a net-zero GHG target by 2050. Many of our recommendations here are not new: the Committee has already recommended strengthened approaches to heat decarbonisation, CCS and hydrogen, electric vehicles, agriculture, waste, and low-carbon power. The interdependencies between these sectors must be taken adequately into account, emphasising the importance of a coherent overall strategy.

- **Heating buildings.** An overhaul of the approach to low-carbon heating and energy efficiency is needed. The Government's planned 2020 Heat Roadmap must establish a new approach that will lead to full decarbonisation of buildings by 2050. This must be fully-funded, following the Spending Review, and it is essential that the Treasury commits now to working with BEIS on this. Recent announcements on new build must be delivered.
- **CCS.** Carbon capture and storage is essential. We previously recommended that the first CCS cluster should be operational by 2026, with two clusters, capturing at least 10 $MtCO_2$, operating by 2030. For a net-zero target it is very likely that more will be needed. At least one of the clusters should involve substantial production of low-carbon hydrogen. The Government will need to take a lead on infrastructure development, with long-term contracts to reward carbon capture plants and encourage investment.
- **Electric vehicles.** By 2035 at the latest all new cars and vans should be electric (or use a low-carbon alternative such as hydrogen). If possible, an earlier switchover (e.g. 2030) would be desirable, reducing costs for motorists and improving air quality. This could help position the UK to take advantage of shifts in global markets. The Government must continue to support strengthening of the charging infrastructure, including for drivers without access to off-street parking.
- **Agriculture.** Agriculture is already facing a period of considerable change. Future success will require diversification of incomes and taking the opportunities that come with transformational land use change. Policy to encourage farming practices that reduce emissions must move beyond the existing voluntary approach. Financial payments in the UK Agriculture Bill should be linked to actions to reduce and sequester emissions, to take effect from 2022.

- **Waste.** Biodegradable waste streams should not be sent to landfill after 2025. This will require regulation and enforcement, with supporting actions through the waste chain, including for example mandatory separation of remaining waste.
- **Low-carbon power.** The supply of low-carbon power must continue to expand rapidly, and increasingly, from around 2030, some may need to run for only part of the year. While many options no longer need subsidies, Government intervention may still be needed, for example by backing long-term contracts aligned to expected wholesale prices. Policy and regulatory frameworks should also encourage flexibility (e.g. demand response, storage and interconnection).

In setting a net-zero target, these actions must be supplemented by stronger approaches to policy for industry, land use, HGVs, aviation and shipping, and GHG removals:

- **Industry.** Government must implement an approach to incentivise industries to reduce their emissions through energy and resource efficiency, electrification, hydrogen and CCS in ways that do not adversely affect their competitiveness. In the short-term, this is likely to imply a role for Exchequer funding. Longer term, it could involve international sectoral agreements (e.g. for industries like steel where there are relatively few global companies), procurement and product standards that drive change by requiring consumers to buy or use low-carbon products (e.g. where UK consumption is a large part of an industry's market) or through border-tariff adjustments that reflect the carbon content of imports. Wider infrastructure developments to support CCS and hydrogen roll-out will support industry to make the required changes.
- **Land use.** Consumer-facing policies should be used to support shifts to healthier diets with lower beef, lamb and dairy consumption. These would allow changes in UK land use without increasing reliance on imports. Forest cover should increase from 13% of UK land to 17% by 2050. Policy must support land managers with skills, training and information.
- **HGVs.** The Government will need to make a decision on the required infrastructure for zero emission HGVs, with international coordination, in the mid-2020s ready for deployment in the late 2020s and throughout the 2030s. To help prepare for that, trials of zero emission HGVs and associated refuelling infrastructure are now needed. Vehicle and fuel taxation from the 2020s onwards should be designed to incentivise commercial operators to purchase and operate zero-emission HGVs.
- **Aviation and shipping.** ICAO and IMO, the international agencies for aviation and shipping, have adopted targets to tackle emissions. The scenarios in this report go beyond those targets, suggesting increased ambition and stronger levers will be required in the long run. We will write to the Government later this year on its approach to aviation, building on the advice in this report.
- **GHG removals.** The Government should expand support for early-stage research across the range of GHG removal options, including trials and demonstration projects. It should also signal the longer-term market, which is clearly needed to meet a net-zero target, by developing the governance rules and market mechanisms to pay for emissions removals. Aviation stands out as an obvious sector that could require removals to offset its emissions – either through CORSIA (the international aviation industry's planned trading scheme), the EU ETS or unilaterally the UK could support a net-zero target for aviation, requiring that all emissions are offset by removals.

While a net-zero GHG target brings additional challenges, it also brings clarity around policy objectives and what each sector is aiming for. There are opportunities for UK businesses to gain competitive advantage as they shift to the future zero-carbon basis required in the UK and the world. Government should make the most of those opportunities with a bold new programme for emissions reduction, which it should begin to introduce immediately.

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